

Sustainability as a dynamic game*

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Abstract

Sustainability is a fundamental concept in the environmental domain, but also in other domains, e.g., regarding personal health. Sustainability means using resources today in a way that does not compromise the availability of resources tomorrow. In this paper, we propose and test a model that incorporates the essential features of sustainability, as they are not fully covered in the pre-existing literature. First, our Sustainability Game is dynamic in the sense that the actions played in each period have consequences for future periods. Second, there is a contribution threshold that must be reached in order to maintain the level of resources. The threshold captures that some use of resources can be absorbed, while over-using leads to a decline. Third, it incorporates that the temptation to over-use resources is strong when more than one individual is involved. We first derive equilibrium behavior analytically and then test these pre-registered predictions in the lab. Our main results are the following: (i) Theoretically and experimentally, strategic interaction reduces cooperative behavior and undermines sustainability. (ii) Theoretically and experimentally, lowering the threshold fosters cooperative behavior (i.e., contributing according to the threshold) and sustainability. Our results suggest that technological advancements that lower the threshold for sustainability and behavioral change toward sustainability need not be viewed as alternatives, but rather as complementary.

Keywords: Sustainability, conservation, dynamic game, social dilemma, threshold, cooperation

JEL Classification Codes: C73, C92, H41, Q56

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1 Introduction

Sustainability has become the cornerstone of many policy goals, project plans and personal decisions. The United Nations define sustainability as “meeting the needs of the present without compromising the ability of future generations to meet their own needs”. In other words, considering that not only future generations but also the same generation in the future can be affected, sustainability means using resources today in a way that does not compromise the availability of resources tomorrow. We develop a model to study sustainability theoretically and experimentally. Our Sustainability Game has three essential features that make it suitable for studying this concept. First, it is dynamic so that decisions made today have an impact on the availability of resources in the future. Second, it includes threshold effects, such that a limited amount of resource utilization can be absorbed and has no impact on the future, but an over-use (i.e., usage above the threshold) leads to a decline in future resources. Third, the game features a tension between private and collective interests when there are multiple decision makers. As discussed extensively below, combining these features set our model apart from most of the pre-existing literature. The way our model captures sustainability fits particularly well to problems of *conservation*, be it concerning personal health or concerning a natural resource that cannot grow arbitrarily.

We first derive theoretical predictions from this Sustainability Game by studying its equilibria. As an equilibrium concept, we use Markov Perfect Equilibrium (MPE), following, e.g., Vespa (2020).¹ We then test these predictions in a pre-registered laboratory experiment. In the experiment, we focus on varying two dimensions: the number of decision makers and the sustainability threshold. We divide participants into three treatment groups. In the baseline treatment (*T-Baseline*) there are four decision makers, while in the *T-OnePlayer* treatment there is only one. Comparing the two treatments allows an assessment of the extent to which free-riding incentives impact sustainability. In many applications, such as climate and environment preservation, cooperation between many individuals is required to reach a sustainable path, and the temptation to free ride and over-use resources is strong. There are however also instances where an individual is solely involved in maintaining a resource. One such example is personal health. An individual can refrain from unhealthy habits such as smoking, drinking, or eating sugary or fatty products and thereby maintain a good health level. Our model enables us to compare how an individual manages sustainability compared to the case of multiple decision makers involved. The results (both theoretical and experimental) clearly show that players are more likely to reach the sustainability threshold when they are solely responsible for the decision and they are also less likely to contribute zero.

We then analyze how varying the sustainability threshold affects the strategies chosen by players. The treatment *T-LowThreshold* features a lower sustainability threshold than *T-Baseline*, which should theoretically lead to more cooperation (i.e., contributing according to the threshold), as mutual cooperation becomes an equilibrium. Our experimental results confirm the theoretical prediction: a lower threshold increases cooperation and sustainability, while it reduces defection (i.e., contributing zero). In the context of climate change, lowering the threshold could be interpreted as an improvement of technology to absorb CO2 emissions, for example. Such a technology would lower the effort required by the population to actually meet a sustainability threshold and could in principle make cooperation easier to sustain.

Finally, we investigate how specific personal characteristics affect the choice of strategies in the Sustainability Game. We find that agents who score higher on agreeableness tend to contribute

¹MPE is a strong equilibrium concept in the sense that it reduces the number of equilibria in dynamic settings. Its main assumption is that strategies do not depend on the history of play other than through the current state variables.

more, in particular when contributing zero is the only equilibrium strategy – resonating the findings of, e.g., Volk et al. (2011). Our results also show that agents with higher cognitive ability scores more often play equilibrium strategies. Specifically, we find for situations with several feasible equilibria, that participants with high cognitive ability are more likely to choose the socially optimal equilibrium – resonating the findings of, e.g., Proto et al. (2019). Finally, when controlling for agreeableness, cognitive ability and further characteristics, cooperation in our Sustainability Game still correlates positively with pro-environmental orientation, yielding suggestive evidence for the external validity of our setup.

This paper’s contribution is multi-fold. First, it brings together essential features of sustainability in one tractable model. In particular, our proposed Sustainability Game is dynamic, features a threshold challenge, and incorporates a social dilemma when multiple decision makers are involved. It contributes to the literature (discussed in the next section and illustrated in Table 1) not only by providing an innovative social dilemma experiment, but also by providing a novel way to elicit sustainable behavior. Second, our first theoretical and experimental result shows that there is a tension between individual free-rider incentives and collective outcomes, which is resolved if there is only one player. The fact that our game can be played meaningfully by one person, hence highlights the core problem that is common to all social dilemma games. This shows that our model “works,” not only because it captures the social dilemma aspect, but also because the theoretical predictions from the equilibrium analysis are strongly supported by the experimental results. Third, we address how threshold effects trigger sustainable behavior. We find that a lower threshold increases cooperation and reduces defection.² This result is remarkable because defection is still an equilibrium. It shows that there are participants who target the efficient equilibrium when it comes to equilibrium selection. Moreover, this result suggests for any domain of application (here: environment and health), that a technology that reduces the bar for sustainable behavior need not work as a substitute to own efforts, but can work as a complement and hence foster sustainability even more. This insight contrasts with many public debates about sustainability where it is argued that either we have to change our behavior *or* we have to find a technological solution.

While the first contributions above are fundamental to introduce a meaningful and robust model of sustainability, the follow up questions concern how behavior in this Sustainability Game is related to personality traits. We predict and show that contributions correlate positively with a participant’s agreeableness. Moreover, in situations of equilibrium selection, cooperative behavior correlates positively with cognitive ability. Our results hence suggest three remedies for any challenge of sustainability: first, the problem is relaxed when a single decision maker is made responsible. Second, the problem is relaxed when there is a technology that lowers the threshold sufficiently – and participants are smart enough to choose the efficient equilibrium. Third, the problem is relaxed even if the first two remedies are not available, if the involved decision makers are agreeable people.

The remainder of this paper is organized as follows. In Section 2, we discuss the relation to the literature. In Section 3, we present the theoretical model and characterize its equilibria. In Section 4, we describe the experimental design. In Section 5, we report the experimental results. Section 6 concludes.

Model	Reference	Dynamic	Recurring	Threshold	Absorption	Irreversible	Intra-generational
<i>Public Goods (PG) Game</i>	e.g., Ledyard (1995), Chaudhuri (2011), Dal Bó and Fréchet (2018)	no	yes	no	no	no	yes
<i>Threshold PG Game</i>	e.g., Cadsby and Maynes (1999)	no	yes	yes	yes	no	yes
<i>Common Pool Resource (CPR) Game</i>	e.g., Walker et al. (2000), Vespa (2020), Przepiorka and Diekmann (2020)	yes	yes	no	no	no	yes
<i>Dynamic Free Rider Problem</i>	Battaglini et al. (2016), Gächter et al. (2017), Rockenbach and Wolff (2019)	yes	yes	no	no	both	yes
<i>Collective-Risk Social Dilemma</i>	Milinski et al. (2008)	yes	no	yes	yes	yes	yes
<i>Intergenerational Goods Game</i>	Hauser et al. (2014)	yes	yes	yes	yes	yes	no
<i>Threshold CPR Games</i>	Walker and Gardner (1992), Kimbrough and Vostroknutov (2015)	yes	yes	yes	no	yes	yes
<i>Sustainability Game</i>	This paper	yes	yes	yes	yes	yes	yes

Table 1: Comparison of our modeling approach to the experimental literature.

Notes: Model: Name tag as in original article(s) (if applicable). Reference: original article(s) or survey thereof. Dynamic: State that evolves. Recurring: infinitely recurring challenge (in contrast to finite sequence of actions in one challenge). Threshold: Discontinuity at given threshold of contributions. Absorption: Some extraction is absorbed (e.g., contributions above threshold have the same consequences for the public good). Irreversible: Contributions (e.g., below threshold) can have irreversible consequences. Intra-generational: Externalities concerning the same generation of players (in contrast to externalities concerning future generations of players).

2 Related Literature

There are two classic approaches to model social dilemmas: public goods (PG) games and common pool resource (CPR) games. The literature on PG games mostly focuses on a *static* environment to test cooperation and self-interested behavior under different assumptions. The general result is that individuals fail to fully cooperate and under-contribute to the collective good even when interactions are repeated. For reviews of the literature, see Ledyard (1995), Chaudhuri (2011) and Dal Bó and Fréchette (2018). A static environment, be it repeated or not, is however insufficient for analyzing sustainability. Dynamics is essential: the chosen actions today, if unsustainable, affect the possible actions in the future. Moreover, most PG games do not embody a threshold that can be used to distinguish sustainable behavior from unsustainable behavior, the next essential aspect of sustainability. The sub-literature on threshold PG games (e.g., Cadsby and Maynes, 1999) builds a notable exception. These models seem better suited to address sustainability, but most of them are not dynamic either. Moreover, the threshold has a special role in threshold PG games: The expected marginal returns to contributions are zero up to the threshold and become positive only after it has been reached. We want to model situations where contributions have a positive return up to the threshold, which has the interpretation that sustainability is achieved, and become zero after it has been reached. This models the absorption capacity of health or of a natural resource: different small levels of extraction do not change the resource.

The common pool resource (CPR) games go back to the problem of the commons (see Levhari and Mirman, 1980, Ostrom, 1990, and Walker et al., 2000). Our setup differs from the classic common pool resource (CPR) game in several ways. First and foremost, our game includes threshold effects while the CPR game features a continuous growth, respectively decay, of the pool. This means in particular that a CPR game does not include the possibility that different small levels of usage are absorbed in the sense that they do not affect the size of the resource. Rather, in CPR games the resource grows if there is no extraction and it grows differently for different small levels of extraction. The CPR game is often used for studying renewable resources such as fisheries or forests. Our setup better represents situations in which threshold effects are important. In the case of global warming, for example, a certain level of CO₂ emissions can be absorbed by the earth. Experts argue that it is only above the threshold that negative consequences occur. Second, in our game, the depletion of resources due to over-use is irreversible. This feature is well-suited to study environmental issues. In the context of global warming experts predict some adverse consequences of global warming that are irreversible, such as permafrost thaw, the increase in the levels of the oceans or species extinction (see Portner et al., 2022).³

More recently, dynamic PG games and variations of CPR games are being considered in the literature. Battaglini et al. (2016) study free-riding incentives in a durable PG game and compare the evolution of the durable public good when investment in it is reversible or irreversible. Gächter et al. (2017) (and similarly Rockenbach and Wolff, 2019) investigate a public goods game where the current endowments depend on the past actions. Generally, this dynamic aspect makes cooperation harder to sustain (a classic finding in that respect is provided by Herr et al., 1997). Vespa (2020) analyzes the selection of strategies in a CPR game. He shows that the Markov Perfect Equilibrium (MPE) is the modal strategy in this context. Finally, Przepiorka and Diekmann (2020) study a variation of the CPR games, where a negative externality cumulates over time. Our theoretical

²In the literature on threshold public goods games, the parallel effects are discussed in particular in Cadsby and Maynes (1999). For threshold public goods games, it is less surprising that higher thresholds reduce cooperation because expected marginal returns are zero up to the threshold and, hence, high thresholds may simply appear out of reach.

³Irreversible damage can also occur when acting unsustainably in the domain of health. Likewise, in this domain there might be some capacity for absorption.

framework and laboratory study essentially differs from these contributions in its introduction of a threshold.

Looking for dynamic social dilemma games that incorporate a threshold we found three modeling approaches:⁴ First, in the “collective-risk” game introduced by Milinski et al. (2008) and further studied, e.g., by Tavoni et al. (2011) and Szekely et al. (2021), players sequentially decide how much to contribute. If at the end of ten periods the sum of contributions does not reach a given threshold, there is the risk that all payoffs are lost. This model is dynamic, as the contributions accumulate over time, but it is finite, as the challenge is to reach a single threshold in a fixed number of periods. In contrast, our model studies agents who face a similar challenge in every period, while a state variable evolves over time. The second approach for a dynamic model with a threshold is the “intergenerational goods” game introduced by Hauser et al. (2014), where a common resource pool is handed over from one generation to the next. If one generation extracts from the pool more than a given threshold, the pool is not refilled for the next generations of decision makers. A special feature of this game is that it considers the interaction between overlapping generations, while in most other games, players stay the same. Finally, there are also CPR games that do introduce a threshold. The classic model by Walker and Gardner (1992) features even two thresholds. The first one incorporates the idea of a “safe yield” zone, a (small enough) level of extraction where the probability of destruction of the resource is zero. Similar in spirit but different in consequences, we consider a safe zone, where the resource maintains its size for different (small enough) levels of extraction. This is also a difference to the threshold CPR model provided by Kimbrough and Vostroknutov (2015). In their model, the returns to extracting the resource depend on whether the collective level of extraction is below or above the given threshold, while the resource grows for small amounts of extraction. Hence, both models differ from ours by capturing a different view on absorption capacity. That is why our model fits best to problems of conservation and less to problems of a resource that grows when there is no extraction.

