

Incentivizing Conservation of de facto Community-Owned Forests

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Abstract

Payments for environmental services are a nature conservation policy in which landowners receive financial compensation conditional on verified environmental service delivery. Contracts for payments for environmental services have been found to be effective in inducing conservation on private lands, but they may give rise to strong free-riding incentives when implemented on lands that are, de facto or de jure, commonly owned. This study implemented a randomized controlled trial in arid Burkina Faso to test the relative effectiveness of two collective payment for environmental services schemes in inducing forest conservation—a linear group payment scheme, in which group payments increase linearly with tree survival rates,

and a threshold group payment scheme. The extant theory predicts that the latter incentive mechanism will (weakly) outperform the former. This paper develops a new theory that shows that the reverse may also hold—but only if the relationship between effort and tree survival rates is very uncertain. The findings show that threshold group payments increase intermediate measures of cooperation, but—consistent with Burkina Faso’s harsh conditions rendering tree survival quite stochastic—actual survival rates are higher with the linear group payments. The paper presents field experimental evidence as well as lab experimental results to explore the mechanisms giving rise to these results.

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Incentivizing Conservation of de facto Community-Owned Forests*

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1 Introduction

Reducing net deforestation is one of the key strategies to reduce global warming. With a share of about 12%-15% in global anthropogenic greenhouse gas emissions, deforestation and forest degradation are the second-largest source of carbon emissions (Le Quéré *et al.*, 2018), while they are also among the most cost-effective options to combat climate change (Watson *et al.*, 1996; Stern *et al.*, 2006). This holds especially true for forest conservation in developing countries – because of the relatively low returns to alternative land uses like agriculture, and because of the relatively high conservation co-benefits such as biodiversity conservation, local climate regulation, and soil and watershed protection (Wilson *et al.*, 1988; Pearce *et al.*, 2013; Busch *et al.*, 2019). Not surprisingly, stimulating forest conservation in the tropical zone is a key element of the International Panel on Climate Change’s (IPCC) climate change mitigation strategy, as is evidenced by the scaling-up of the United Nations’ Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD+) program following the Paris Agreement.

Payments for Environmental Services (PES) are a conservation policy in which landowners receive financial compensation conditional on realized conservation outcomes (Boza, 1993; Simpson and Sedjo, 1996; Ferraro, 2001; Wunder, 2005; Wunder *et al.*, 2008). The rationale behind PES is that without compensation, landowners incur the costs of conserving forests while they reap only a small share of the conservation benefits. That means that while the societal benefits of conservation typically exceed the costs, individual decision-making is biased against conservation and towards resource degradation. Offering financial compensation, conditional on environmental service delivery, changes the resource owner’s cost-benefit evaluation outcome in favor of conservation (Engel *et al.*, 2008). The scarce available evidence indeed suggests that PES is effective in reducing net deforestation. Applying a meta-analysis to the few studies designed to uncover causal impacts (almost exclusively observational studies using matching protocols), Samii *et al.* (2014a) estimate that PES schemes are effective in increasing forest cover by between 0.5 and 1.6 percentage points. A Randomized Controlled Trial, implemented by Jayachandran *et al.* (2017), supports this conclusion, as PES is found to significantly and substantially reduce deforestation among private forest owners in Uganda.

While PES is thus found to be effective on average, the actual impact on forest conservation crucially depends on both PES contract design as well as on the context in which PES policies are implemented (Engel *et al.*, 2016). Regarding the context, PES policies provide strong conservation incentives on (de facto) privately owned forest lands, because the agent who signs the PES contract (the landowner) is also the one who can ensure that the necessary actions are taken to meet the payment criteria. Whether PES payment schemes are likely to provide equally strong conservation incentives for (de facto) commonly-owned resources (like forests on communal lands), is not obvious. Here, (changes in) conservation outcomes cannot be linked, one-to-one, to the actions of each individual agent having access to the communal land (Feeny *et al.*, 1990; Ostrom, 1990). Contracts to conserve commonly-owned forest areas thus need to be collective, and the same holds for the conservation payments. Even if the conservation payments are sufficiently generous to cover the costs of providing conservation effort, too little (or maybe even zero) effort may be supplied if each individual community member’s opportunity costs of sustainable behavior are larger than the share of group payments she is entitled to (Narloch *et al.*, 2012; Kerr *et al.*, 2014; Kaczan *et al.*, 2017). PES payments aimed at inducing forest conservation on commonly-owned lands may thus pose a social dilemma, and hence the question arises how PES policies can be designed to mitigate or even overcome this “financial tragedy of the commons”. This question is especially pertinent for forest conservation initiatives to be implemented in Sub-Saharan Africa, as an estimated 95% of all forests in that region are under some form of common-property ownership, either *de jure* or *de facto* (Chhatre and Agrawal, 2008; Barbier and Tesfaw, 2012; Hayes *et al.*, 2017).¹

In this paper we aim to contribute to the quest for optimal PES design by comparing the environmental outcomes of two different payment mechanisms aimed at fostering forest conservation in (de facto) commonly-owned forests. One scheme offers payments that increase linearly in the conservation outcome. According to Kaczan *et al.* (2017) this is the PES scheme that is typically implemented in practice. In the context of collective

¹Typically, forests on non-private lands are state-owned, but the government is not always able to effectively regulate access to and usage of the forest resources. That does not mean that forests are necessarily open access – typically it is the nearby communities that *de facto* manage the local forest resources.

payments, however, it poses a social dilemma, as standard game theory predicts that agents will choose their conservation efforts such that the marginal cost of effort are equal to the share of the collective marginal benefits they receive. The second payment scheme we consider is one in which the collective amount paid depends on whether the conservation outcome is better than a specific threshold level. Threshold group payments may be effective in overcoming the tragedy of the commons because they change the nature of the game from a social dilemma to a coordination game (Andreoni, 1998). As group payments fall substantially (if not dramatically) if the environmental outcome falls below a threshold, the costs an individual incurs when providing effort to prevent crossing the threshold may be smaller than her foregone revenues if the threshold is crossed. Extant theory posits that absent uncertainty regarding the relationship between effort and public good provision outcomes, threshold group payments are expected to strictly outperform linear group payments (Isaac *et al.*, 1989; Andreoni, 1998). And it also predicts that the larger the uncertainty about the effort-survival relationship, thresholds tend to become less effective, and outcomes converge to those without thresholds (Barrett, 2016). While the extant theory thus predicts threshold group payments to (weakly) outperform linear group payments, in this paper we develop new theory (presented in full in Appendix A) that public good provision outcomes can actually be worse under threshold group payments – if and only if uncertainty is sufficiently large.² Whether or not threshold group payments can provide better conservation incentives than linear ones, is thus an open question.

To test whether threshold group payments provide better incentives for commonly-owned forest conservation than linear group payments we implemented a Randomized Controlled Trial (RCT) in arid Burkina Faso. Local community members were invited to protect and conserve, in total, about 33,500 saplings that had recently been planted (as part of a larger project) on degraded land areas within, in total, 11 protected forests. Our environmental outcome variable is the number of saplings still alive at the beginning of the next rainy season, nine months after the start of the intervention. Participants

²We construct our theory based on an assumed distribution of positive and negative shocks affecting the relationship between effort and survival rates. In that sense, the term ‘risk’ is more appropriate for the theory, but then it is unlikely that our subjects had a clear prior on how the tree survival production function would look like. Because ‘risk’ is a better term than ‘uncertainty’ for the theory whereas the opposite holds for the field, we decided to use both terms interchangeably in the remainder of this paper.

were randomly allocated to tree maintenance groups of five, half of which were offered collective PES contracts with payments that increase linearly in the number of trees still alive at endline, and the other half where payments depended on the highest survival threshold that was met at endline. To ensure balance with respect to climatic as well as socio-economic characteristics, treatment allocation was stratified at the sub-forest level.