Table 1 compares our model to modeling approaches from the experimental literature. As the table shows, having a model that is dynamic and has a threshold, already distinguishes our model from several approaches (see the four rows starting with PG games down to the dynamic free rider problem). The three approaches that share these features (the collective-risk social dilemma, the intergenerational goods game, and the threshold CPR games) differ in other respects as discussed immediately above. Our game contributes to the literature by incorporating important aspects of many sustainability problems, as highlighted in Table 1. Despite these features, our model is simple enough to be solved analytically and to be implemented in laboratory settings, as we demonstrate.

Concerning the findings, our model also adds to a literature that studies how personal traits affect cooperative behavior. Cognitive ability is related to playing close to equilibrium and to efficient equilibrium selection (Gill and Prowse, 2016; Proto et al., 2019, 2022), while agreeableness is associated with cooperative behavior and with positive reciprocity (e.g. Volk et al., 2011; Dohmen et al., 2008).

3 The Model

Our Sustainability Game features n agents who interact for an infinite number of periods. At the beginning of every period $t = 0, 1, 2, \dots$, each player $i = 1, 2, \dots, n$ receives an endowment e_t .

⁴Lange (2022, Table 5) provides an overview of social dilemma experiments that are used to measure pro-environmental behavior. His table shows that many of the experimentally studied games are either dynamic or incorporate a threshold. It also reveals that those who have both features, relate back to the modeling approaches of Milinski et al. (2008) and Hauser et al. (2014) that we discuss. Lange (2022)’s survey also includes various measures of pro-environmental behavior with real-world consequences. Fixing such a consequence, helps to make the external validity credible, but clearly restricts the domain of applications.

Each player i must then decide what share $c_{i,t}$ thereof she contributes to a special account; the remaining part of the endowment, $(1 - c_{i,t})e_t$, goes to her private account. After each period t , the game continues to period $t + 1$ with probability $\delta \in (0, 1)$, and ends with probability $(1 - \delta)$.

If the game continues to period $t + 1$, the total amount put on the special account by all n players in period t determines the endowment in period $t + 1$ in the following way:

$$e_{t+1} = \begin{cases} e_t & \text{if } \sum_{i=1}^n c_{i,t}e_t \geq Z_t \\ e_t - g(Z_t - \sum_{i=1}^n c_{i,t}e_t) & \text{else,} \end{cases} \quad (1)$$

where $Z_t = zne_t$ is the sustainability threshold set by a parameter $z \in [0, 1]$, and $g \in (0, \frac{1}{zn}]$ is a loss parameter. In words, the sustainability threshold parameter z defines which fraction of the overall endowment needs to be contributed to the special account in order to maintain the level of endowment from one period to the next. If the group as a whole contributes the sustainability threshold or more, the endowment in the next period will be identical to the current endowment. If the sustainability threshold is not met, the next endowment will decline proportionately to the shortfall, according to loss parameter g . Linearity of decline is assumed since it seems to be the simplest functional form. Note that the initial endowment e_0 is exogenous but endowments in all subsequent periods depend on players' decisions in past periods. Each player's payoff consists of the amounts kept in her private account.

Two specific characteristics of the game are worth mentioning. First, since the sustainability threshold is proportional to endowment, the situation is the same in relative terms for any endowment level and at any time.⁵ Second, the reduction in endowment, if it happens, is irreversible. A special case occurs when $g \equiv \frac{1}{zn}$, as contributing zero by all players then fully depletes the next endowments. While our theoretical analysis is not restricted to this special case, we will focus on it in the laboratory experiment.

3.1 The social planner's solution

Imagine a benevolent social planner could decide which fraction c_t of the aggregate endowment ne_t the whole group contributes to the special account in every period t . This social planner maximizes the aggregate expected payoff $EP_0 = \sum_{t=0}^{\infty} \delta^t (ne_t - c_t ne_t)$ over the contribution share c_t . The solution to the social planner's problem delivers the socially optimal allocation of the Sustainability Game.

Proposition 1 (Social Planner's Solution). *Suppose $\delta > \underline{\delta} := \frac{1}{1+ng(1-z)}$. The socially optimal contribution is $c_t^* = z$ in every period t .*

This proposition is proven in Appendix A.1. It means that if the probability of reaching the following period is not too small, contributing the threshold – and thereby investing in future endowments without wasting contributions – maximizes social welfare. This solution determines the optimal average contribution suggesting, but not requesting, that every player contributes equally. We are interested in problems where it is worthwhile from a social perspective to behave in a sustainable manner and therefore mostly restrict our analysis to cases where $\delta > \underline{\delta}$.

3.2 Markov perfect equilibria

To study individually rational contributions in the Sustainability Game described above, we look at symmetric Markov-perfect equilibria (MPE). MPE are a subset of sub-game perfect equilibria in

⁵While realism of this assumption depends on the application, it certainly buys tractability and parsimony.

which agents use stationary Markov strategies. Markov strategies do not depend on past decisions taken in a game, other than through the current levels of the state variables. In our game, the only state variable is the endowment. Each player thus maximizes her expected payoff conditional on the state variable e_t , which evolves according to Equation 1, and taking the actions of other players as given:

$$\max_{c_{i,t}} EP_{i,0} = \sum_{t=0}^{\infty} \delta^t (e_t - c_{i,t}e_t). \quad (2)$$

Proposition 2 (Symmetric Markov Perfect Equilibria).

1. If $\delta < \bar{\delta} := \frac{1}{1+g(1-z)}$, contributing zero (*Defection*) is the unique symmetric MPE.
2. If $\bar{\delta} \leq \delta \leq \bar{\bar{\delta}} := \frac{1}{1+g(1-zn)}$, there are three symmetric MPE (for $n > 1$):
 - i. contributing $c_{i,t} = 0$ (*Defection*),
 - ii. contributing $c_{i,t} = z$ (*Cooperation*),
 - iii. contributing $c_{i,t} = \frac{1-\delta(1-g(zn-1))}{\delta g(n-1)} \in [0, z]$ (*Inbetween*).
3. If $\delta > \bar{\bar{\delta}}$, contributing $c_{i,t} = z$ (*Cooperation*) is the unique symmetric MPE.

The proposition is proven in Appendix A.2. It shows that for low discount factor δ (while still $\delta > \underline{\delta}$) the Sustainability Game is a social dilemma situation, in which individual incentives are to contribute zero (*Defection*), while the collective optimum is achieved with contribution of z (*Cooperation*) by Proposition 1. For a high discount factor, *Cooperation* is the unique equilibrium and for an intermediate discount factor both behaviors are symmetric MPE, while there is an additional equilibrium with intermediate contributions. This additional equilibrium, *Inbetween*, is weak in the sense that individual deviations do not reduce utility of the deviating agent, but leave her indifferent (as shown at the end of the Proof of Proposition 2). For the special case that there is only a single player ($n = 1$), we have $\underline{\delta} = \bar{\delta} = \bar{\bar{\delta}}$. Then the individually and socially optimal behavior is *Cooperation* (*Defection*) for a discount factor above (below) these thresholds.

Note that in the Sustainability Game, players' contributions are typically strategic complements as long as the aggregate contribution lies below the threshold. As soon as the threshold is reached, the contributions of different players become strategic substitutes.

4 Experimental Design

This pre-registered experiment consists of two parts. In the first part, participants play the Sustainability Game six times. We use a between-subject design where each participant is assigned to one out of the three treatments called *T-Baseline*, *T-OnePlayer*, and *T-LowThreshold*. The treatments differ from one another with respect to (i) the number of players and (ii) the sustainability threshold, as explained below. The second part of the experiment is identical for all treatments and used to elicit personal characteristics of the players, including cognitive ability, agreeableness, risk aversion, ecological attitudes and some socio-demographic characteristics.

4.1 Implementation and procedures

We programmed the experiment using the o-Tree framework of Chen et al. (2016), and ran the sessions online on the Prolific platform between January 19th and January 25th 2022. We ran a total of 18 sessions (6 per treatment), with a minimum of 4 and a maximum of 7 groups or

single players per session. The assignment of sessions to treatments was randomly drawn by the computer. Participants were provided with detailed instructions for each part of the experiment and we ensured their understanding of the Sustainability Game with a comprehension questionnaire.⁶ The study duration was around 60 minutes.⁷ A total of 282 participants completed the study and earned on average 7.80 GBP.

For each participant the timeline is as follows. First she reads the instructions and completes the comprehension questionnaire. Then she is matched into a group of $n = 4$ or stays single ($n = 1$), depending on the treatment. Then she plays the Sustainability Game for the first time. In each period of the game she decides how to allocate her current endowment between the private and the special account, i.e., how much to contribute. The game continues from one period to the next with probability $\delta = 0.65$. Technically, the game is played in blocks of five periods and when the end of the game is drawn within a block, the participant is informed after the block. This means that each participant certainly makes decisions in the first five periods.⁸ After the end of the first game, the participant is informed about her payoff of this game. Now, the second game starts. After six games with the same group composition, this part ends. In the second part the participant completes a survey about personal characteristics. Finally, one game is randomly selected to be payoff relevant and the payoff is received.

4.2 Social dilemma treatment *T-Baseline*

Participants are matched into groups of four players ($n = 4$). Each player receives an initial allocation of 100 points in the first period. Then each player decides how to allocate this endowment between the private and the special account, i.e., how much to contribute to the special account. At the end of the period, she receives information about how much the other members of her group have contributed, the aggregate contribution, whether the threshold was met and how large the next period's endowment is. The game continues to the next period with probability $\delta = 0.65$. Each player faces the new endowment, which either equals the current endowment (if the total amount in the special account reached the threshold), or is smaller (if the threshold was not reached), and decides again how to allocate it between the special and the private account. In the whole experiment, the loss parameter is $g \equiv \frac{1}{zn}$, which ensures that zero contributions by all players reduce the next endowments to zero. In the baseline Treatment *T-Baseline*, the sustainability threshold parameter z is set to 0.5. With this parametrization, the endowment evolution of Equation 1 simplifies to $e_{t+1} = \min\{e_t, C_t/2\}$, where C_t is the aggregate contribution of the group in period t .

The parametrization in *T-Baseline* yields $\underline{\delta} = 0.50$ and $\bar{\delta} = 0.80$, which implies $\underline{\delta} < \delta < \bar{\delta}$. By Propositions 1 and 2.1 (where 2.1 stands for the first part of Proposition 2), *T-Baseline* therefore represents a pure social dilemma: it is socially optimal for the group to contribute the threshold amount but it is individually rational for each player to defect, i.e., contribute zero (independent of the other player's behavior).

⁶The instructions, the questionnaire and all materials of the study design including the pre-registered hypotheses can be found at <https://doi.org/10.1257/rct.6132>. All information had been provided and uploaded until January 18th, 2022 and there were no changes since then.

⁷Some potential participants did not complete the study, but typically dropped out at the very beginning. This affected seven groups in *T-Baseline*, one in *T-OnePlayer* and four in *T-LowThreshold*. Clearly, the likelihood that a group member drops out is higher in the two treatments with $n = 4$ than in the treatment with $n = 1$. To additionally control for attrition, we use a set of control variables.

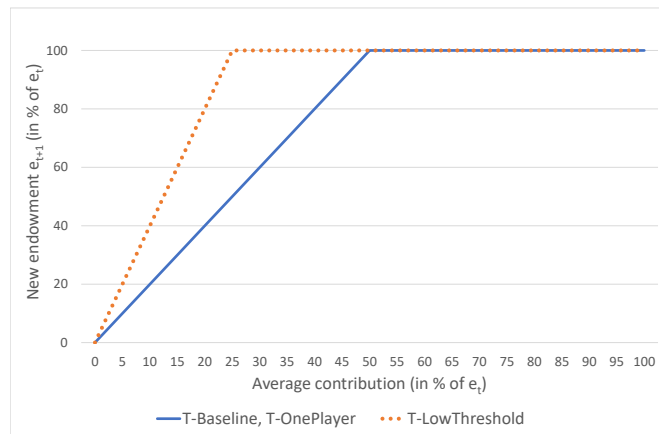
⁸If the end of the game was drawn within this block, say after the third period, then the decisions in period four and five are not payoff-relevant. If the end of the game was not drawn within this block, then this group plays a block of five further periods. This approach, called block random design, follows Fréchette and Yuksel (2017).

4.3 No strategic interactions treatment *T-OnePlayer*

T-OnePlayer eliminates strategic interactions by setting the group size to $n = 1$, but it imitates *T-Baseline* in the other respects. Hence, the sustainability threshold parameter is kept at $z = 0.5$ and zero contributions still lead to full exhaustion. The formula for the evolution of endowments now reduces to $e_{t+1} = \min\{e_t, 2C_t\}$. Figure 1 illustrates the relationship between average contribution and future endowment, which is identical for *T-OnePlayer* and *T-Baseline*. Like all treatments, this treatment has an initial allocation of 100 points and the continuation probability is $\delta = 0.65$.

Under *T-OnePlayer* we have $n = 1$ which yields $\underline{\delta} = \bar{\delta} = \bar{\bar{\delta}} = 0.5 < \delta$. By Propositions 1 and 2.3, *T-OnePlayer* therefore features a unique equilibrium that coincides with the social optimum: *Cooperation* (i.e., contributing according to the threshold).

Figure 1: Next endowment as a function of current average contribution



Notes: This figure shows how next period individual endowment e_{t+1} depends on the average contribution to the special account by the n group members in period t . Both variables are expressed as percent of current individual endowment e_t . This graph applies to any period t because, in relative terms, the stage game is the same in every period.

4.4 Low-threshold treatment *T-LowThreshold*

T-LowThreshold keeps group size $n = 4$ of the baseline, but lowers the threshold. Specifically, the sustainability threshold parameter is set to $z = 0.25$, while zero contributions still lead to full exhaustion. Figure 1 shows that in *T-LowThreshold* it is sufficient to reach an average contribution share of 25% of the endowment to maintain future endowments at the current level, whereas in *T-Baseline* (and in *T-OnePlayer*) an average contribution share of 50% is necessary. The formal expression for the evolution of endowments, Equation 1, now reduces to $e_{t+1} = \min\{e_t, C_t\}$.

The parametrization of *T-LowThreshold* yields $\underline{\delta} = 0.25$, $\bar{\delta} \approx 0.57$ and $\bar{\bar{\delta}} = 1$, which implies $\underline{\delta} < \bar{\delta} < \delta = 0.65 < \bar{\bar{\delta}}$. By Propositions 1 and 2.2, *T-LowThreshold* therefore represents a problem of equilibrium selection, where both *Defection* and *Cooperation* are MPE, while *Cooperation* is still the social optimum. Table 2 summarizes the three treatments and their respective implications for the equilibria of the game.⁹ We considered *T-Baseline* as the natural baseline because it captures a pure social dilemma.

⁹A combination of one player and low threshold is also thinkable, but it has the same theoretical predictions as the one player treatment.

Table 2: Treatments summary

	<i>T-Baseline</i>	<i>T-OnePlayer</i>	<i>T-LowThreshold</i>
group size n	4	1	4
sustainability threshold param. z	0.5	0.5	0.25
discount factor δ	0.65	0.65	0.65
social optimum	<i>Cooperation</i>	<i>Cooperation</i>	<i>Cooperation</i>
equilibria	<i>Defection</i>	<i>Cooperation</i>	<i>Cooperation, Defection, Inbetween</i>

Notes: *Cooperation* is defined as contributing according to the threshold, $c_{i,t} = z$. *Defection* is defined as contributing zero, $c_{i,t} = 0$. We restrict attention to symmetric Markov-perfect equilibria.

4.5 Personal characteristics

In the second part of the experiment, we elicit information about various characteristics of the participants. First, participants complete a risk aversion game. Players receive 30 points and must decide how many to invest in a profitable but risky project. We measure risk tolerance with the amount invested by each player. Then, we measure cognitive abilities of participants using 12 questions out of the Set 2 of the Raven Advanced Progressive Matrices. The number of questions a participant answers correctly gives her/his *Raven* score. Participants then take a personality test that consists of 24 items from the International Personality Item Pool, based on Maples-Keller et al. (2019). We measure two aspects of participants' personality: agreeableness and conscientiousness. Agreeableness measures a person's altruism, trust in others, cooperation and morality. Conscientiousness measures self-discipline, efficiency, achievement-striving and dutifulness. We then use the New Ecological Paradigm (NEP) of Dunlap et al. (2000) to assess pro-environmental orientation of participants.¹⁰ After that, participants are asked to complete a short CO2 footprint questionnaire that consists of six questions from the WWF Swiss footprint calculator, following Berger and Wyss (2021). Our study finishes with a standard short demographic questionnaire.

4.6 Hypotheses

Before running the experiments, we had pre-registered four primary hypotheses and two secondary hypotheses.¹¹ The primary hypotheses concern treatment effects (derived from the game-theoretic equilibrium analysis); the secondary hypotheses concern expected correlations between individual traits and behavior.

Let us begin with the primary hypotheses about treatment *T-OnePlayer*. In the baseline setting, *T-Baseline*, *Defection* (i.e., contributing zero) is the unique equilibrium. In contrast, in the setting without strategic interaction, *T-OnePlayer*, *Cooperation* (i.e., contributing z) is the unique equilibrium. Hence, we predict:

Hypothesis 1 (H-CoopDef-One). *Without strategic interaction (i.e., in T-OnePlayer), Cooperation is more often played and Defection is less often played (than in the baseline, T-Baseline).*

This game-theoretic prediction captures free-riding incentives that arise when there are multiple players. As usual, free-rider incentives are accompanied by strategic uncertainty and by the aversion of being exploited by free-riders. Since *Cooperation* means reaching the threshold, while

¹⁰The New Ecological Paradigm Scale is a revised and extended version of the original New Environmental Paradigm Scale, also abbreviated with NEP.

¹¹These hypotheses were pre-registered at AEAregistry-6132. They are copied and pasted here with identical wording and order. We here only add the treatment names in brackets, replacing longer explanations between the hypotheses in the pre-registered 'Analysis plan' document. As Brodeur et al. (2024) document, pre-registration, as practiced by economists, varies in terms of having or not having a pre-analysis plan and its level of specificity. Our analysis plan's specificity can be seen from the following example. To test Hypothesis H-CoopDef-One, we wrote: "Compare frequency of contributing near Cooperation and near zero between T-Baseline and T-OnePlayer."

Defection does not, the behavior predicted in Hypothesis H-CoopDef-One has the following direct consequence:

Hypothesis 2 (H-Reached-One). *Without strategic interaction (i.e., in T-OnePlayer), the threshold is reached more often (than in the baseline, T-Baseline).*

We now turn to treatment *T-LowThreshold*, which differs from the baseline by its lower threshold. In *T-LowThreshold* both *Defection* and *Cooperation* are equilibria. Thus, participants in that treatment might more often play *Cooperation* than in the baseline *T-Baseline*, where *Defection* is the unique equilibrium. Hence, we hypothesize:

Hypothesis 3 (H-CoopDef-Low). *When the threshold is lower (i.e., in T-LowThreshold), Cooperation is more often played and Defection is less often played (than in the baseline, T-Baseline).*

This hypothesized behavior on the individual level has the following consequences on the collective level:

Hypothesis 4 (H-Reached-Low). *When the threshold is lower (i.e., in T-LowThreshold), it is reached more often (than in the baseline, T-Baseline).*

Notice that Hypothesis H-Reached-Low is in some sense less challenging than the others, as it is additionally supported by a mechanical effect: the same contributions that are insufficient for a high threshold, may be sufficient to reach a small threshold.

In addition to these four primary hypotheses we also pre-registered two secondary hypotheses. First, the standard index of *Agreeableness* that we use includes measures of altruism, cooperation, trust and morality. These aspects of personality should translate into more pro-social behavior in our game and more specifically correlate positively with contributions. Hence, we hypothesize:

Hypothesis 5 (H-Agree). *Agreeable people contribute more.*

Second, people with high cognitive ability might play more often the game-theoretic equilibrium strategies than people with lower cognitive ability. The intuition behind this hypothesis is that high cognitive ability individuals could act more strategically: they might use a deeper level of reasoning when taking into account their own and the other players' incentives. Hence, we expect participants with high *Raven* score to play more often *Cooperation* (in *T-OnePlayer* and *T-LowThreshold*) and to play more often *Defection* (in *T-Baseline* and *T-LowThreshold*) than the agents with a low *Raven* score. This is summarized by Hypothesis H-Raven.

Hypothesis 6 (H-Raven). *People with high cognitive ability play more often Cooperation and play more often Defection.*

5 Experimental Results

Before testing the six hypotheses, we briefly describe the data set.

5.1 Descriptive statistics

We have 282 participants in our study. They are aged between 19 and 63, with an average of around 27 years. 52% of participants declare themselves as women and 48% as men or other (with 1.4% choosing other). On average our participants have a *Raven* score of 6.5 out of 12 with substantial variation between participants, and an agreeableness index of 45.0 (on a scale from 12 to 60). These and further descriptive statistics are summarized in the first block of Table 3.

The participants form 63 groups of four (of which 31 are in treatment *T-Baseline* and 32 in treatment *T-LowThreshold*) and 30 remain single players (those in *T-OnePlayer*). Table 3 summarizes all important outcome variables, first those on the individual level, then those on the collective level. Each game lasts at least five periods and is repeated six times, yielding 2,790 observations on the group level and 8,460 observations on individual behavior.¹² The binary variables *Close to Cooperation*, *Close to Defection*, and *Close to Inbetween*, equal 1 if a participant has submitted a contribution share within a $\pm 2pp$ band around the strategy.¹³ Pooling all individual decisions, participants play *Close to Cooperation* in 30.1% of all cases, while they play *Close to Defection* in 7.8% of all cases. The strategy *Close to Inbetween* can only be played in *T-LowThreshold* and is chosen in only 3.2% of these cases. *Threshold met* is a binary variable that equals 1 if the participant’s group has reached the sustainability threshold in a given period t and zero otherwise. On average, participants reach the sustainability threshold 55% of the time. *Sustainability* is a binary variable that equals 1 if the group reached the threshold in all periods until t , or equivalently, maintained their endowment at its original level of 100.

Table 3: Summary statistics

Variable	N	Mean	St. Dev.	Min	Max
<i>Female</i>	282	0.521	0.500	0	1
<i>Age</i>	282	27.372	7.784	19	63
<i>Raven</i>	282	6.518	3.113	0	12
<i>Risk Tolerance</i>	282	14.372	7.403	0	30
<i>Agreeableness</i>	282	44.993	6.380	26	58
<i>Conscientiousness</i>	282	43.323	7.012	24	60
<i>Contribution</i>	8,460	29.549	19.747	0	100
<i>Contribution Share</i>	8,460	0.354	0.217	0.000	1.000
<i>Private account</i>	8,460	51.982	23.724	0	100
<i>Close to Cooperation</i>	8,460	0.301	0.459	0	1
<i>Close to Defection</i>	8,460	0.078	0.268	0	1
<i>Close to Inbetween</i>	3,840	0.032	0.177	0	1
<i>Endowment</i>	2,790	81.904	27.362	0	100
<i>Threshold met</i>	2,790	0.551	0.497	0	1
<i>Sustainability</i>	2,790	0.349	0.477	0	1

Notes: The variable *Raven* measures cognitive ability of the participants and corresponds to the number of questions that they answered correctly in the *Raven* test that consisted of 12 questions. *Risk Tolerance* is the number of points out of 30 invested in the profitable risky project in the risk aversion game, where a higher score indicates higher tolerance to risk. *Agreeableness* and *Conscientiousness* report participants’ scores on the International Personality Item Pool test. Observations on individual behavior and on group outcomes are here pooled over all three treatments, all five periods, and all six repetitions of the game.

Figure 2 illustrates the evolution of the main variables over time separated by treatment. In particular, it displays the percentage of participants who played *Close to Cooperation* (upper left panel) and *Close to Defection* (upper right panel), as well as the *Threshold met* (lower panel). Figure 2 thus yields a first impression of potential treatment effects.

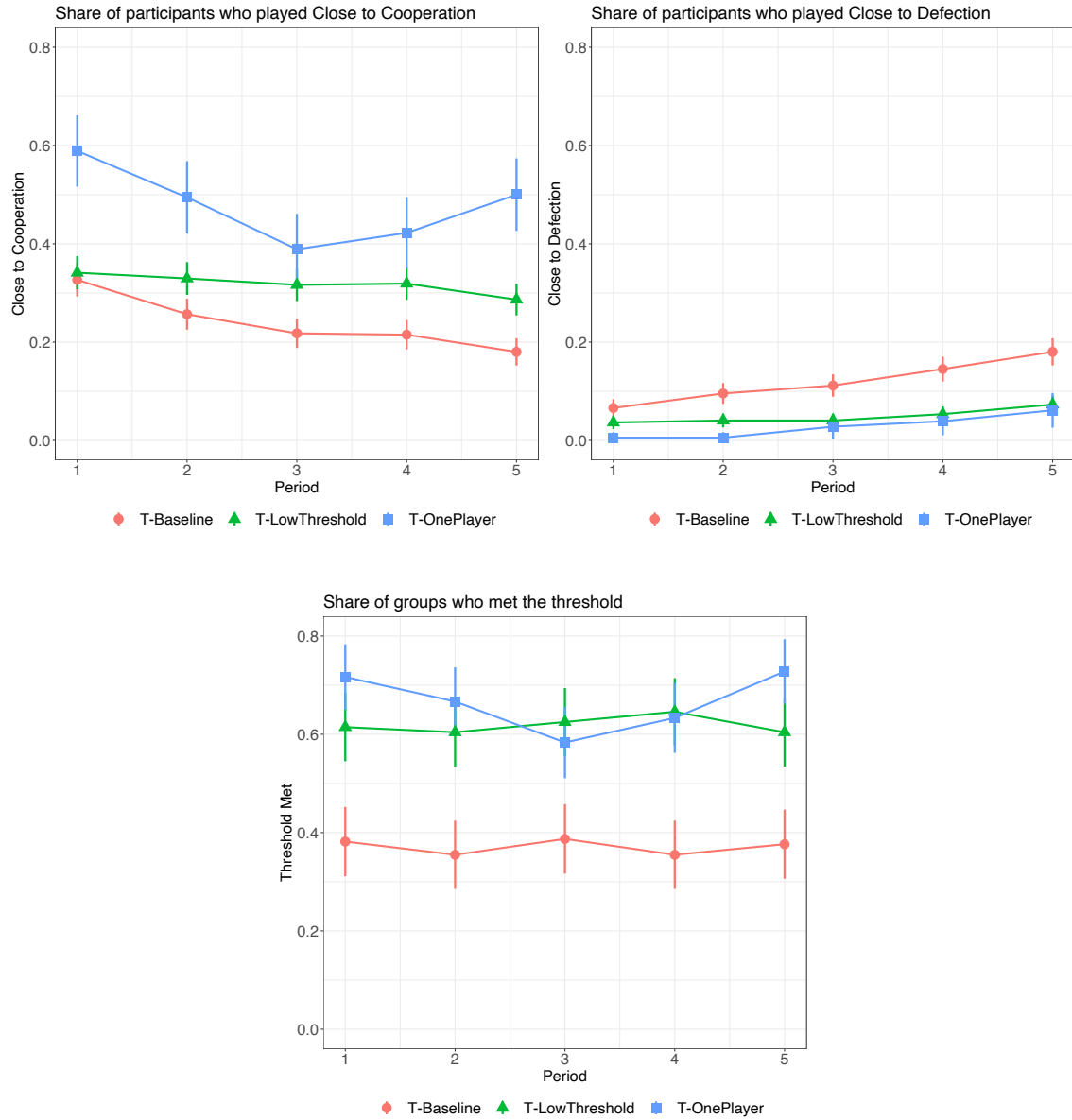
To causally identify treatment effects, we again compare these outcomes in the three treatments but also account for interdependencies of observations. First, the behavior of a group across the five periods of the game is clearly interdependent. Therefore, each analysis uses either only a single

¹²We focus on the first five periods in each game because these can be observed independent of the actual end of the game, thanks to the block random design.