Consistent with threshold group payments changing the nature of the strategic interaction from a social dilemma to a coordination game, we find that threshold group payment schemes have positive impacts on a number of coordination indicators, such as the number of maintenance planning meetings, trust in fellow group members, and the extent to which group members contributed equally to the maintenance activities. Despite the positive impact on these intermediate coordination indicators – but consistent with Burkina Faso’s very harsh climatic conditions making tree survival very uncertain – we also find that survival rates are significantly higher with linear (as opposed to threshold) group payments. We propose two possible mechanisms giving rise to these results – cooperation dynamics and uncertainty about the effort-survival relationship – and test their relevance using data from our RCT as well as from a real-effort laboratory experiment, implemented using students from Tilburg University, that closely mimics the key features of the tree maintenance task in the field.

We are not the first to consider the issue of how to overcome the financial tragedy of the commons that standard PES payment schemes give rise to. [Narloch *et al.* \(2012\)](#) implemented a lab-in-the-field experiment in Bolivia and Peru and found that individual rewards were more effective in promoting agrobiodiversity conservation than collective rewards. Using a setup similar to that of [Narloch *et al.* \(2012\)](#), [Salk *et al.* \(2017\)](#) find the opposite result in their study in the Lao People’s Democratic Republic, possibly because they allowed for open communication. [Kerr *et al.* \(2014\)](#) draw attention to the risk of collective financial compensation resulting in crowding-out of community members’ intrinsic motivation to contribute, and suggest that non-monetary compensation may outperform financial payments. [Hayes *et al.* \(2017\)](#) exploit the gradual rollout of a PES program in Ecuador and find that, as predicted by [Travers *et al.* \(2011\)](#), the effectiveness of collective PES payments crucially depends on the (strength of the) community’s governance structure in place. [Kaczan *et al.* \(2017\)](#) report the results of a lab-in-the-field experiment

in Mexico and find that the introduction of a coordination device, in the form of higher levels of conditionality, increases the effectiveness of collective PES schemes. While we are thus not the first to consider the relevance of the financial tragedy of the commons that collective PES may give rise to, to the best of our knowledge our study is the first to offer field-experimental evidence on how the design of collective PES payments affects outcomes.

PES schemes are not the only policy that has been developed to induce forest conservation. So-called Integrated Conservation and Development Programs (ICDP) and Community-Based Forest Management (CFM) are forest conservation policies that take a more indirect route to reduce deforestation. They aim to do so by reducing local communities' dependence on the unsustainable exploitation of nearby forest resources – by stimulating the diffusion of land-saving agricultural techniques, or by creating conservation-friendly alternative employment possibilities (McNeely, 1993; Angelsen and Kaimowitz, 1999; Angelsen, 2010; Andrabi and Das, 2017). The actual policy impact of these so-called “indirect approaches” is, however, generally small and oftentimes insignificant (Bowler *et al.*, 2012; Samii *et al.*, 2014b; Börner *et al.*, 2016; Burivalova *et al.*, 2019). And because the interventions are not conditional on achieved environmental outcomes, they may even prove to be counter-effective. Evidence for the latter comes from two recent RCTs, implemented in Sierra Leone and Namibia, that find that ICDPs actually result in reduced forest conservation – because the program's financial assistance resulted in the relaxation of binding constraints on land clearing (Wilebore *et al.*, 2019), or because the improvement in the quality of grazelands resulted in a more than proportional increase in cattle ranching Coppock *et al.* (2020). PES thus holds promise as a conservation policy because the conditionality on actual conservation outcomes prevents the emergence of such boomerang effects – at least as long as the policy is in place.³

³PES is not without issues either that may jeopardize the effectiveness of the mechanism. These include a lack of additionality (Alix-Garcia *et al.*, 2012; Engel *et al.*, 2008; Persson and Alpizar, 2013), leakage, in the form of direct displacement of unsustainable activities by the PES recipients from the contracted land to non-contracted lands, or indirectly via market interactions (Wunder *et al.*, 2008; Alix-Garcia *et al.*, 2012; Alpizar *et al.*, 2017), lack of (political) will to actually enforce conditionality (Wunder, 2015; Kaczan *et al.*, 2013; OECD, 2010), the risk of breach of contract – in case of (an unexpected) increase in opportunity costs (MacKenzie *et al.*, 2012; Reutemann *et al.*, 2016), and the risk of excess forest loss if the payment scheme would happen to come to an end (Pagiola *et al.*, 2016). While to date very little evidence is available on the empirical relevance of these issues, it is interesting to note that none of the three most important potential threats – adverse selection into the PES program, leakage, and deforestation catch-up after PES discontinuation – materialized in the RCT implemented by Jayachandran *et al.* (2017); see also

The setup of this paper is as follows. In section 2 we present the design of the RCT we implemented in Burkina Faso. Section 3 presents the results, and section 4 provides insight into the mechanisms why the threshold group payment scheme performed worse than the linear group payment scheme. Section 5 presents the results of the laboratory experiment, and section 6 concludes.

2 Design of the randomized controlled trial

2.1 Intervention description and conceptual framework

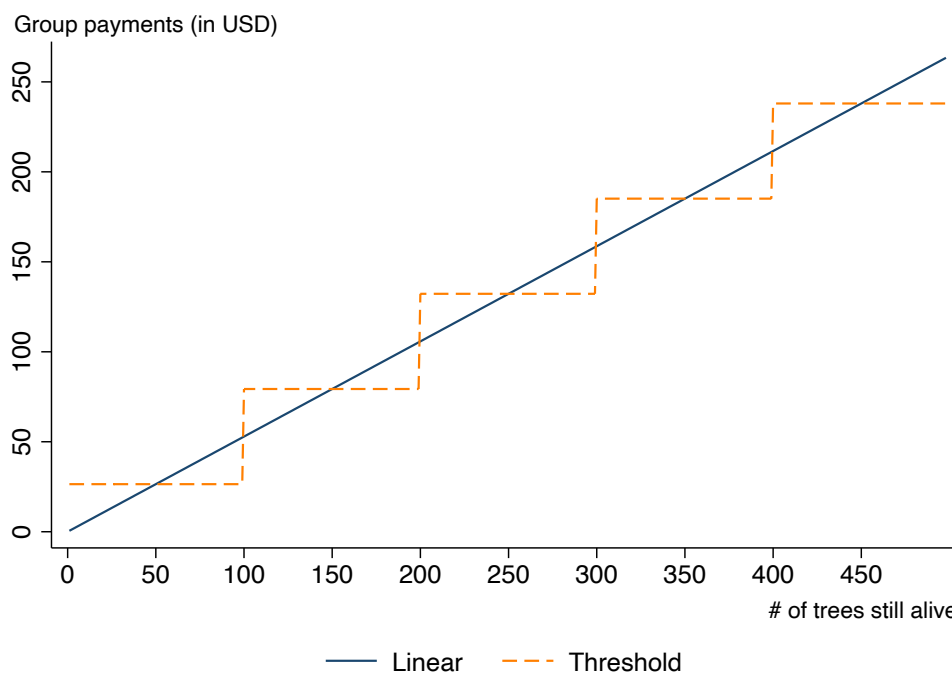
Our project started in July/August 2017 with planting about 33,500 young trees on 66 well-defined degraded forest lands across 11 protected forests – on average about 500 trees per reforestation plot. The trees on each of these plots were to be maintained by groups of five individuals recruited for the project from nearby communities. Each management group would receive money depending on the number of newly planted trees still alive on their plot at the beginning of the next rainy season, nine months later. Each individual group member would receive an equal share of the group payment, independent of the amount of effort they themselves invested in tree maintenance.

Two different payment schemes were implemented. The linear group payment scheme consisted of paying maintenance groups 300 FCFA (about 53 US cents⁴) for each tree that is still alive at endline. The amount of money received by management groups in the threshold group payment scheme depended on the highest threshold level met by the number of trees still alive, at endline, on their plot. Thresholds were set at 400, 300, 200 and 100 living trees. The group payment was 135,000 FCFA (about US \$ 239) if 400 or more trees were still alive at the beginning of the next rainy season, and it fell by 30,000 FCFA (or about 53 dollars) with every threshold that was crossed. Figure 1 provides a graphical representation of the two incentive schemes. Because parameters were chosen such that group payments are the same in the two treatment groups for survival rates in the middle of each threshold level, the two treatments are ex-ante payoff equivalent; see Appendix A for a formal proof.

World Bank (2018).

⁴At endline the official exchange rate was \$1.77 for 1,000 FCFA.

Figure 1: The amount of compensation maintenance groups are entitled to (in US dollars) as a function of the number of trees still alive at the end of the evaluation period, in the linear and the threshold group payment scheme.



Ex-ante payoff equivalence does not mean that the incentives for tree maintenance are the same too. In the linear group payment scheme group payments decrease by 300 FCFA (or \$ 0.53) with every tree that dies. This payment per tree is about half the daily wage of an unskilled worker during the agricultural season, but the opportunity costs of time are even lower in the dry season, when maintenance activities are most urgently needed. That means that even though putting in effort does not guarantee tree survival, the benefit-cost comparison is expected to be such that putting in at least some effort is optimal from the group’s perspective. Standard game theory predicts, however, that with linear group payments the privately optimal effort level is lower than the socially optimal one, because the costs of effort are private whereas the individual only receives one-fifth of the group payment – i.e., 60 FCFA (or about \$0.10) for every tree the individual helps to survive; see Appendix A for a formal proof. According to standard game theory linear group payments are thus expected to pose a social dilemma.

When introducing threshold group payments instead, the nature of the game changes from a social dilemma to a coordination game; see Andreoni (1998) and also Appendix A.

In the threshold group payment scheme, an extra tree dying causes group payments to fall if and only if the number of trees still alive falls below the next threshold. In that case, group payments fall by 30,000 FCFA (or \$ 53), and hence each of the five group members see their payments decrease by 6,000 FCFA (or almost \$ 11). Private incentives to keep trees alive are small as long as the number of trees alive is still far away from a threshold. But the private benefits of preventing the number of living trees from crossing a threshold may be such that each individual agent is willing to put in substantial amounts of effort to actually prevent the number of living trees from falling below that threshold.

In Appendix A we derive under what circumstances the threshold group payment scheme is predicted to yield higher tree survival rates than the linear group payment scheme. Standard neoclassical economics assumes that individuals compare the (expected) private marginal benefits of effort to its marginal costs. With linear group payments, each agent's optimal effort decision is independent of the amount of effort put in by the other members of their group. As proved in Appendix A, with linear benefits, quadratic effort costs and $n > 1$ agents in a group, each agent's dominant strategy is to put in an amount of effort that is just $1/n$ of the socially optimal individual effort level. With threshold group payments, however, each agent's willingness to contribute to keeping trees alive crucially depends on the amount of effort put in by their peers. For any amount of effort put in by their peers, an agent compares her costs of providing effort to make the number of living trees pass the threshold to the *extra* amount of money she will receive at that higher level. As shown in Appendix A, multiple thresholds can be equilibria of the game, with the highest equilibrium threshold being the payoff-dominant one.

So under what circumstances does the threshold group payment scheme provide stronger incentives to keep trees alive than the linear group payment scheme? The extant literature predicts that thresholds can always be constructed such that the payoff dominant equilibrium dominates the Nash equilibrium outcome with linear group payments – either strictly (if there is no uncertainty about the relationship between effort and tree survival; Andreoni, 1998), or weakly (with increased uncertainty causing threshold group payment outcomes to converge to those in the linear group payment's Nash equilibrium; see Barrett and Dannenberg, 2014). In Appendix A we extend these insights by showing that threshold group payments can actually result in worse outcomes than linear group payments –

if and only if the relationship between effort and outcome is very uncertain. More specifically, we determine the (set of) equilibrium outcomes in the linear and threshold group payment schemes assuming that the relationship between effort and the number of trees alive is deterministic, but also when it is stochastic. A first result of the theory is that it is not necessarily true that all thresholds are equilibria of the game – the probability that a threshold is indeed an equilibrium is lower the higher the threshold is. However, we also prove that, for the parameters implemented in the RCT (maintenance groups consisting of 5 members, payoff-equivalent payment schemes, and having at least four equidistant thresholds in the threshold group payment scheme) and absent uncertainty, there is at least one equilibrium threshold level that results in a strictly larger number of trees kept alive in the threshold group payment scheme than in the linear group payment scheme. Because the highest equilibrium threshold is also the payoff dominant one, we conclude that absent uncertainty the threshold group payment scheme will result in higher tree survival rates than the linear group payment scheme.

We also prove, however, that if the relationship between effort and tree survival is stochastic, threshold group payments may not succeed in inviting higher effort levels than the linear group payment scheme. If agents are risk neutral and the stochastic distribution is such that risk is mean-preserving, the presence of uncertainty does not affect an (own profit maximizing) agent's behavior in the linear group payments scheme. A selfish, risk-neutral agent compares the expected private marginal benefits of putting in effort to the marginal costs of doing so; with mean-preserving risk, the dominant strategy remains unchanged. Uncertainty does, however, affect the willingness of an agent to provide effort in the threshold group payment scheme. For a given amount of effort provided by the other members of a group, an agent can affect the probability with which a threshold is met. We prove that for the lowest thresholds it may be an equilibrium to put in so much effort to eliminate all risk (implying the targeted number of trees kept alive is sufficiently far above the threshold such that the threshold is still met even with nature's worst possible draw). But we also prove that the likelihood of eliminating all risk being optimal is smaller the higher the targeted threshold. Hence, the conclusion that the higher threshold levels may not necessarily be equilibria of the game, holds even more strongly in the presence of uncertainty about the effort-survival relationship.

Higher uncertainty affects behavior in the threshold group scheme in two ways. First, for any threshold it makes it more costly (and hence less likely optimal) to eliminate all risk. Second, the larger the uncertainty, the lower the expected private marginal benefits of putting in effort. The larger the possible range of outcomes, the smaller the increase in the probability of meeting the threshold an extra unit of effort give rise to. If uncertainty is large enough, eliminating all risk is not an equilibrium for even the lowest threshold, and the expected private marginal benefits of putting in effort to increase the probability of meeting that threshold may be so low that the equilibrium effort level is lower than the Nash equilibrium effort level in the linear group payment scheme.

2.2 Implementation of the interventions

We implemented the two treatments as follows. In 11 of Burkina Faso's protected forests, consisting of, in total, 33 forest blocks, we selected degraded areas that were to be reforested – two geographically distinct plots in each block. In July/August 2017 about 500 trees were planted on each of these 66 plots. The trees planted were of a variety of indigenous species, and the same varieties of species were planted in each of the two plots in each block. One plot within each block was randomly assigned to be maintained under the linear group payment scheme, and hence the other was to be maintained under the threshold group payment scheme.

Each of the two plots within a block was to be managed by a maintenance group of five members of nearby communities. For each of the 33 blocks, members of the adjacent communities were informed of the opportunity to participate in a tree maintenance program, in which participants were to be remunerated depending on the number of newly planted trees still alive at the beginning of the next rainy season, nine months later. Community members aged 18 or older and who were physically able to take care of the trees, were eligible to participate in the program. In all 33 blocks the number of community members interested in participating was larger than the number of positions available. Assignment of interested community members to the maintenance groups thus took place in two steps. First, ten individuals were selected from the group of interested and eligible community members. Second, of those ten we randomly selected five to form the maintenance group for the plot that had been assigned to the linear group payment treatment, and the other

five then formed the maintenance group for the plot assigned to the threshold group payment treatment.⁵

Upon completion of the recruitment and assignment process, all five members of each maintenance group were assembled on the reforestation plot assigned to them. They received training on tree maintenance including how to water the newly planted trees (and at what frequency), how to remove dead leaves and other flammable materials in saplings' vicinity, how to set up firebreaks, and how to protect the newly planted trees from being eaten by wildlife or livestock. The members of each group were also informed of the mechanism via which they would be remunerated at endline – either the linear group payment scheme, or the threshold one. We ensured that any payment earned by the group would be shared equally between all members of that group, independent of how much effort they put in. We did so by transferring one-fifth of the group payment to each of the five group members via mobile money bank accounts, and we announced this payment procedure beforehand.