¹³For *T-Baseline* and *T-OnePlayer* *Close to Cooperation* therefore equals 1 for contribution shares between 0.48 and 0.52 and 0 otherwise. For *T-LowThreshold* *Close to Cooperation* equals 1 for contribution share between 0.23 and 0.27 and 0 else. *Close to Defection* equals 1 if a participant chose a contribution share between 0 and 0.02. This approach is in the tradition of, e.g., Walker et al. (2000).

outcome period or the (single) average of all five outcome periods. Second, apart from period 1 in the first game, each group has a common history, which can make their choices interdependent. We deal with this dependency by clustering standard errors on the group level, which generally helps when there is intra-group correlation of residuals (see Abadie et al., 2017). Moreover, as a robustness test, we additionally run the main analyses restricting the sample to the first game for each group and explicitly report the first round outcome. Finally, we include control variables to assure that different behavior across treatments (if any) is not driven by an unlucky draw of allocating different types to treatments or by attrition.

Figure 2: Main variables evolution over time, by treatment



Notes: Mean and standard 95% confidence intervals, pooling groups and repetitions of the game. *Close to Cooperation* and *Close to Defection* are binary variables that equal 1 if a participant has submitted a contribution share within a $\pm 2pp$ band around the *Cooperation* and *Defection* strategies, respectively. *Threshold met* is a binary variable that equals 1 if a participant's group has reached the sustainability threshold.

5.2 Test of primary hypotheses: treatment effects

This first part of our econometric analysis estimates treatment effects on the three main outcome variables, *Close to Cooperation* (Table 4), *Close to Defection* (Table 5), and *Threshold met* (Table 6). We use dummy variables for the treatments *T-LowThreshold* and *T-OnePlayer* and keep *T-Baseline* as the reference category. We run each regression once without and once with controls. The set of control variables is *Age*, *Female*, *Raven*, *Risk Tolerance*, *Agreeableness* and *Conscientiousness*. All regression models report robust standard errors clustered at the group level.

Table 4 reports treatment effects on a participant’s probability of playing *Close to Cooperation*. Columns (1) and (2) only consider the first period of each game, Columns (3) and (4) only consider period five. (Recall that for all participants we have observations of their first five periods.) The dependent variable is binary, so we estimate the coefficients using a logistic regression model. The raw coefficients of the logit regressions are the log-odds (which are easily transformable into marginal effects). In Columns (5) and (6), we take the individual’s average of the binary variable *Close to Cooperation* over periods one to five of each game. The dependent variable therefore represents the frequency of playing *Close to Cooperation* over the five periods of the game; it is no longer binary but can take values $\in [0, 0.2, 0.4, 0.6, 0.8, 1]$. To easily interpret coefficients, we treat this dependent variable as continuous and run an OLS regression.

The results in Table 4 show that removing strategic interactions significantly increases the probability of playing *Close to Cooperation*. This effect is illustrated in the upper left panel of Figure 3, which shows the regression coefficients when running it for each of the five periods. We observe that the effect of removing strategic interaction occurs already in period one, is stable and persists until period five. Columns (5) and (6) of Table 4 indicate that this effect increases the frequency of playing *Close to Cooperation* by about 24-25pp. Transforming the coefficients of the logit regressions into marginal effects yields a similar quantification. For instance, the coefficient of *T-OnePlayer* in Column (1), 1.083, turns into a marginal effect of 0.262, again indicating an increase of around 25pp (or even larger when using the other coefficients).¹⁴ The effect is large and statistically significant. Note that the inclusion of the controls does not change the size or significance of the estimates. Finally, we challenge the robustness of these results by re-running the analysis of Table 4, now restricted to the sub-sample of the first game of each group (Appendix Table B.1). The findings are confirmed even with this smaller number of observations. These results fully support Hypothesis H-CoopDef-One, first with respect to *Cooperation*.

The results in Table 4 also indicate that, in line with Hypothesis H-CoopDef-Low, lowering the threshold significantly increases the probability of *Close to Cooperation*, in period five, but not in period one (compared to *T-Baseline*). The left panel of Figure 3 confirms that treatment effects of *T-LowThreshold* increase over time and only become significant toward the end of the first five periods. Columns (5) and (6) of Table 4 suggest that lowering the threshold results in an increase of about 8pp in the frequency of playing *Close to Cooperation*. The weak significance of the *T-LowThreshold* coefficients in Columns (5) and (6) is due to the insignificance of treatment effects in early periods of the game. The robustness test in Table B.1 supports significance of these effects. Hence, Hypotheses H-CoopDef-One and H-CoopDef-Low are largely supported concerning *Cooperation*.

Concerning *Defection*, the right panel of Figure 3 illustrates the treatment effects on a participant’s probability of playing *Close to Defection*. Table 5 shows the corresponding regressions. Lowering the threshold significantly reduces the probability of *Close to Defection*, again with

¹⁴We currently refrain from reporting all marginal effects in the paper, as we have a good assessment of the effect size with the descriptive statistics that compare treatments reported before (i.e., Figure 2) and with the OLS accompanying all logit regressions (i.e., Columns 5-6 of Table 4).

Table 4: Treatment effects on playing Close to Cooperation

Dependent Variable:	Close to Cooperation					
	period 1		period 5		average 1-5	
Model:	(1)	(2)	(3)	(4)	(5)	(6)
	Logit	Logit	Logit	Logit	OLS	OLS
<i>Variables</i>						
T-OnePlayer	1.083*** (0.3396)	1.275*** (0.3407)	1.516*** (0.3409)	1.657*** (0.3518)	0.2396*** (0.0672)	0.2508*** (0.0617)
T-LowThreshold	0.0654 (0.2575)	0.0814 (0.2566)	0.6030** (0.2849)	0.6451** (0.2747)	0.0792 (0.0510)	0.0821* (0.0461)
Constant	-0.7235*** (0.1889)	-1.676 (1.045)	-1.516*** (0.2285)	-1.432* (0.8541)	0.2392*** (0.0360)	0.1412 (0.1545)
Controls	No	Yes	No	Yes	No	Yes
<i>Fit statistics</i>						
Observations	1,692	1,692	1,692	1,692	1,692	1,692
R ²					0.04257	0.13610
Pseudo R ²	0.01973	0.09267	0.03928	0.07353		
Wald (joint nullity)	5.7419	5.3471	9.9380	4.8813	6.3765	7.1612

Clustered (Group) standard errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

stronger effect in period five than in period one. The average frequency of playing *Close to Defection* falls by about 8 to 9pp in *T-OnePlayer* and by 7pp in *T-LowThreshold* relative to *T-Baseline*. The results in Table 5 and Figure 3 show that Hypotheses H-CoopDef-One and H-CoopDef-Low are not only supported concerning *Cooperation* but also concerning *Defection*.¹⁵

The remaining primary hypotheses are Hypotheses H-Reached-One and H-Reached-Low, which predict that without strategic interaction, or with a lower threshold, the threshold is reached more often. Table 6 presents the results.¹⁶ It shows that both *T-OnePlayer* and *T-LowThreshold* significantly increase the groups' probability of reaching the threshold in period one and period five. For all periods in between the coefficients are also significant, as illustrated in the lower panel of Figure 3. The average frequency of reaching the threshold increases by 29-33pp for *T-OnePlayer* and by 25-27pp for *T-LowThreshold* (Columns (5) and (6) of Table 6). Again, transforming the coefficients of the logit regression into marginal effects supports the quantification of the effects. (For *T-OnePlayer* they indicate even a slightly larger effect of around 33-39pp.) The effects are large and highly significant and hence fully support Hypotheses H-Reached-One and H-Reached-Low.

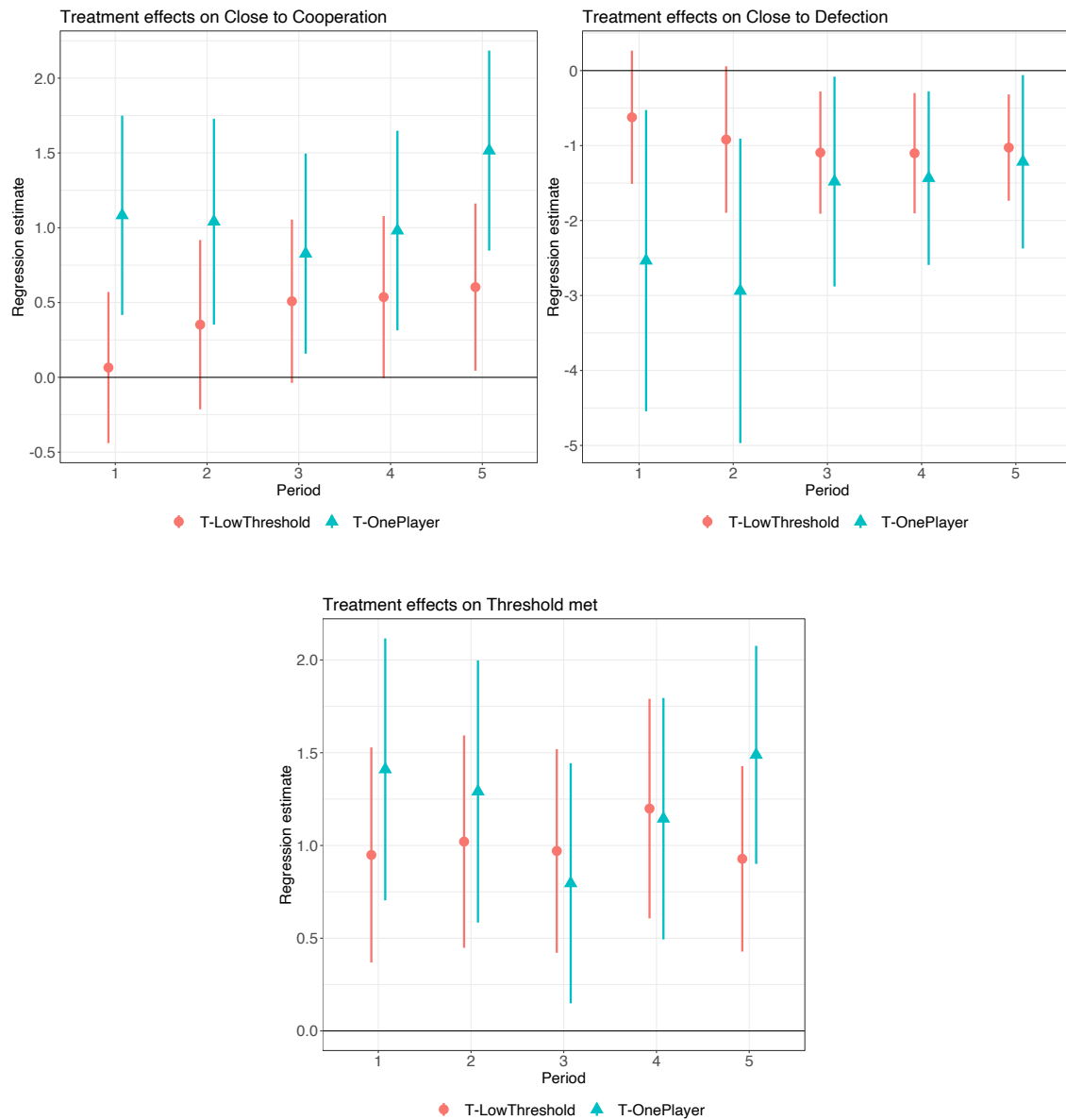
5.3 Further treatment effects

The treatment effects that we find above should have implications for further outcome variables of interest, in particular for the evolution of endowments and for maintaining sustainability. Figure 4 illustrates the evolution of endowments and sustainability over time for each treatment. While in the baseline treatment only 10.8% of the groups act sustainably in the first five periods, this fraction increases to 33.9% when there is no strategic interaction and to 21.9% when the threshold is lower. Notice that there is a mechanical effect that *T-LowThreshold* leads to weaker decrease

¹⁵Notice that for the strategy *Inbetween* there are no treatment effects to consider, as it is only playable in one treatment, *T-LowThreshold*.

¹⁶Note that the regression in Table 6 concern group-level data and not individual data, which is why the number of observations is smaller.

Figure 3: Treatment effects relative to T -Baseline on strategies played, over time



Notes: Coefficient and 95% confidence intervals from logistic regression with dependent variable *Close to Cooperation* (upper left panel) and *Close to Defection* (upper right panel) and *Threshold met* (lower panel), on T -LowThreshold and T -OnePlayer dummies, and on a constant. Estimation as in Tables 4-6 with standard errors clustered on the group level.