Trees had been planted in two reforestation plots in each of the 33 forest blocks, and 325 of our 330 participants participated in our baseline survey.⁶ Unfortunately, we were not able to visit two of our 33 blocks at endline. Etouayou of the Nosebou forest in the western part of Burkina Faso was not accessible at endline because of a flood, and Matiacoali of the Tapoaboopo forest in the east could not be visited at endline because of armed unrest. We thus have endline tree survival information on 31 blocks (consisting of 62 reforestation plots); we have baseline survey information for 305 of the 310 participants in these blocks, and endline information for 290.

⁵Whether threshold group payments are able to outperform linear group payments obviously depends on the severity of the free-rider problem within maintenance groups, which, in turn, depends on both group size and on group composition. In laboratory experiments with random group assignment, four subjects in a group are enough to induce (strong) free-riding (Huck *et al.*, 2004). Still, compared to the practice of local forest management, our group sizes are small, and hence we decided to impose an exogenous group formation process (as opposed to allowing subjects to self-select into groups on the basis of pre-existing personal ties including kinship) to ensure that if we find that linear group payments outperform threshold group payments, this would not simply be the result of implausibly high levels of cooperation (among kin, or friends). Whether our design is indeed such that there is scope for threshold group payments to yield higher levels of cooperation than with linear group payments, is tested in Table 2 below.

⁶Due to logistical reasons the baseline survey was implemented in September and October 2017, about one month after the maintenance groups had been formed and the tree maintenance contracts had been signed. The enumerators were unable to interview five of our 330 participants, four of the linear group payment treatment and one of the threshold group payment treatment.

2.3 Sample characteristics and balance test

Table 1 presents the characteristics of the participants who ended up in each of the two treatment arms, as well as the outcomes of the balance tests. As shown in column (1) of that table, almost 87% of our participants are male. Furthermore, participants are, on average, about 40 years old, almost 70% are the head of their household, and less than 20% completed primary education or higher. Almost 85% of our participants own at least some land and the area they can cultivate is, on average, about 16 acres. Agricultural income is about 340,000 FCFA (about \$ 600) per annum, and the value of their livestock is estimated to be almost six times their annual agricultural income (although the values are quite unequally distributed). Next, slightly more than half of the participants are member of a Forest Management Group (FMG⁷). Finally, relatively few live close to the reforestation area they are supposed to manage, but most of them have access to some means of transportation to visit their plot (typically a bicycle or a moped).

Table 1: Summary statistics of characteristics of the participants in the tree maintenance program, and associated balance test between those in the linear and those in the threshold group payment treatments.

Variable	(1) Total Mean/SE	(2) Linear group payments Mean/SE	(3) Threshold group payments Mean/SE	Absolute difference (2)-(3)	Normalized difference (2)-(3)
Female	0.131 (0.019)	0.149 (0.029)	0.113 (0.026)	0.037	0.109
Age	39.718 (0.607)	38.701 (0.874)	40.755 (0.836)	-2.054*	-0.194
Household head	0.675 (0.027)	0.623 (0.039)	0.728 (0.036)	-0.105*	-0.224
Primary school completed, or better	0.177 (0.022)	0.182 (0.031)	0.172 (0.031)	0.010	0.025
Owens land	0.823 (0.022)	0.786 (0.033)	0.861 (0.028)	-0.075*	-0.197
Land area (acres)	13.184 (3.950)	12.325 (4.855)	14.060 (6.272)	-1.735	-0.025
Agricultural income (in kFCFA)	335.884 (28.309)	321.409 (44.392)	350.646 (35.039)	-29.237	-0.059
Value of livestock (in kFCFA)	1911.938 (343.090)	2048.062 (613.840)	1773.109 (299.392)	274.952	0.046
Member, Forest Management Group	0.570 (0.028)	0.597 (0.040)	0.543 (0.041)	0.054	0.110
Lives close to reforestation area	0.125 (0.019)	0.130 (0.027)	0.119 (0.026)	0.011	0.032
Disposes of means of transport	0.869 (0.019)	0.851 (0.029)	0.887 (0.026)	-0.037	-0.109
N	305	154	151		

Having described the average characteristics of our participants, we now turn to as-

⁷In 1986, the Government of Burkina Faso initiated a new forest management system in which (sustainable) use and access rights were transferred to the local communities surrounding the forests. These communities were to form FMGs, who would subsequently manage the forest area that had been assigned to the community. FMG members are thus community members with prior experience with forest management activities.

sessing whether the randomization process has been successful – are the two treatment groups fairly similar in terms of each of these characteristics? Comparing columns (2) and (3) of Table 1, the differences are quite small. As shown in column (4), only three are significantly different at the 10% level, or less. Participants in the threshold group payment treatment are on average 2 years older ($p = 0.091$), they are 10 percentage points more likely to be household head ($p = 0.050$), and they are also 10 percentage points more likely to own land ($p = 0.086$). Balance is thus decent, and this conclusion is reinforced when assessing the size of the normalized differences for each of the characteristics; see column (5) of Table 1. Normalized differences are generally preferred to t -tests because they provide a scale-free comparison, and imbalances are typically identified as problematic if normalized differences exceed 0.25 (Imbens and Rubin, 2015; Abadie and Imbens, 2011). Most of the normalized differences are about 0.10 standard deviations or less, and none is larger than 0.22.⁸

2.4 Empirical approach

We thus obtained endline tree survival data for 62 plots, 31 in each treatment arm. Our randomization procedure allows us to (i) treat the observed tree survival rates of the two treatments in the same block as matched pairs, and (ii) run regression models using forest-block fixed effects to capture any unobserved heterogeneity (such as the specific ecological circumstances) between blocks. Assuming an average survival rate of 30 percent and a standard deviation of the difference between the paired means of 20 percentage points, we have a 77% chance of detecting a minimum treatment difference of 10 percentage points (using a 5% significance criterion), or better.

Our study is thus adequately powered to provide reliable estimates of possible treatment differences – but only just so. Practical constraints prevented us from implementing a third treatment arm – a control treatment in which no financial conservation incentives were offered. While our study is able to comment on the relative effectiveness of the linear and threshold group payment schemes in improving forest conservation, it does not speak

⁸We have also implemented balance tests for management group averages (as opposed to individual values) between the two treatment groups, with 31 observations in each treatment group. None of the difference in management group averages (not shown here, but available upon request) are significantly different at 10 percent, or lower, and only two (age, and the share of household heads) had a normalized difference larger than 0.25.

to the question of the overall effectiveness of providing collective conditional conservation payments. While we cannot provide formal proof of additionality, it is very likely that our study’s outcomes are substantially better than absent financial incentives. As discussed in more detail below, we observe an average survival rate of about 34 percent, and this is substantially higher than the survival rates that are typically obtained in such dry agro-ecological conditions (Carey, 2020).⁹

We assess the impact of the threshold versus the linear group payment scheme on both intermediate and ultimate measures of within-management-group cooperation. Theory suggests that, unless uncertainty is too high, threshold group payments should induce higher survival rates through stricter coordination between participants. Our endline survey included several questions that intended to measure the (self-reported) extent to which maintenance groups managed to cooperate. These measures are (i) how often members of a maintenance group organized and/or attended group meetings to discuss and plan maintenance activities, (ii) their assessment of their fellow group members’ trustworthiness, and (iii) the extent to which they feel that all group members contributed more or less equally to the maintenance effort.

These three variables constitute our intermediate measures of cooperation; the actual tree survival rate is the key output measure – and hence also our ultimate measure of cooperation. We employed independent tree survival verification teams to measure the number of trees still alive at endline. To be able to accurately determine the number (and share) of trees surviving we georeferenced all planted trees at baseline in every reforestation plot. Accurate estimation of tree survival rates was facilitated because, in line with standard reforestation practice, all saplings were planted in hand-dug holes of about 20 centimeters in diameter and about 10 centimeters deep. Still, it proved to be very challenging to systematically verify the health status of each individual sapling. Obviously, there is GPS measuring error when the newly planted trees were georeferenced, and again when we revisited the trees nine months later. We solved this issue by programming virtual bands of 10 meters wide in the independent verification teams’ GPS location devices. Within those 10-meter bands it is very easy to find back all holes, and to verify

⁹For example, Wade *et al.* (2018) report an average survival rate of only about 20 percent from the reforestation efforts conducted as part of the pan-African Great Green Wall for the Sahara and the Sahel Initiative (GGW).

the status of the tree that had been planted therein (well alive, alive, dead, or missing). We kept small distances between the bands to avoid double counting. Overall, the bands covered a minimum of 80 per cent of a plot’s surface. The survival rate within the grids on each plot is an unbiased and precise estimate of the survival rate of all trees planted on the plot, because we ensured that the surface covered by the grids is representative of the plot.

The independent verification process thus yielded an assessment of the number of trees alive at endline, but also an evaluation of each sapling’s health status – barely alive, or in such a good state that they were very likely to survive another dry season. While the sheer number of trees alive at endline forms the basis of the group payments, the number of trees (still) in good health can be viewed as a measure of quality, and also as an assessment of the longer-run treatment effects. In the analysis we present the outcomes of both output measures for each of the two payment schemes.

Finally, and importantly, we measured survival rates at endline, but we did not undertake any ‘mid-term evaluations’ – participants themselves may have decided to go out and count how many trees were still alive at various moments during the intervention period, but we did not do so on their behalf. We did discuss the possibility of providing mid-term feedback on survival rates with Burkina Faso’s project team, but unfortunately funds were lacking to implement such mid-term visits. While, in view of the theory presented in section 2.1 and in Appendix A, providing information on survival rates is not of particular importance for groups in the linear group payment scheme, it would have been of high interest to those in the threshold group payment scheme.

3 Results

Table 2 presents the estimates of the differential treatment effect of threshold versus linear group payments on both the intermediate measures of cooperation (columns (1)-(6)) as well as on the ultimate measures of cooperation (the survival rates; see columns (7) and (8)). Regarding the former, we use two types of regression specifications. The simplest version merely consists of using OLS to regress the relevant dependent variables on the treatment indicator using block-fixed effects – the unit within which treatment assignment

was randomized. The coefficient on the treatment dummy then reflects the outcome of a paired-means t -test. Because outcomes may be more similar within forests than between forests, standard errors are clustered at the forest level. These regression results are presented in the odd-numbered columns of Table 2. The other version includes, in addition to the treatment dummy and block fixed effects, a series of individual characteristics (gender, age and the size of land holdings) as controls. The results using this regression model are presented in the even-numbered columns of Table 2.

Table 2: The impact of threshold group payments on intermediate and ultimate measures of cooperation, compared to linear group payments.

	Intermediate measures of cooperation				Ultimate measures of cooperation			
	Frequency group deliberations		Trust in fellow group members		Assessed lack of equal effort		Share of trees alive	Share of trees well alive
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
treatment	0.705 ⁺ (0.393)	0.950 ⁺ (0.580)	0.140 (0.095)	0.163* (0.088)	-0.054 ⁺ (0.032)	-0.109** (0.046)	-0.077* (0.041)	-0.095** (0.040)
Constant	5.290*** (0.191)	6.239*** (0.834)	3.995*** (0.046)	4.294*** (0.276)	0.179*** (0.016)	0.152** (0.052)	0.453*** (0.062)	0.426*** (0.059)
Observations	272	230	251	212	290	242	62	62
F-Test	3.22	2.81	2.19	4.84	2.90	187.20	3.41	5.81
Controls	N	Y	N	Y	N	Y	N	N
Block fixed effects	Y	Y	Y	Y	Y	Y	Y	Y

Robust standard errors clustered at the forest level in columns (1)-(6), and at the block level for columns (7) and (8). The participants' characteristics controlled for in columns (2), (4) and (6) include gender, age, and land area.

⁺ $p < 0.125$, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

We obtain the following results. First, as shown in columns (1) and (2) of Table 2, we find some evidence that the threshold incentives resulted in increased maintenance planning activity. Participants in the threshold group payment treatment report having met significantly more frequently with their fellow group members (on average 6.0 times, versus 5.3 times in the linear group payments treatment), and this difference only just fails to be significant at the 10% level in regression (1); $p = 0.106$. Outcomes do not appreciatively change when controlling for individual characteristics; see column (2).

While we find (weak) evidence of the threshold group payments inducing more frequent group deliberations, we find stronger effects for the other two intermediate measures of cooperation. When only using block fixed effects average trust in one's fellow group members is not significantly higher in the threshold group payment treatment than in the linear group payment treatment (see column (3); $p = 0.173$), but the difference does become significant when controlling for individual characteristics as well (see column (4);

$p = 0.098$). Trust is key to not just cooperation, but also coordination; meeting to plan activities is not very useful unless one can also be reasonably certain that all participants stick to the plan. Finally, we also find that threshold group payments resulted in more equal effort; the likelihood of a respondent assessing each of their other group members having put in much more or much less effort than they themselves, is smaller among participants in the threshold group payment scheme. As was the case with the trust regression, this difference is not significant when only using block fixed effects (the p -value on the threshold treatment indicator in (5) is equal to 0.123), but it is when we additionally control for individual characteristics (see column (6); $p = 0.043$). So we also find that the process of cooperation was assessed to be more equitable in the threshold group payment treatment than with linear group payments.

We thus find that the threshold group payments resulted in better outcomes for our three intermediate measures of cooperation – even though a group size of five is relatively small, it was still sufficiently large to still leave room for improvements in cooperation; cf. footnote 5. But did the threshold group payments also result in higher survival rates? As shown in columns (7) and (8) of Table 2, the better performance on the intermediate measures of cooperation did not result in higher survival rates in the threshold group payment scheme – not in terms of the share of trees alive, and also not in the share of trees with good survival prospects. In fact, the share of trees alive is 7.7 percentage points lower in the threshold group payment treatment ($p = 0.072$), and the share of trees with good survival prospects is 9.5 percentage points lower ($p = 0.021$).

We thus find that while the intermediate indicators of cooperation (coordination, trust and equal effort) are higher in the presence of threshold group payments, the actual survival rates are lower. Before delving in potential mechanisms, we calculate the probability of *incorrectly* concluding that the linear group payments outperform threshold group payments. Conditional on having found the opposite outcome, we can estimate the probability that we incorrectly conclude that the linear group payment scheme outperforms the threshold scheme. Suppose that, in fact, the threshold group payment scheme outperforms the linear group payment scheme by, say, 7.6 percentage points. Following [Gelman and Carlin \(2014\)](#), the probability of having found the reverse outcome – a sign error – is about 1 in 10,000.

4 Mechanisms

So what are the potential mechanisms via which the threshold scheme did not yield higher survival rates than the linear group payment scheme? In view of the theory presented in section 2.1 and in Appendix A, we hypothesize two. First, survival rates were measured at endline, and the survey questions aimed at gauging treatment impacts on the intermediate measures of cooperation analyzed above asked for an endline evaluation of the process of cooperation. The reported outcomes may, however, hide important differences in the dynamics of cooperation over time – consistent with our theory’s prediction that the higher thresholds are less likely to be equilibria. Second, coordination in the threshold group payment schemes becomes more difficult when there is uncertainty regarding the probability of accidentally crossing the target threshold. In the following two subsections we aim to test the relevance of each of the two.