Table 5: Treatment effects on playing Close to Defection

Dependent Variable:	Close to Defection					
	period 1		period 5		average 1-5	
Model:	(1)	(2)	(3)	(4)	(5)	(6)
	Logit	Logit	Logit	Logit	OLS	OLS
<i>Variables</i>						
T-OnePlayer	-2.535** (1.024)	-2.585** (1.083)	-1.216** (0.5897)	-1.122* (0.5889)	-0.0919*** (0.0288)	-0.0834*** (0.0294)
T-LowThreshold	-0.6224 (0.4533)	-0.7173* (0.3921)	-1.027*** (0.3612)	-1.069*** (0.3650)	-0.0709** (0.0284)	-0.0703** (0.0270)
Constant	-2.652*** (0.2482)	3.297 (2.205)	-1.516*** (0.2322)	2.137 (1.382)	0.1196*** (0.0245)	0.3959*** (0.1098)
Controls	No	Yes	No	Yes	No	Yes
<i>Fit statistics</i>						
Observations	1,692	1,692	1,692	1,692	1,692	1,692
R ²					0.03533	0.07386
Pseudo R ²	0.02890	0.08459	0.03888	0.08263		
Wald (joint nullity)	3.6184	3.0670	5.0063	6.0010	5.1168	3.6988

Clustered (Group) standard errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Table 6: Treatment effects on Threshold Met

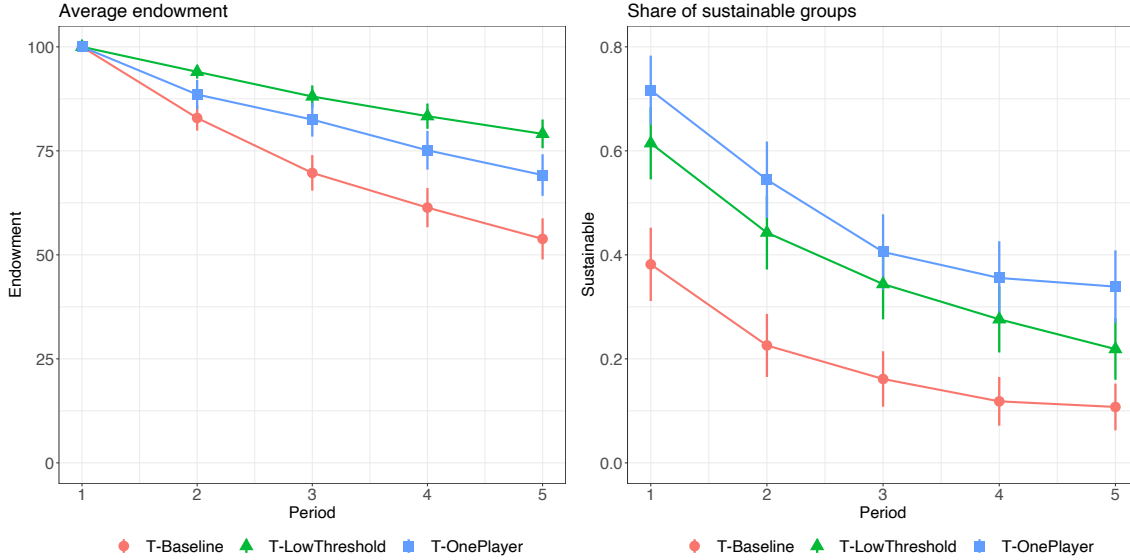
Dependent Variable:	Threshold met					
	period 1		period 5		average 1-5	
Model:	(1)	(2)	(3)	(4)	(5)	(6)
	Logit	Logit	Logit	Logit	OLS	OLS
<i>Variables</i>						
T-OnePlayer	1.410*** (0.3595)	1.686*** (0.3665)	1.488*** (0.2993)	1.768*** (0.2995)	0.2946*** (0.0647)	0.3325*** (0.0597)
T-LowThreshold	0.9489*** (0.2951)	1.124*** (0.3217)	0.9280*** (0.2546)	1.088*** (0.2796)	0.2478*** (0.0521)	0.2711*** (0.0536)
Constant	-0.4823** (0.2133)	2.958* (1.707)	-0.5051*** (0.1630)	4.477** (1.740)	0.3710*** (0.0408)	1.118*** (0.2725)
Controls	No	Yes	No	Yes	No	Yes
<i>Fit statistics</i>						
Observations	558	558	558	558	558	558
R ²					0.14110	0.19742
Pseudo R ²	0.05860	0.09264	0.06326	0.09412		
Wald (joint nullity)	9.1344	4.0404	14.443	5.5233	14.535	7.5775

Clustered (Group) standard errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

in endowments than the two other treatments for the same contributions (below 50%, as it can be seen in Figure 1). This mechanical effect, which comes on top of the behavioral response to the treatments established above, explains why endowments decrease the least in *T-LowThreshold*. For the binary outcome variable *Sustainability* this mechanical effect is absent.

Figure 4: Evolution of Endowments and Sustainability over time, by treatment



Notes: Mean and standard 95% confidence intervals, pooling groups and repetitions of the game. *Sustainability* is a binary variable that equals 1 if a participant's group has reached the sustainability threshold in all periods so far.

Table 7 estimates the treatment effects of removing strategic interactions and lowering the threshold on groups' *Sustainability* at the end of period five and on their endowments at period six.¹⁷ Columns (1) and (2) indicate that *T-OnePlayer* and *T-LowThreshold* both have a positive impact on a group's probability of maintaining a sustainable behavior until the end of period five. Columns (3) and (4) reveal an increase in the period 6 endowment by 18-21 points for *T-OnePlayer* and by 27-28 points for *T-LowThreshold*, in comparison to *T-Baseline*. The effects are hence substantial. Finally, we estimate treatment effects on the time trend of *Endowment*. Appendix Table B.4 shows that in *T-Baseline*, *Endowment* falls by 11.4 points on average in every period. The decline in *Endowment* is significantly smaller in *T-OnePlayer* (7.5 points) and *T-LowThreshold* (5.3 points). To summarize, we find that that without strategic interaction and with a lower threshold, indeed, endowments remain higher and sustainability can be more often maintained.

5.4 Test of secondary hypotheses: agreeableness and cognitive ability

Hypothesis H-Agree stipulates a positive relation between *Agreeableness* and *Contribution Share*. In Table 8, we test this hypothesis by regressing *Contribution Share* on *Agreeableness*, treatment dummies and the set of control variables (*Age*, *Female*, *Raven*, *Risk Tolerance*, *Conscientiousness*). Columns (2), (4) and (6) additionally include the interaction of *Agreeableness* with treatment dummies to allow for heterogeneous effects of *Agreeableness* across treatments.¹⁸

¹⁷The endowment at period six only depends on decisions in the first five periods. Recall that sustainability is defined as 1 if the endowment has never decreased, and 0 otherwise.

¹⁸For treatment effects concerning the outcome variable *Contribution Share*, see Appendix B.3.

Table 7: Treatment effects on Sustainability and Endowment

Dependent Variables:	Sustainability		Endowment	
	period 5		period 6	
Model:	(1)	(2)	(3)	(4)
	Logit	Logit	OLS	OLS
<i>Variables</i>				
T-OnePlayer	1.448*** (0.5007)	1.593*** (0.5117)	17.66** (6.880)	21.11*** (6.792)
T-LowThreshold	0.8433* (0.4597)	1.004** (0.4731)	26.71*** (5.406)	28.14*** (5.653)
Constant	-2.116*** (0.4112)	1.353 (2.048)	47.34*** (4.504)	91.80*** (28.99)
Controls	No	Yes	No	Yes
<i>Fit statistics</i>				
Observations	558	558	558	558
R ²			0.10391	0.15144
Pseudo R ²	0.05001	0.07411		
Wald (joint nullity)	4.2717	1.8266	12.214	4.3837

Clustered (Group) standard errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Table 8 indicates that *Agreeableness* does not significantly affect *Contribution Share* in the first period of the game, while there is a significant effect in period five and on the average. A one-point increment in *Agreeableness* raises contribution shares by 0.36pp in period five (Column (3)) and by 0.26pp on average (Column (5)), a small effect.¹⁹ The result suggests that participants who score high on *Agreeableness* maintain slightly higher contribution levels throughout the game.²⁰

Columns (4) and (6) indicate that *Agreeableness* has heterogeneous effects across treatments.²¹ The effect of *Agreeableness* is strongest in the baseline treatment. The effect is weaker in *T-LowThreshold* indicating that *Agreeableness* matters more in situations where *Cooperation* is more difficult, i.e., when it is not an equilibrium of the game. We also observe that the effect of *Agreeableness* disappears in *T-OnePlayer*, indicating that *Agreeableness* only matters when multiple players are involved in the game. Intuitively, participants with higher agreeableness score show more agreeable behavior toward others. Hypothesis H-Agree hence finds some support, but mainly in the pure social dilemma situation.

The final hypothesis, Hypothesis H-Raven, predicts that participants with high cognitive abilities, as measured by high *Raven* scores, more often play equilibrium strategies in the Sustainability Game. Tables 9 and 10 test the relation between *Raven* score and playing *Close to Cooperation* and *Close to Defection*, respectively.

Columns (1) and (3) of Table 9 report the effect of *Raven* on the probability of playing *Close to Cooperation* in period one and five, respectively. We control for treatments and the set of other control variables which is *Age*, *Female*, *Risk Tolerance*, *Agreeableness* and *Conscientiousness*. The estimate is positive and highly significant in both periods, thus supporting that more intelligent

¹⁹The *Agreeableness* score ranges from 12 to 60 points with a standard deviation of 6.38. A participant whose *Agreeableness* is one standard deviation higher than another participant's would therefore contribute on average $6.38 \times 0.26 = 1.7pp$ more.

²⁰This observation is in line with the finding that agreeableness is associated with cooperative behavior and with positive reciprocity (e.g. Dohmen et al., 2008; Volk et al., 2011).

²¹Studying interaction effects reduces statistical power (e.g., Maxwell et al., 2017). We use the interaction effects to qualitatively show which treatments drive the overall effect.

Table 8: Effect of Agreeableness on Contribution Shares (OLS)

Dependent Variable: Model:	Contribution Share					
	period 1		period 5		average 1-5	
	(1)	(2)	(3)	(4)	(5)	(6)
<i>Variables</i>						
Agreeableness	0.0003 (0.0013)	0.0003 (0.0025)	0.0036*** (0.0013)	0.0060*** (0.0019)	0.0026*** (0.0010)	0.0046*** (0.0015)
T-OnePlayer \times Agree.		-0.0033 (0.0039)		-0.0076** (0.0035)		-0.0069** (0.0030)
T-LowThreshold \times Agree.		0.0009 (0.0027)		-0.0040* (0.0023)		-0.0029 (0.0019)
Constant	0.4500*** (0.0793)	0.4469*** (0.1334)	0.2891*** (0.0703)	0.1566 (0.1029)	0.3464*** (0.0600)	0.2400*** (0.0840)
Treatment dummies	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
<i>Fit statistics</i>						
Observations	1,692	1,692	1,692	1,692	1,692	1,692
R ²	0.19261	0.19396	0.16136	0.16592	0.30834	0.31503
Wald (joint nullity)	28.954	25.023	24.533	26.462	38.345	38.567

Clustered (Group) standard errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

players more often play the cooperative equilibrium. Column (5) reports the effect of *Raven* on the average frequency of playing *Close to Cooperation* in the five periods of the game. It indicates that a one-point increase in *Raven* is associated with a 3pp increase in the frequency of playing *Close to Cooperation*. It follows that a participant whose *Raven* score is one standard deviation higher than another participant's would cooperate on average $3.11 \times 0.03 = 9pp$ more often.

However, it is important to remember that *Close to Cooperation* is not an equilibrium strategy in *T-Baseline*, but only in *T-OnePlayer* and *T-LowThreshold*. According to Hypothesis H-Raven, the effect of cognitive ability should therefore be stronger in *T-OnePlayer* and *T-LowThreshold* relative to *T-Baseline*. Columns (2), (4), and (6) examine the heterogeneity of the effect of *Raven* across treatments. In the baseline treatment *T-Baseline* the effect is weaker than overall. On the other hand, we observe a weakly significant increase in the effect of *Raven* on playing *Close to Cooperation* in *T-LowThreshold* relative to *T-Baseline* in period one and on average. Therefore, the effect of *Raven* on playing *Close to Cooperation* is mainly driven by *T-LowThreshold* where *Cooperation* is indeed an equilibrium. This observation is in line with the causal evidence provided by Proto et al. (2019) who show that participants with high *Raven* score are better able to select the Pareto-dominant equilibrium.

Concerning *Defection*, Columns (1), (3) and (5) of Table 10 indicate no significant influence of *Raven* on the probability of playing *Close to Defection*. According to Hypothesis H-Raven though, we only expect *Raven* to have an impact on playing *Close to Defection* when *Defection* is an equilibrium strategy, i.e., in treatments *T-Baseline* and *T-LowThreshold*. For *T-Baseline* Columns (2), (4) and (6) show a significant positive effect in period five and on average, but not in period one. This suggests that high cognitive ability players do not necessarily play the unique equilibrium strategy more often from the beginning of the game, but settle for it more frequently later. Hence, if *Raven* positively affects the probability of *Close to Defection*, this is mainly driven by the treatment where *Defection* is the unique equilibrium strategy. Interestingly, in the treatment

Table 9: Effect of Raven on playing Close to Cooperation

Dependent Variable:	Close to Cooperation					
	period 1		period 5		average 1-5	
Model:	(1)	(2)	(3)	(4)	(5)	(6)
	Logit	Logit	Logit	Logit	OLS	OLS
<i>Variables</i>						
Raven	0.2058*** (0.0434)	0.1165* (0.0639)	0.1317*** (0.0344)	0.0717 (0.0592)	0.0302*** (0.0063)	0.0150 (0.0098)
T-OnePlayer \times Raven		0.1420 (0.1158)		0.0108 (0.0993)		0.0241 (0.0178)
T-LowThreshold \times Raven		0.1587* (0.0899)		0.1126 (0.0795)		0.0256* (0.0135)
Constant	-1.676 (1.045)	-0.8863 (1.044)	-1.432* (0.8541)	-0.8301 (0.8730)	0.1412 (0.1545)	0.2609* (0.1471)
Treatment dummies	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
<i>Fit statistics</i>						
Observations	1,692	1,692	1,692	1,692	1,692	1,692
R ²					0.13610	0.14817
Pseudo R ²	0.09267	0.10015	0.07353	0.07753		
Wald (joint nullity)	5.3471	6.0530	4.8813	4.3861	7.1612	7.4095

Clustered (Group) standard errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

T-LowThreshold, in which both *Defection* and *Cooperation* are equilibria, this effect is nullified, again consistent with the idea that in a situation of equilibrium selection, high *Raven* participants might more often select the Pareto-efficient equilibrium.