4.1 The dynamics of cooperation

At endline, the intermediate measures of cooperation were higher in the threshold group payment treatment, while the ultimate measures of cooperation were lower. These opposing outcomes may be reconciled if cooperation improved over time, but that this improvement materialized too late in the process. To probe this possible mechanism, we asked participants in the endline survey how they evaluated the (dynamics of the) amount of cooperation in their maintenance group; answers are summarized in Table 3. Overall, we do not find that the distributions in answers differ significantly between the two treatments ($p = 0.275$ according to a χ^2 test). About 69% of the subjects in the linear group payment scheme reported that the cooperation was intensive from the start and that it remained very good over the entire nine-month period; about 2% of them stated that there was hardly any cooperation. In the threshold group payment scheme these percentages were, respectively, 65% and 1.5%. However, we also find that, if anything, cooperation was more likely to increase in the threshold group payment scheme. Focusing on those who reported a change in cooperation over time, we find, however, that the share of respondents stating that their group’s cooperation improved over time is significantly larger in the threshold group payment treatment than in the linear group payment treatment ($p = 0.080$ using

a χ^2 test). The result that cooperation strengthens over time is in line with our model’s theoretical prediction that the higher thresholds are less likely to be equilibria than the lower ones; see Appendix A.

Table 3: Participants’ evaluation of (the dynamics of) their group’s cooperation intensity.

Variable	N	(1)	N	(2)	p-value Chi2 test
		Linear group payments Mean/SE		Threshold group payments Mean/SE	
Good cooperation throughout	146	0.664 (0.039)	144	0.597 (0.041)	0.236
Zero cooperation throughout	146	0.021 (0.012)	144	0.014 (0.010)	0.663
Cooperation changed over time	146	0.274 (0.037)	144	0.306 (0.039)	0.553
- improved over time	40	0.650 (0.076)	44	0.818 (0.059)	0.080*
- worsened over time	40	0.350 (0.076)	44	0.182 (0.059)	0.080*

4.2 Uncertainty with respect to the distance to the thresholds

Attempting to coordinate on reaching a threshold is one thing, actually reaching it may be another. As proved in Appendix A, the higher the uncertainty about the actual effort needed to reach a specific threshold, the lower the amount of effort risk-neutral agents are likely to be willing to invest in keeping trees alive.¹⁰ Our data do not allow us to explicitly measure risk, but we can analyze whether the endline numbers of trees alive are bunched around the various thresholds. If participants are able to predict reasonably well how much effort needs to be invested to ensure that a specific threshold is not crossed, we would expect an over-representation of threshold group payment plots with a number of surviving trees just above each threshold, and relatively few threshold group payment plots with a number of surviving trees just below each threshold.

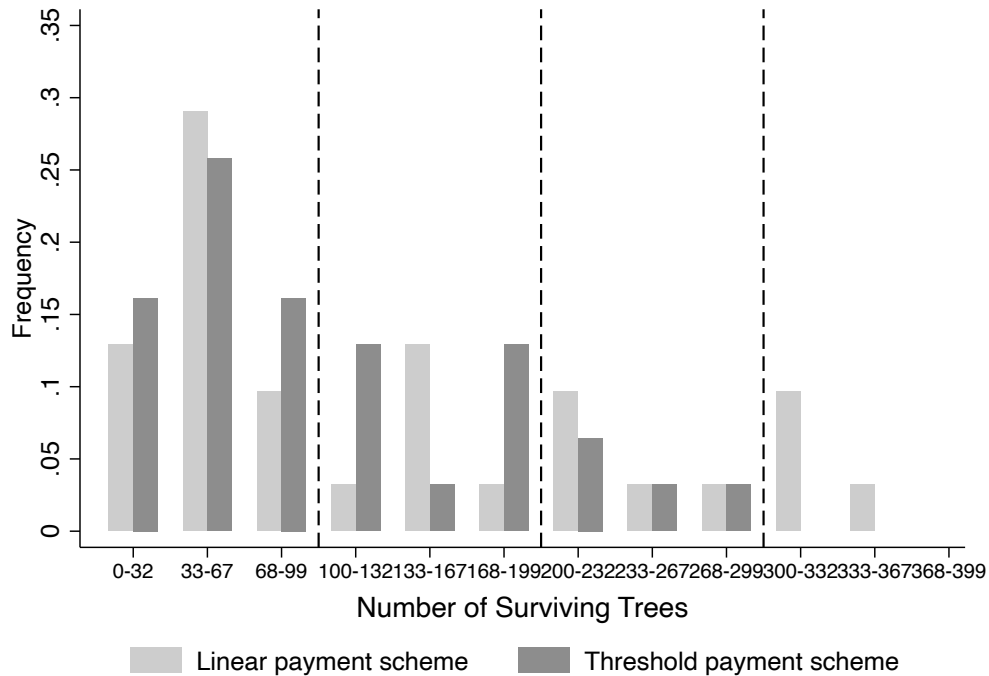
Figure 2 presents the distribution of the number of trees still alive in the threshold group payment scheme vis-à-vis the payment thresholds, as well as compared to the distribution of the number of trees still alive in the linear group payment scheme. On the horizontal axis, the bin size of the number of trees surviving is 33, and hence we can distinguish plots with between 0 and 32 surviving trees above the threshold, those with

¹⁰In Appendix A we derive our predictions assuming that agents are risk neutral. Note, however, that the prediction holds a fortiori if agents are risk averse, because the costs of effort are incurred with certainty while benefits are uncertain.

between 1 and 33 surviving trees below the threshold, and those being 33 or more trees away from the nearest threshold.

We do not find much evidence of the endline number of living trees in the threshold group payment treatment being bunched just above the payment thresholds (of 100, 200 and 300, indicated by the vertical dashed lines), and there are also no marked differences with the distribution of the number of trees still alive in the linear group payment scheme. If anything, there are more linear group payment plots with just over 200 or just over 300 surviving trees than in the threshold group payment treatment. And although there are more threshold group payment plots with just above 100 trees surviving than linear group payment plots, the former are also quite over-represented in the range just below the threshold of 100 surviving trees. More formally, only 33% of the plots in the threshold group payment scheme have surviving tree numbers in the terciles above any of the thresholds, compared to 39% in the linear group payment scheme ($p = 0.729$, according to a χ^2 test).

Figure 2: The distributions of the number of trees still alive in the linear and threshold group payment schemes, vis-à-vis the payment thresholds.



Not having been able to stay above the threshold does not necessarily mean that

the groups in the threshold group payment scheme have not tried it, and maybe they were unlucky with their number of trees still alive just falling below a threshold. So are the plots in the threshold group payment treatment more likely to have surviving tree numbers in the terciles either just above or just below the threshold (and hence with fewer plots ending up in the middle terciles between two thresholds) than plots in the linear group payment scheme?¹¹ We find that 68% of the threshold group payment plots ended up with surviving tree numbers in a tercile just above or just below any of the three thresholds, compared to 52% of the plots in the linear group payment scheme. Although this difference is not statistically significant from zero ($p = 0.196$, using a χ^2 test), it does suggest that the uncertainty in survival rates is so high that the maintenance groups in the threshold group payment scheme were unable to target endline survival rates with much precision.

5 Supporting evidence from a laboratory experiment

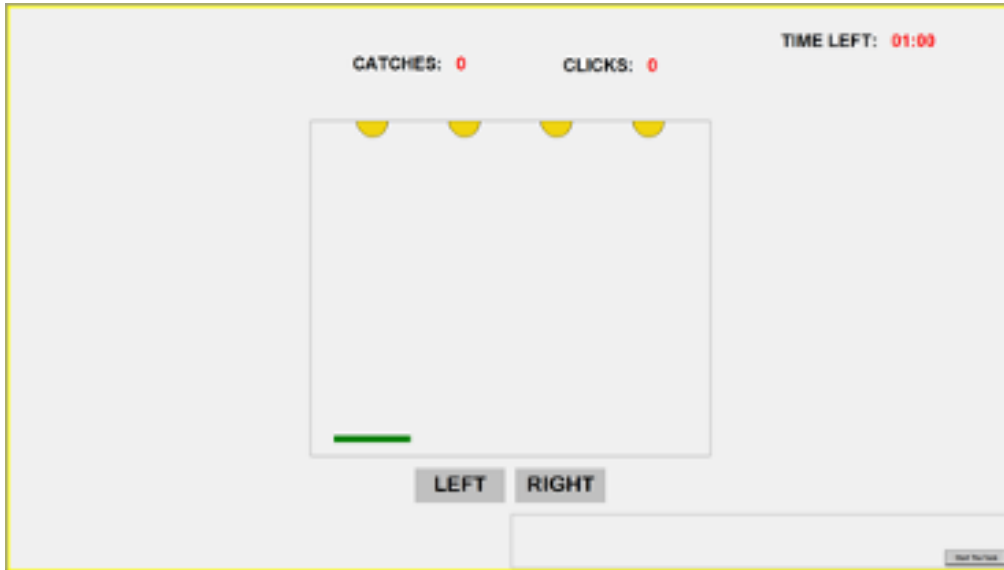
The findings in Section 4 provide suggestive evidence as to why the linear group payment scheme was found to give rise to higher survival rates than the threshold group payment scheme. Maintenance groups in the threshold group payment scheme may have been too late in establishing cooperation, and the fact that we do not find evidence of clear bunching of survival rates above or even just below thresholds suggests that indeed there is considerable uncertainty in the relationship between effort and the number of trees kept alive. This suggests that the threshold group payment scheme resulted in performing less well because (i) a lack of (real-time or mid-term) information on survival rates made it more difficult to coordinate, and (ii) given that participants reported that cooperation improved over time, the threshold payment scheme ultimately invited more cooperation, but too late to actually yield better survival outcomes at endline.

¹¹If the number of surviving trees just falls below a threshold, the marginal benefits of maintenance effort are negligible, and only become non-negligible again if the number of surviving trees continues to decrease and gets closer to the next threshold. The number of surviving trees in the threshold group payment plots is thus only likely to end up in the tercile just below a threshold if the threshold was crossed fairly recently; it is less likely to end up in the middle tercile because here the marginal benefits of maintenance effort are very low. Direct financial incentives to keep trees alive are also zero in the bottom tercile (the one with 0-32 trees surviving), and hence, even though a zero survival rate is not an actual payment threshold, we also code the bottom tercile as one in which threshold group payment plots should be overrepresented.

To complement the insights from the field experiment, we implement a laboratory experiment that mimics some of the essential features of the field, while allowing for monitoring of changes in cooperation over time as well as manipulating the amount of information participants have on real-time survival rates. The so-called “ball catching task” (Gächter *et al.*, 2016) is ideally suited for our purposes. The game was developed as a real effort interface for a variety of (individual and multi-person) experimental paradigms, including social dilemma games. Real effort games have the advantage of increased realism with respect to the interaction while still maintaining considerable control over the (material) costs of effort. We now briefly describe the game; for more details see Gächter *et al.* (2016).

In the ball-catching task, a subject has a fixed amount of time to catch balls that fall randomly from the top of her screen. Balls can be caught by moving a tray at the bottom of the screen by clicking the left and right buttons. A screenshot of the game is presented in Figure 3. Balls fall at irregular intervals in four columns, and catching the next ball may involve between zero and three mouse clicks, depending on whether the next ball to be caught dropped in the same column as where the previous ball was caught, or whether it is dropped in the column farthest away. A social dilemma can be created by making an individual’s payments depend on the total number of balls caught by herself and by the other members of her group, and by setting the proper values for the payment for balls caught vis-à-vis the costs of clicking the mouse to move the tray.

Figure 3: Screenshot of the ball-catching task as developed by [Gächter *et al.* \(2016\)](#).



5.1 Experimental design

We modified [Gächter *et al.* \(2016\)](#)'s ball-catching task to obtain four different treatments, using a full factorial design. The treatment variables are the payment scheme (linear group payments, or threshold group payments) and the information on the total number of balls caught in the previous period by oneself and by the rest of one's group (information provided, or not provided). Groups consisted of four subjects, and these subjects interacted with the same three other individuals throughout the entire session. The task consisted of catching balls over three one-minute periods. In each of the four treatments 240 balls were released in the first period of each task, and we programmed the treatments such that the number of balls released in the next period was equal to the total number of balls caught by the group in the previous period. This mimics the irreversibility of trees dying in the field; any ball not caught in the one period is no longer available in the next. Each group participated in four tasks in just one treatment (e.g., threshold group payments without information); one trial task was followed by three paid tasks. In each of the three paid tasks the amount of money earned by a group depended on the total number of balls caught by its four members in the last period of the task. Because balls that are not caught in one period were not dropped in the next, group payments were thus based on the total number of balls surviving all three periods of the task. Each of the four members of a group received 25% of the group payment, independent of the amount

of effort they put into catching balls.

In the linear group payments scheme we set the reward of each ball surviving all three periods equal to 12 points; the cost of moving one's tray by one column was equal to 1 point. Balls needed to survive all three periods to earn money for the group. To maximize group payments, 12 is thus the maximum number of times that participants should click to make a ball survive all three periods. As there are three periods and four columns from which balls can be dropped, group payments are maximized if all balls are caught in every period. Because balls are dropped at irregular intervals and in different columns, multiple balls can be caught with zero clicks – if consecutive balls are dropped in the same column. However, the frequency with which balls are dropped, is such that it is not always feasible to catch them all – if consecutive balls are dropped in different columns. The relationship between (aggregate) effort and the number of balls caught is thus stochastic. Because group revenues were shared equally among all four members of a group, an own-payoff-maximizing subject in the linear group payment scheme would be willing to maximally click three times to save a ball throughout a task in expectation – it is not privately optimal to click more than once to catch a ball in a period.

In the threshold group payment scheme, the costs of moving one's tray by one column were also 1 point, and groups would earn money only for those balls that survived all three periods. We set thresholds at fifty-ball intervals (i.e., at 200, 150, 100 and 50 balls surviving), and we ensured ex-ante payoff equivalence between the two treatments by setting the group payments associated with reaching threshold h equal to $12 \times (50h + 25)$; see also equation (A2) in Appendix A. Whether or not the threshold group payment treatment results in higher survival rates than the linear group payment scheme, is expected to depend on whether or not subjects receive information on current survival rates, or not.

In total, 128 subjects participated in our between-subjects laboratory experiment, in 32 groups of 4 subjects. A summary of the experimental design is presented in Table 4. Each group participated in three tasks, each lasting three periods. We thus have information on 1,152 per-period effort decisions. Our non-parametric tests are, however, at the level of the amount of effort put in a group, averaged over all tasks and all periods. This yields between 7 and 10 independent observations. When using parametric methods,

we analyze the amount of effort put in by a group per period in each task, clustering standard errors at the group level.

Table 4: Number of groups and the total number of observations (over all periods, tasks and subjects), presented in panels A and B respectively, in each of the four treatments in the laboratory experiment.

Thresh. payments	Information		Thresh. payments	Information	
	Yes	No		Yes	No
Yes	10	7	Yes	360	252
No	7	8	No	252	288

(a) Group level

(b) Subject - Period - Task level

5.2 Results of the laboratory experiment

We first test whether there are any treatment differences between the threshold and linear group payment schemes in either the presence or the absence of information on the number of balls caught by one’s group in the previous period. The most conservative test compares the average number of times members of a group clicked to move her tray during a task, averaged over all tasks, between the two treatments. As shown in Table 5 the differences are small, and statistically insignificant. That means that overall, we find no evidence of the one treatment inviting more effort than the other.

Table 5: Amount of effort put into catching balls in each period of a task, averaged over all subjects and all tasks in a group, in the four treatments of the laboratory experiment.

Threshold	Information		p-value
	Yes	No	
Yes	72.675 (2.574)	75.524 (3.459)	0.501
No	73.417 (3.360)	71.625 (2.465)	0.663
p-value	0.859	0.351	

Notes: Standard errors, clustered at the group level, are presented in parentheses.