5.5 Further results: waste and environmental attitudes

The test of the secondary hypotheses shows that there are associations between the personality traits agreeableness and cognitive ability with behavior in the Sustainability Game. In particular, in line with Hypothesis H-Raven high cognitive ability players more often play equilibrium strategies. As a corollary, we expect that they are less likely to choose “wasteful” strategies. *Waste* occurs when a group contributes to the special account more than the sustainability threshold. In Appendix B.4 we explore this relation between cognitive ability and *Waste*. Participants with higher Raven score indeed less often contribute above the threshold z (Appendix Table B.6) with the consequence that groups with higher average Raven score less often induce waste (Appendix Table B.7).

Finally, we explore how cooperative behavior in the Sustainability Game correlates with environmental attitudes. We find systematic correlations with the New Ecological Paradigm (NEP) score, but no relation with our small CO2 footprint score. The NEP measures the endorsement of a “pro-ecological” world view (Dunlap et al., 2000).²² The results in Appendix Table B.5 indicate that participants with a stronger ecological concern are more likely to play *Close to Cooperation* beyond the effects of other control variables (Table B.8). The effect is significant overall, but seems to be mainly driven by *T-OnePlayer*. Appendix Table B.9 further shows that a higher NEP score is associated with a lower probability of playing *Close to Defection*, without any clear differences

²²The NEP score ranges from 26 to 71 with mean 55.5 and standard deviation 7.7.

Table 10: Effect of Raven on playing Close to Defection

Dependent Variable:	Close to Defection					
	period 1		period 5		average 1-5	
Model:	(1)	(2)	(3)	(4)	(5)	(6)
	Logit	Logit	Logit	Logit	OLS	OLS
<i>Variables</i>						
Raven	-0.0486 (0.0615)	-0.0554 (0.0671)	0.0727 (0.0488)	0.1171** (0.0529)	0.0029 (0.0035)	0.0101* (0.0059)
T-OnePlayer \times Raven		0.1547 (0.1007)		0.0096 (0.1668)		-0.0093 (0.0074)
T-LowThreshold \times Raven		0.0100 (0.1346)		-0.1340 (0.1051)		-0.0127* (0.0072)
Constant	3.297 (2.205)	3.368 (2.071)	2.137 (1.382)	1.644 (1.359)	0.3959*** (0.1098)	0.3365*** (0.1046)
Treatment dummies	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
<i>Fit statistics</i>						
Observations	1,692	1,692	1,692	1,692	1,692	1,692
R ²					0.07386	0.08242
Pseudo R ²	0.08459	0.08511	0.08263	0.08750		
Wald (joint nullity)	3.0670	2.9632	6.0010	5.5413	3.6988	3.2550

Clustered (Group) standard errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

among the treatments. Therefore, sustainable behavior in our Sustainability Game is positively associated with pro-environmental orientation.

6 Discussion

Sustainability is defined as using resources today in a way that does not compromise the availability of resources in tomorrow. This definition entails that there is a threshold that distinguishes sustainable behavior, which can be repeated, from unsustainable behavior, which cannot. In this paper we propose a model of sustainability. It differs from the standard public goods (PG) and common pool resource (CPR) games by being dynamic and having a threshold. Both these aspects are necessary to capture the meaning of sustainability, as defined above. In particular, our model incorporates a resource's capacity to absorb a certain level of consumption, while over-consumption (irreversibly) diminishes the resource. This feature further differentiates our model from most of the pre-existing literature and makes conservation of personal health or of the environment ideal applications.

Theoretically and experimentally, we find that cooperation is fostered by excluding interaction and by lowering the sustainability threshold. The former result reflects analogous fundamental findings for PG and CPR games, where making one player solely involved eliminates the free-rider problem. The latter result goes beyond a mechanical effect of reaching a threshold more often just because it is set lower. We find in particular that lowering the threshold makes people choose Defection less frequently. Drawing conclusions for the goal of sustainability (be it in the environmental domain or concerning personal health), our results suggests that technological progress need not be always seen as a substitute to behavioral change; if it lowers the threshold, it can also

work as a complement that fosters behavioral change toward sustainability.

A Appendix: Proofs

A.1 Proof of Proposition 1: social planner's solution

Proposition A.1 below nests Proposition 1 of the main text as a special case.

Proposition A.1 (Social Planner's Solution, General). *Consider a social planner that maximizes the aggregate expected payoff $EP_0 := \sum_{t=0}^{\infty} \delta^t (ne_t - c_t ne_t)$ over the fraction c_t of the total endowment that the group contributes.*

1. If $\delta > \underline{\delta} := \frac{1}{1+ng(1-z)}$, the social planner chooses $c_t^* = z$ at each period t .
2. If $\delta = \underline{\delta}$, the social planner chooses $c_t^* \in [0, z]$.
3. If $\delta < \underline{\delta}$, the social planner chooses $c_t^* = 0$.

An aggregate contribution above the threshold is wasteful, which means that the social planner chooses the aggregate contribution share c_t such that $c_t \leq z \forall t$. It follows from Equation 1 that $e_{t+1} = e_t - g(zne_t - c_t e_t) \forall t$. To find the social planner's solution, we can therefore maximize the value $V(e_t)$ depending on consumption in t and the discounted future value $V(e_{t+1})$ in the following way:

$$\begin{aligned} \max_{c_t} V(e_t) &= ne_t - c_t ne_t + \delta V(e_{t+1}) \\ &\text{s.t.} \\ c_t &\leq z \\ c_t &\geq 0 \\ e_{t+1} &= e_t - g(zne_t - c_t ne_t). \end{aligned} \tag{A.1}$$

Maximizing the corresponding Lagrangian

$$\max_{c_t} V(e_t) = ne_t - c_t ne_t + \delta V(e_t - gzne_t + gc_t ne_t) - \lambda_{1,t}(c_t - z) + \lambda_{2,t}c_t,$$

we get a first order condition w.r.t. c_t (the FOC), an envelope condition capturing the derivative of the value function with respect to the endowment (the EC) and two complementary slackness conditions:

$$\begin{aligned} \text{(FOC)} \quad & -ne_t + \delta V'(e_{t+1})gne_t - \lambda_{1,t} + \lambda_{2,t} = 0 \\ \text{(EC)} \quad & V'(e_t) = n - nc_t + \delta V'(e_{t+1})(1 - gnz + gnc_t) \\ & \lambda_{1,t}(c_t - z) = 0 \\ & \lambda_{2,t}c_t = 0 \\ & c_t - z \leq 0 \\ & c_t \geq 0 \\ & \lambda_{1,t}, \lambda_{2,t} \geq 0. \end{aligned} \tag{A.2}$$

We distinguish three cases. First, suppose that the condition $c_t \leq z$ is binding. In this case, $c_t = z$, and $\lambda_{2,t} = 0$. Moreover, for $c_t = z$ it holds that $e_{t+1} = e_t$. The FOC and EC in System of Equations A.2 become $\delta V'(e_t)gne_t = ne_t + \lambda_{1,t}$ and $V'(e_t) = n - nz + \delta V'(e_t)$. Solving for $\lambda_{1,t}$ and $V'(e_t)$ yields $V'(e_t) = \frac{n(1-z)}{1-\delta}$ and $\lambda_{1,t} = \frac{\delta gn^2 e_t (1-z)}{1-\delta} - ne_t$. The condition $\lambda_{1,t} \geq 0$ is then equivalent to $\delta \geq \frac{1}{1+ng(1-z)}$. Hence, $c_t = z$ is a solution iff $\delta \geq \frac{1}{1+ng(1-z)}$ ($= \underline{\delta}$).

Second, suppose that the condition $c_t \geq 0$ is binding, and in consequence that $c_t = 0$, $\lambda_{1,t} = 0$. It follows for the FOC and the EC in System of Equations A.2 that $-ne_t + \delta V'(e_{t+1})gne_t + \lambda_{2,t} = 0$ and $V'(e_t) = n + \delta V'(e_{t+1})(1 - gnz)$. We guess and verify that the value function $V(e_t)$ is linear in e_t : $V(e_t) = ke_t$, with k being a positive constant. This implies $V'(e_t) = V'(e_{t+1}) = k$. We can then use the EC to determine that $k = V'(e_t) = \frac{n}{1-\delta+\delta gnz}$. Using the FOC we determine that $\lambda_{2,t} = ne_t - \frac{\delta gn^2 e_t}{1-\delta+\delta gnz}$. The condition $\lambda_{2,t} \geq 0$ is then equivalent to $\delta \leq \frac{1}{1+ng(1-z)}$ ($= \underline{\delta}$). Thus, $c_t = 0$ is a viable solution to our problem iff $\delta \leq \underline{\delta}$.

Third, consider an interior solution $c_t \in [0, z]$. This is the case if $\lambda_{1,t} = 0$ and $\lambda_{2,t} = 0$, which leads to the following FOC and EC: $\delta V'(e_{t+1})gne_t = e_t n$ and $V'(e_t) = n(1 - c_t) + \delta V'(e_{t+1})(1 -$

$gzn + gc_t n$). The FOC implies that $V'(e_t) = \frac{1}{\delta g}$, $\forall t$, such that the EC holds independently of c_t . It follows for $\delta ng(1 - z) + \delta = 1$, or equivalently for $\delta = \bar{\delta}$, that any contribution level above or equal to zero and below or equal to the sustainability threshold z is optimal. These three results together establish Proposition A.1.

A.2 Proof of Proposition 2: Markov Perfect Equilibria

We prove Proposition 2 here. For $n = 1$ the solution of the social planner's problem, Proposition A.1, applies. Observing that for $n = 1$, we have $\bar{\delta} = \bar{\delta} = \bar{\delta}$, it follows that a single player chooses *Defection* for $\delta < \bar{\delta}$; and *Cooperation* for $\delta > \bar{\delta}$, as claimed by Proposition 2. Suppose from now on that $n > 1$.

We first show that there is no MPE with waste. Assume the contrary. Then there is a time t at which the sum of contributions is above the threshold, i.e., $\sum_{i=1}^n c_{i,t} e_t > Z_t$. A single player l could deviate by slightly reducing her contribution to $c'_{l,t} = c_{l,t} - \varepsilon$, with $\varepsilon > 0$ and $\varepsilon e_t \leq \sum_{i=1}^n c_{i,t} e_t - Z_t$. Her benefits in time t increase, while the state variable e_{t+1} stays constant. As Markov strategies only depend on the state variable, the continuation of the game is unchanged. Hence, reducing her contribution is a strict improvement for player l , in contradiction to the assumption of the original situation being a MPE. Moreover, using the same argument, if there is a beneficial deviation that yields waste, there is a more attractive deviation that does not exceed the aggregate threshold.

Player i maximizes (2), taking the contributions of the others as given. Let \bar{c}_t denote the average contribution share of the other players. Using that the overall contributions never exceed the threshold, player i maximizes

$$\begin{aligned} \max_{c_{i,t}} V(e_t) &= e_t - c_{i,t} e_t + \delta V(e_{t+1}) \\ &\text{s.t.} \\ c_{i,t} e_t + (n-1) \bar{c}_t e_t &\leq z n e_t \\ c_{i,t} &\geq 0 \\ e_{t+1} &= e_t - g(z n e_t - c_{i,t} e_t - (n-1) \bar{c}_t e_t). \end{aligned} \tag{A.3}$$

Taking derivatives of the corresponding Lagrangian

$$\begin{aligned} \max_{c_{i,t}} V(e_t) &= e_t - c_{i,t} e_t + \delta V(e_t - g z n e_t + g c_{i,t} e_t + g(n-1) \bar{c}_t e_t) \\ &\quad - \lambda_{1,t} e_t (c_{i,t} + (n-1) \bar{c}_t - z n) + \lambda_{2,t} c_{i,t} \end{aligned}$$

leads to the following first order condition (FOC), envelope condition (EC) and two complementary slackness conditions:

$$\begin{aligned} \text{(FOC)} \quad & -e_t + \delta V'(e_{t+1}) g e_t - \lambda_{1,t} + \lambda_{2,t} = 0 \\ \text{(EC)} \quad & V'(e_t) = 1 - c_{i,t} + \delta V'(e_{t+1}) (1 - g z n + g c_{i,t} + g \bar{c}_t (n-1)) \\ & \lambda_{1,t} e_t (c_{i,t} + (n-1) \bar{c}_t - z n) = 0 \\ & \lambda_{2,t} c_{i,t} = 0 \\ & c_{i,t} + (n-1) \bar{c}_t - z n \leq 0 \\ & c_{i,t} \geq 0 \\ & \lambda_{1,t}, \lambda_{2,t} \geq 0. \end{aligned} \tag{A.4}$$

If the endowments are zero, $e_t = 0$, then contributions in all further periods are zero for any strategy profile. Hence, we focus on $e_t > 0$. Then the first complementary slackness condition simplifies to $\lambda_{1,t} (c_{i,t} + (n-1) \bar{c}_t - z n) = 0$. We search for symmetric equilibria, meaning that all players contribute the same fraction of their endowment

First, suppose that $c_{i,t} \geq 0$ is binding. In this case it holds that $c_{i,t} = 0$ and the first complementary slackness condition further simplifies to $\lambda_{1,t} ((n-1) \bar{c}_t - z n) = 0$. This is satisfied either if $(n-1) \bar{c}_t = z n$ or $\lambda_{1,t} = 0$. The former subcase cannot constitute a symmetric equilibrium, as $c_{i,t} = 0$ while $\bar{c}_t = \frac{z n}{n-1} > 0$. Consider hence the latter subcase: $\lambda_{1,t} = 0$. It follows for the FOC

and the EC that:

$$\begin{aligned} \text{(FOC)} \quad & -e_t + \delta V'(e_{t+1})ge_t + \lambda_{2,t} = 0 \\ \text{(EC)} \quad & V'(e_t) = 1 + \delta V'(e_{t+1})(1 - gzn + g\bar{c}_t(n-1)). \end{aligned} \quad (\text{A.5})$$

We guess and verify that the value function $V(e_t)$ is linear in e_t : $V(e_t) = ke_t$, with k being a positive constant. This implies $V'(e_t) = V'(e_{t+1}) = k$. We can then use the EC in System of Equations A.5 to determine k and the FOC to determine $\lambda_{2,t}$:

$$\begin{aligned} k &= V'(e_t) = \frac{1}{1 - \delta + \delta gzn}, \\ \lambda_{2,t} &= \left(1 - \frac{\delta g}{1 - \delta + \delta gzn}\right) e_t. \end{aligned} \quad (\text{A.6})$$

With $V(e_t) = \frac{1}{1 - \delta + \delta gzn} e_t$ we found a consistent solution for the value function that satisfies the FOC and the EC. The condition $\lambda_{2,t} \geq 0$ is then equivalent to $\delta g(1 - zn) \leq 1 - \delta$. Thus, $c_t = 0$ is a symmetric MPE iff $\delta \leq \frac{1}{1 + g(1 - zn)} (= \bar{\delta})$.

Second, suppose that $c_{i,t}e_t \leq nze_t - \bar{c}_t(n-1)e_t$ is binding. In this case it holds that $c_{i,t} = nz - \bar{c}_t(n-1)$. The second complementary slackness condition, $\lambda_{2,t}c_{i,t} = 0$, is satisfied either if $c_{i,t} = 0$ or if $\lambda_{2,t} = 0$. The former subcase cannot constitute a symmetric equilibrium, as $c_{i,t} = 0$ while $\bar{c}_t(n-1) + c_{i,t} = nz$ implies $\bar{c}_t = \frac{nz}{n-1} > 0$. Consider hence the latter subcase: $\lambda_{2,t} = 0$. It follows for the FOC and the EC that

$$\begin{aligned} \text{(FOC)} \quad & -e_t + \delta V'(e_{t+1})ge_t - \lambda_{1,t} = 0 \\ \text{(EC)} \quad & V'(e_t) = 1 - zn + \bar{c}_t(n-1) + \delta V'(e_{t+1}). \end{aligned} \quad (\text{A.7})$$

For $c_{i,t} = nz - \bar{c}_t(n-1)$, endowments are constant, such that $e_{t+1} = e_t$. We can solve the System of Equations A.7 for $\lambda_{1,t}$ and $V'(e_t)$ using that it follows from symmetry and $c_{i,t} = nz - \bar{c}_t(n-1)$ that $c_{i,t} = \bar{c}_t = z$:

$$\begin{aligned} V'(e_t) &= \frac{1 - z}{1 - \delta} \\ \lambda_{1,t} &= \left(\frac{\delta g(1 - z)}{1 - \delta} - 1\right) e_t. \end{aligned} \quad (\text{A.8})$$

The condition $\lambda_{1,t} \geq 0$ is then equivalent to $\delta \geq \frac{1}{1 + g(1 - z)} (= \bar{\delta})$. Thus, $c_t = z$ is a symmetric MPE iff $\delta \geq \bar{\delta}$.

Third, suppose that we have an interior solution, in which case it holds that $\lambda_{1,t} = 0$ and $\lambda_{2,t} = 0$. The FOC and EC from System of Equations A.5 become

$$\begin{aligned} \text{(FOC)} \quad & \delta V'(e_{t+1})ge_t = e_t, \\ \text{(EC)} \quad & V'(e_t) = 1 - c_{i,t} + \delta V'(e_{t+1})(1 - gzn + gc_{i,t} + g\bar{c}_t(n-1)). \end{aligned} \quad (\text{A.9})$$

It follows from the FOC that $V'(e_{t+1}) = \frac{1}{\delta g} \forall t$. Plugging this result into the EC, while using symmetry in the sense that $c_{i,t} = \bar{c}_t = \tilde{c}$, we find:

$$\tilde{c} = \frac{1 - \delta + \delta g(zn - 1)}{\delta g(n - 1)}. \quad (\text{A.10})$$

These results together establish Proposition 2. Notice, however, that the *Inbetween* strategy profile derived last is only a weak equilibrium: If the other players all contribute \tilde{c} , player i is indifferent with respect to her own contribution (up to a level where she starts to induce waste). We can see this by replacing \bar{c}_t by \tilde{c} in EC A.9. After some simplifications, we receive $V'(e_t) = 1 - c_{i,t} + V'(e_{t+1})(\delta gc_{i,t} + 1 - \delta g)$. Now, using $V'(e_t) = V'(e_{t+1}) = \frac{1}{\delta g}$, we observe that the equation holds independently of the level of $c_{i,t}$.

B Appendix: Additional Figures and Tables

B.1 Robustness test: first game only

Table B.1: Treatment effects on playing Close to Cooperation (first game only)

Dependent Variable:	Close to Cooperation					
	period 1		period 5		average 1-5	
Model:	(1)	(2)	(3)	(4)	(5)	(6)
	Logit	Logit	Logit	Logit	OLS	OLS
<i>Variables</i>						
T-OnePlayer	1.480*** (0.4176)	1.792*** (0.4739)	2.178*** (0.4809)	2.409*** (0.5118)	0.3145*** (0.0716)	0.3284*** (0.0643)
T-LowThreshold	-0.1241 (0.2782)	-0.1664 (0.2899)	0.9323** (0.3802)	0.9915** (0.3993)	0.1098** (0.0475)	0.1077** (0.0458)
Constant	-0.9333*** (0.1680)	-4.118** (1.704)	-1.910*** (0.3050)	-2.610 (1.634)	0.1855*** (0.0285)	-0.0513 (0.1737)
Controls	No	Yes	No	Yes	No	Yes
<i>Fit statistics</i>						
Observations	282	282	282	282	282	282
R ²					0.08825	0.19977
Pseudo R ²	0.04412	0.14571	0.08006	0.13015	0.16457	0.39698
Wald (joint nullity)	7.1876	6.1437	10.271	3.6140	10.485	7.9443

Clustered (Group) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Table B.2: Treatment effects on playing Close to Defection (first game only)

Dependent Variable:	Close to Defection					
	period 1		period 5		average 1-5	
Model:	(1)	(2)	(3)	(4)	(5)	(6)
	Logit	Logit	Logit	Logit	OLS	OLS
<i>Variables</i>						
T-OnePlayer	-15.75*** (1.001)	-16.51*** (1.065)	-0.6931 (1.094)	-0.4356 (1.068)	-0.0482*** (0.0133)	-0.0414*** (0.0137)
T-LowThreshold	0.6690 (1.222)	0.4704 (1.549)	-0.1757 (0.5638)	-0.1343 (0.5232)	-0.0251 (0.0178)	-0.0225 (0.0164)
Constant	-4.812*** (1.001)	6.492 (5.192)	-2.674*** (0.3798)	4.062 (3.289)	0.0548*** (0.0116)	0.2911*** (0.1043)
Controls	No	Yes	No	Yes	No	Yes
<i>Fit statistics</i>						
Observations	282	282	282	282	282	282
R ²					0.01806	0.10140
Pseudo R ²	0.02983	0.39067	0.00409	0.17393	-0.01300	-0.07630
Wald (joint nullity)	397.74	656.95	0.21476	2.4504	6.8059	3.4844

Clustered (Group) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Table B.3: Treatment effects on Threshold Met (first game only)

Dependent Variable:	Threshold met					
	period 1		period 5		average 1-5	
Model:	(1)	(2)	(3)	(4)	(5)	(6)
	Logit	Logit	Logit	Logit	OLS	OLS
<i>Variables</i>						
T-OnePlayer	3.099*** (0.6994)	4.036*** (0.8380)	2.442*** (0.6240)	2.893*** (0.7950)	0.3778*** (0.0720)	0.4137*** (0.0655)
T-LowThreshold	2.556*** (0.6631)	2.876*** (0.7451)	1.994*** (0.5778)	2.011*** (0.6392)	0.3708*** (0.0597)	0.3621*** (0.0683)
Constant	-1.910*** (0.5446)	-1.215 (3.042)	-1.056** (0.4172)	-0.1138 (3.257)	0.3355*** (0.0476)	0.8449** (0.3533)
Controls	No	Yes	No	Yes	No	Yes
<i>Fit statistics</i>						
Observations	93	93	93	93	93	93
R ²					0.32822	0.39260
Pseudo R ²	0.24224	0.32997	0.17765	0.22325	0.82506	1.0340
Wald (joint nullity)	10.699	3.4754	9.2501	2.2215	21.986	9.1482

Clustered (Group) standard-errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

B.2 Evolution of endowments

Table B.4: Treatment effects and endowment time trend

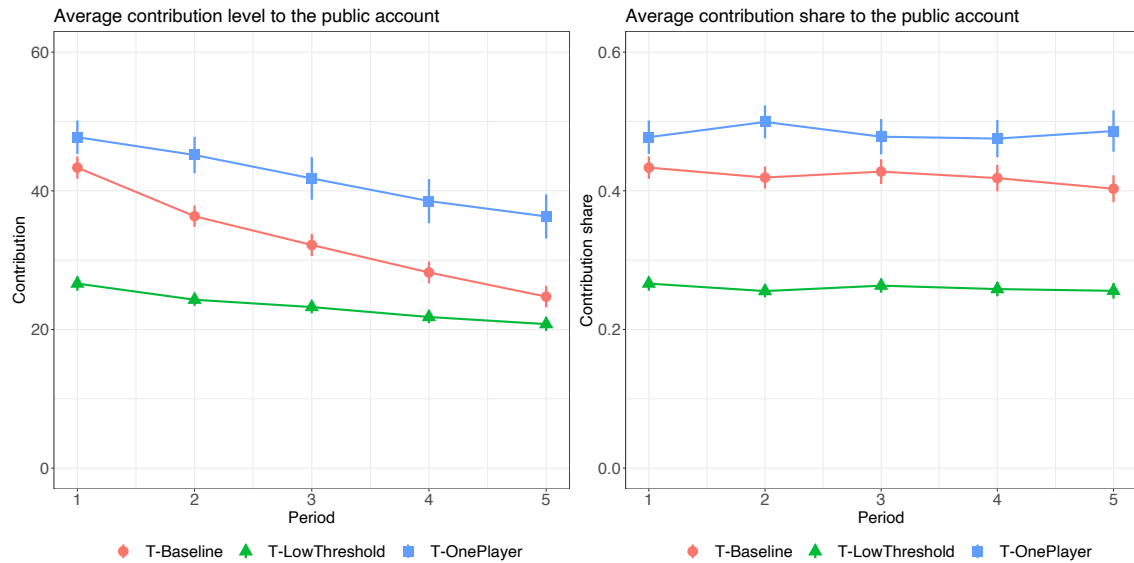
Dependent Variable: Model:	Endowment	
	(1)	(2)
<i>Variables</i>		
Period	-11.39*** (1.144)	-11.39*** (1.146)
T-OnePlayer \times Period	3.883** (1.616)	3.883** (1.618)
T-LowThreshold \times Period	6.139*** (1.311)	6.139*** (1.313)
T-OnePlayer	-2.129 (1.443)	0.2379 (2.505)
T-LowThreshold	-3.076*** (1.117)	-2.020 (1.808)
Constant	107.7*** (1.007)	135.3*** (17.71)
Controls	No	Yes
<i>Fit statistics</i>		
Observations	2,790	2,790
R ²	0.24353	0.28172
Wald (joint nullity)	42.612	21.592

Clustered (Group) standard errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

B.3 Evolution of contributions

Figure B.1 shows the levels and shares of contributions over time, separated by treatment.

Figure B.1: Contribution to the special account (levels and shares)



Notes: Mean and standard 95% confidence intervals, pooling groups and repetitions of the game

Table B.5 estimates the effect of *T-OnePlayer* and *T-LowThreshold* on the contribution shares to the special account. The dependent variable is considered as continuous, which allows us to run OLS regression in all columns. Removing strategic interactions increases contribution shares by about 4pp in period one and 8pp in period five. The effect is significant and amounts to about 6pp on average for all periods. The result is consistent with Hypothesis H-CoopDef-One: if more players choose *Cooperation* and fewer choose *Defection*, we can expect an increase in average contribution shares. The results also indicate that lowering the threshold reduces contribution shares by about 16pp. When comparing contribution shares in *T-LowThreshold* and *T-Baseline* there are two opposing effects at play. On the one hand, *T-LowThreshold* should increase average contribution shares, since fewer players choose *Defection*. On the other hand, we can expect a decrease of contribution shares since the socially efficient share is lower. Both effects seem to play a role, as we observe a decline in average contribution shares of 16pp that is smaller than the reduction in the efficient contribution share of 25pp.

Table B.5: Treatment effects on Contribution Shares (OLS)

Dependent Variable:	Contribution Share					
	period 1		period 5		average 1-5	
Model:	(1)	(2)	(3)	(4)	(5)	(6)
<i>Variables</i>						
T-OnePlayer	0.0439*	0.0448*	0.0832***	0.0752***	0.0629***	0.0600***
	(0.0258)	(0.0254)	(0.0278)	(0.0274)	(0.0224)	(0.0223)
T-LowThreshold	-0.1673***	-0.1663***	-0.1473***	-0.1523***	-0.1606***	-0.1631***
	(0.0165)	(0.0165)	(0.0175)	(0.0165)	(0.0146)	(0.0139)
Constant	0.4335***	0.4500***	0.4030***	0.2891***	0.4203***	0.3464***
	(0.0153)	(0.0793)	(0.0156)	(0.0703)	(0.0137)	(0.0600)
Controls	No	Yes	No	Yes	No	Yes
<i>Fit statistics</i>						
Observations	1,692	1,692	1,692	1,692	1,692	1,692
R ²	0.18750	0.19261	0.13113	0.16136	0.28520	0.30834
Wald (joint nullity)	89.560	28.954	70.348	24.533	122.59	38.345

Clustered (Group) standard errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

B.4 Cognitive ability and wasteful behavior

Table B.6: Effect of Raven on Overcontribution dummy

Dependent Variable:	Overcontribution dummy					
	period 1		period 5		average 1-5	
Model:	(1)	(2)	(3)	(4)	(5)	(6)
	Logit	Logit	Logit	Logit	OLS	OLS
<i>Variables</i>						
Raven	-0.1579*** (0.0314)	-0.0870 (0.0545)	-0.1050*** (0.0240)	-0.0761** (0.0362)	-0.0222*** (0.0043)	-0.0156** (0.0063)
T-OnePlayer \times Raven		-0.0904 (0.1147)		0.0095 (0.0978)		-0.0031 (0.0126)
T-LowThreshold \times Raven		-0.1194* (0.0687)		-0.0560 (0.0505)		-0.0127 (0.0093)
Constant	-1.270 (0.8301)	-1.779** (0.8641)	-2.354*** (0.6772)	-2.623*** (0.7219)	0.1243 (0.1300)	0.0654 (0.1373)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
<i>Fit statistics</i>						
Observations	1,692	1,692	1,692	1,692	1,692	1,692
R ²					0.10152	0.10464
Pseudo R ²	0.06042	0.06506	0.05482	0.05608		
Wald (joint nullity)	4.5983	5.0249	7.5497	6.1891	8.6095	7.4970

Clustered (Group) standard errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Notes: Overcontribution is defined as 1 if the participant's contribution share $c_{i,t}$ is strictly larger than the sustainability threshold parameter z and 0 otherwise.

Table B.7: Effect of Raven on Waste dummy

Dependent Variable:	Waste dummy					
	period 1		period 5		average 1-5	
Model:	(1)	(2)	(3)	(4)	(5)	(6)
	Logit	Logit	Logit	Logit	OLS	OLS
<i>Variables</i>						
Raven	-0.1308*	-0.1656	-0.1286*	-0.2310**	-0.0251***	-0.0363*
	(0.0737)	(0.1224)	(0.0715)	(0.1083)	(0.0094)	(0.0185)
T-OnePlayer \times Raven		-0.0669		0.1338		0.0131
		(0.1662)		(0.1441)		(0.0205)
T-LowThreshold \times Raven		0.2186		0.1293		0.0186
		(0.1825)		(0.1831)		(0.0331)
Constant	-1.633	-1.385	-1.057	-0.3703	0.3355	0.4138
	(1.784)	(1.930)	(1.829)	(1.884)	(0.2736)	(0.2962)
Treatmentdummies	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
<i>Fit statistics</i>						
Observations	558	558	558	558	558	558
R ²					0.18387	0.18565
Pseudo R ²	0.10916	0.11786	0.06902	0.07094		
Wald (joint nullity)	3.7497	3.0584	3.2101	2.9939	6.7304	6.1179

Clustered (Group) standard errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Notes: Waste is defined as 1 if the group's aggregate contribution $\sum_{i=1}^n c_{i,t}e_t$ is strictly larger than the sustainability threshold Z_t and 0 otherwise.

B.5 Association with New Ecological Paradigm (NEP)

Table B.8: Effect of NEP on playing Close to Cooperation

Dependent Variable:	Close to Cooperation					
	period 1		period 5		average 1-5	
Model:	(1)	(2)	(3)	(4)	(5)	(6)
	Logit	Logit	Logit	Logit	OLS	OLS
<i>Variables</i>						
NEP	0.0279*	-0.0059	0.0283**	0.0038	0.0046**	-0.0002
	(0.0147)	(0.0225)	(0.0123)	(0.0256)	(0.0022)	(0.0037)
T-OnePlayer \times NEP		0.0973**		0.0419		0.0099*
		(0.0379)		(0.0400)		(0.0057)
T-LowThreshold \times NEP		0.0427		0.0326		0.0065
		(0.0295)		(0.0283)		(0.0046)
Constant	-3.031**	-1.462	-2.806***	-1.503	-0.0770	0.1617
	(1.327)	(1.506)	(1.024)	(1.473)	(0.1914)	(0.2180)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
<i>Fit statistics</i>						
Observations	1,692	1,692	1,692	1,692	1,692	1,692
R ²					0.14517	0.15137
Pseudo R ²	0.09881	0.10619	0.07978	0.08198		
Wald (joint nullity)	5.2641	4.9003	4.8565	4.7357	7.3428	7.5625

Clustered (Group) standard errors in parentheses

*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Notes: NEP measures pro-environmental orientation (Dunlap et al., 2000).

Table B.9: Effect of NEP on playing Close to Defection

Dependent Variable:	Close to Defection					
	period 1		period 5		average 1-5	
Model:	(1)	(2)	(3)	(4)	(5)	(6)
	Logit	Logit	Logit	Logit	OLS	OLS
<i>Variables</i>						
NEP	-0.0441** (0.0214)	-0.0163 (0.0327)	-0.0271** (0.0128)	-0.0329* (0.0180)	-0.0018** (0.0008)	-0.0020 (0.0018)
T-OnePlayer \times NEP		-0.0055 (0.0482)		0.0558 (0.0603)		0.0006 (0.0021)
T-LowThreshold \times NEP		-0.0581 (0.0396)		0.0040 (0.0250)		0.0002 (0.0022)
Constant	5.252** (2.303)	3.807 (2.403)	3.406** (1.447)	3.587** (1.707)	0.4819*** (0.1261)	0.4887*** (0.1522)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
<i>Fit statistics</i>						
Observations	1,692	1,692	1,692	1,692	1,692	1,692
R ²					0.07813	0.07819
Pseudo R ²	0.09485	0.09993	0.08722	0.08848		
Wald (joint nullity)	3.4517	3.0074	5.4242	4.9883	3.2490	2.8520

Clustered (Group) standard errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

References

- ABADIE, A., S. ATHEY, G. W. IMBENS, AND J. WOOLDRIDGE (2017): “When should you adjust standard errors for clustering?” Tech. rep., National Bureau of Economic Research.
- BATTAGLINI, M., S. NUNNARI, AND T. R. PALFREY (2016): “The Dynamic Free Rider Problem: A Laboratory Study,” *American Economic Journal: Microeconomics*, 8, 268–308.
- BERGER, S. AND A. M. WYSS (2021): “Measuring pro-environmental behavior using the carbon emission task,” *Journal of Environmental Psychology*, 75, 101613.
- BRODEUR, A., N. M. COOK, J. S. HARTLEY, AND A. HEYES (2024): “Do Pre-Registration and Pre-Analysis Plans Reduce p-Hacking and Publication Bias? Evidence from 15,992 Test Statistics and Suggestions for Improvement,” Tech. rep., I4R Discussion Paper Series.
- CADSBY, C. B. AND E. MAYNES (1999): “Voluntary provision of threshold public goods with continuous contributions: experimental evidence,” *Journal of Public Economics*, 71, 53–73.
- CHAUDHURI, A. (2011): “Sustaining cooperation in laboratory public goods experiments: a selective survey of the literature,” *Experimental Economics*, 14, 47–83.
- CHEN, D. L., M. SCHONGER, AND C. WICKENS (2016): “oTree—An open-source platform for laboratory, online, and field experiments,” *Journal of Behavioral and Experimental Finance*, 9, 88–97.
- DAL BÓ, P. AND G. R. FRÉCHETTE (2018): “On the determinants of cooperation in infinitely repeated games: A survey,” *Journal of Economic Literature*, 56, 60–114.
- DOHMEN, T., A. FALK, D. HUFFMAN, AND U. SUNDE (2008): “Representative trust and reciprocity: Prevalence and determinants,” *Economic Inquiry*, 46, 84–90.
- DUNLAP, R., K. V. LIERE, A. MERTIG, AND R. E. JONES (2000): “Measuring endorsement of the new ecological paradigm: A revised NEP scale,” *Journal of Social Issues*, 56, 425–442.
- FRÉCHETTE, G. R. AND S. YUKSEL (2017): “Infinitely repeated games in the laboratory: Four perspectives on discounting and random termination,” *Experimental Economics*, 20, 279–308.
- GÄCHTER, S., F. MENGEL, E. TSAKAS, AND A. VOSTROKNUTOV (2017): “Growth and inequality in public good provision,” *Journal of Public Economics*, 150, 1–13.
- GILL, D. AND V. PROWSE (2016): “Cognitive ability, character skills, and learning to play equilibrium: A level-k analysis,” *Journal of Political Economy*, 124, 1619–1676.
- HAUSER, O., D. RAND, A. PEYSAKHOVICH, AND M. NOWAK (2014): “Cooperating with the future,” *Nature*, 511, 220–223.
- HERR, A., R. GARDNER, AND J. M. WALKER (1997): “An experimental study of time-independent and time-dependent externalities in the commons,” *Games and Economic Behavior*, 19, 77–96.
- KIMBROUGH, E. O. AND A. VOSTROKNUTOV (2015): “The social and ecological determinants of common pool resource sustainability,” *Journal of Environmental Economics and Management*, 72, 38–53.
- LANGE, F. (2022): “Behavioral paradigms for studying pro-environmental behavior: A systematic review,” *Behavior Research Methods*, 1–23.

- LEDYARD, J. O. (1995): “Public Goods: A Survey of Experimental Research,” in *Handbook of Experimental Economics*, Princeton University Press, 111–94.
- LEVHARI, D. AND L. J. MIRMAN (1980): “The great fish war: an example using a dynamic Cournot-Nash solution,” *The Bell Journal of Economics*, 322–334.
- MAPLES-KELLER, J. L., R. L. WILLIAMSON, C. E. SLEEP, N. T. CARTER, W. K. CAMPBELL, AND J. D. MILLER (2019): “Using Item Response Theory to Develop a 60-Item Representation of the NEO PI-R Using the International Personality Item Pool: Development of the IPIP-NEO-60,” *Journal of Personality Assessment*, 101, 4–15, PMID: 29087223.
- MAXWELL, S. E., H. D. DELANEY, AND K. KELLEY (2017): *Designing experiments and analyzing data: A model comparison perspective*, Routledge.
- MILINSKI, M., R. D. SOMMERFELD, H.-J. KRAMBECK, F. A. REED, AND J. MAROTZKE (2008): “The collective-risk social dilemma and the prevention of simulated dangerous climate change,” *Proceedings of the National Academy of Sciences*, 105, 2291–2294.
- OSTROM, E. (1990): *Governing the commons: The evolution of institutions for collective action*, Cambridge university press.
- PORTNER, H. O., D. C. ROBERTS, H. ADAMS, C. ADLER, P. ALDUNCE, E. ALI, R. A. BEGUM, R. BETTS, R. B. KERR, R. BIESBROEK, ET AL. (2022): “Climate change 2022: impacts, adaptation and vulnerability,” .
- PROTO, E., A. RUSTICHINI, AND A. SOFIANOS (2019): “Intelligence, personality, and gains from cooperation in repeated interactions,” *Journal of Political Economy*, 127, 1351–1390.
- (2022): “Intelligence, errors, and cooperation in repeated interactions,” *The Review of Economic Studies*, 89, 2723–2767.
- PRZEPIORKA, W. AND A. DIEKMANN (2020): “Binding contracts, non-binding promises and social feedback in the intertemporal common-pool resource game,” *Games*, 11, 5.
- ROCKENBACH, B. AND I. WOLFF (2019): “The Dose Does it: Punishment and Cooperation in Dynamic Public-Good Games,” *Review of Behavioral Economics*, 6, 19–37.
- SZEKELY, A., F. LIPARI, A. ANTONIONI, M. PAOLUCCI, A. SÁNCHEZ, L. TUMMOLINI, AND G. ANDRIGHETTO (2021): “Evidence from a long-term experiment that collective risks change social norms and promote cooperation,” *Nature communications*, 12, 1–7.
- TAVONI, A., A. DANNENBERG, G. KALLIS, AND A. LÖSCHEL (2011): “Inequality, communication, and the avoidance of disastrous climate change in a public goods game,” *Proceedings of the National Academy of Sciences*, 108, 11825–11829.
- VESPA, E. (2020): “An experimental investigation of cooperation in the dynamic common pool game,” *International Economic Review*, 61, 417–440.
- VOLK, S., C. THÖNI, AND W. RUIGROK (2011): “Personality, personal values and cooperation preferences in public goods games: A longitudinal study,” *Personality and Individual Differences*, 50, 810–815.
- WALKER, J. M. AND R. GARDNER (1992): “Probabilistic destruction of common-pool resources: experimental evidence,” *The Economic Journal*, 102, 1149–1161.

WALKER, J. M., R. GARDNER, A. HERR, AND E. OSTROM (2000): "Collective choice in the commons: Experimental results on proposed allocation rules and votes," *The Economic Journal*, 110, 212–234.