To uncover any differences in the underlying dynamics, we run panel regression analyses using as dependent variable the amount of effort put in by a group in each of the three periods of a task. These regressions are run using task fixed effects, and with standard

errors clustered at the group level. We ran two separate regressions to identify the impact of the imposed payment scheme – when information is provided on the number of balls still surviving from the previous period, and when such information is not provided. The results are presented in columns (1) and (2) of Table 6, respectively.

Table 6: Per-period effort put into catching balls, at the group level, with and without information on the number of balls caught in the previous period.

	No Information	Information
	(1)	(2)
Constant	132.1*** (9.446)	137.8*** (8.120)
Period 2	-37.17*** (3.862)	-47.57*** (4.213)
Period 3	-51.96*** (4.374)	-62.62*** (3.923)
Threshold	13.13 (12.89)	-7.286 (10.93)
Threshold \times Period 2	-6.976 (5.078)	14.40*** (4.617)
Threshold \times Period 3	-16.80** (6.027)	4.486 (5.999)
Observations	135	153
Adjusted R^2	0.543	0.549
Task FE	Yes	Yes
Robust standard errors clustered at the group level.		

Column (1) of Table 6 thus presents the outcomes of the linear and threshold group payment games when subjects are not informed of the total number of balls caught in the previous period of the current task, and column (2) presents the results when this information is provided. Because the linear group payment scheme is the omitted treatment category, the constant in Table 6 captures the linear group payment treatment’s average group effort in the first period of each task, and the coefficients on the subsequent two variables (“Period 2” and “Period 3”) capture how average group effort in the second and third period compares to that in the first period. The coefficients in the second triplet of variables shows how the amount of effort put in in the threshold group payment treatment differs from those in the linear group payment treatment in each of the three periods.

We find the following. As shown in column (1) of Table 6, average group effort in the linear group payment treatment starts at about 132 clicks in the first period of a task in that treatment, and subsequently falls quite substantially over the remaining periods of

the task – because the number of balls that can be caught is declining from one period to the next, and/or because cooperation is decreasing over time. Column (1) also shows that group effort in the threshold group payment treatment is not significantly different from that in the linear group payment treatment, except for the third and last period. Without information threshold group payments are thus unlikely to be able to sustain cooperation above and beyond that in the linear group payment treatment.

Comparing the outcomes in column (1) and column (2) of Table 6 gives insight into the impact of receiving information on the number of balls caught in the previous period of a task. Providing information on the number of balls caught is expected to affect behavior in the second and third period of a task, as information on the number of balls caught in the previous period only becomes available from the beginning of the second period onwards. Moreover, we expect changes to occur in the threshold group payment treatment, but not in the linear group payment treatment. This is not what we find.

Comparing the coefficients for the linear group payment treatment in columns (1) and (2) of Table 6, we see that providing information on the number of balls surviving does not increase effort; if anything, learning how much effort the rest of the group put in in the previous period decreases effort in the linear group payment treatment. Information positively affects group effort in the threshold group payment scheme, however, and especially so the first time this information is provided in a task (i.e., in period 2), as it results in significantly more effort (compared to the linear group payment treatment) of about 14 clicks. The positive impact is still present in the third and final period of the task, albeit that this difference with effort in the linear group payment treatment is not significant. We thus find that the threshold group payment scheme is unlikely to invite higher effort unless conservation status information is provided.

6 Conclusions

In this paper we present the outcomes of a Randomized Controlled Trial, implemented in arid Burkina Faso, aimed at testing whether threshold group payments provide better incentives for forest conservation than linear group payments. Making group payments dependent on tree survival rates falling within specific intervals (as opposed to linear group

payments) changes the nature of the game from a social dilemma into a coordination game. Existing theory predicts that threshold group payments are (weakly) more likely to result in better conservation outcomes (Isaac *et al.*, 1989; Andreoni, 1998; Barrett and Dannenberg, 2014); we develop new theory to prove that conservation outcomes can actually be worse under threshold group payments – if and only if uncertainty about the relationship between conservation effort and tree survival rates is sufficiently large. We find that trees survival rates are higher with linear than with threshold group payments – possibly due to the harsh circumstances for saplings to survive in Burkina Faso. We use both endline surveys as well as a lab experiment to gain more insight into the underlying mechanism.

We find that the threshold incentives can significantly improve the conditions for cooperation (as they induce higher trust among group members, result in more equal effort contribution and give rise to more frequent group meetings for maintenance planning). Our theory suggests that the fact that the thresholds have not outperformed the linear group payment scheme may have been due to two reasons. One is that not all thresholds are equilibria – it may not be optimal to coordinate on reaching the highest ones – and hence cooperation may have started (too) late. The second is that uncertainty about the effectiveness of maintenance activity in ensuring tree survival is substantial, and hence that the marginal benefits of putting in effort may actually become lower under threshold group payments than in the presence of a linear group payment scheme.

We find suggestive evidence in support of both mechanisms in our field-experimental data, but additional evidence for this also comes from the lab experiment, which shows that with threshold group payments initial survival rates are lower but also that they are declining less fast over time than in the linear group payment scheme. The laboratory experiment also provides (suggestive) evidence for the claim that threshold group payments might have outperformed the linear group payment scheme had our participants in the field been given regularly updates on survival rates during the intervention period.

Overall, we conclude that even though in our RCT threshold group payments were less effective than linear group payments, more field tests are needed to determine whether threshold group payments are inferior to linear group payments, as well as to what extent the results are driven by, for example, group size, the group formation process or climatic

circumstances.

References

- ABADIE, A. and IMBENS, G. W. (2011). Bias-corrected matching estimators for average treatment effects. *Journal of Business & Economic Statistics*, **29** (1), 1–11.
- ALIX-GARCIA, J. M., SHAPIRO, E. N. and SIMS, K. R. (2012). Forest conservation and slippage: Evidence from Mexico's national payments for ecosystem services program. *Land Economics*, **88** (4), 613–638.
- ALPIZAR, F., NORDÉN, A., PFAFF, A. and ROBALINO, J. (2017). Spillovers from targeting of incentives: Exploring responses to being excluded. *Journal of Economic Psychology*, **59**.
- ANDRABI, T. and DAS, J. (2017). In aid we trust: Hearts and minds and the Pakistan earthquake of 2005. *Review of Economics and Statistics*, **99** (3), 371–386.
- ANDREONI, J. A. (1998). Toward a theory of charitable fund-raising. *Journal of Political Economy*, **106** (6), 1186–1213.
- ANGELSEN, A. (2010). Policies for reduced deforestation and their impact on agricultural production. *Proceedings of the National Academy of Sciences*, **107** (46), 19639–19644.
- and KAIMOWITZ, D. (1999). Rethinking the causes of deforestation: lessons from economic models. *The world bank research observer*, **14** (1), 73–98.
- BARBIER, E. B. and TESFAW, A. T. (2012). Can REDD+ save the forest? the role of payments and tenure. *Forests*, **3** (4), 881–895.
- BARRETT, S. (2016). Coordination vs. voluntarism and enforcement in sustaining international environmental cooperation. *Proceedings of the National Academy of Sciences*, **113** (51), 14515–14522.
- and DANNENBERG, A. (2014). Sensitivity of collective action to uncertainty about climate tipping points. *Nature Climate Change*, **4** (1), 36–39.
- BÖRNER, J., BAYLIS, K., CORBERA, E., EZZINE-DE BLAS, D., FERRARO, P. J., HONEY-ROSÉS, J., LAPEYRE, R., PERSSON, U. M. and WUNDER, S. (2016). Emerg-

- ing evidence on the effectiveness of tropical forest conservation. *PloS one*, **11** (11), e0159152.
- BOWLER, D., BUYUNG-ALI, L., HEALEY, J., JONES, J., KNIGHT, T. and PULLIN, A. (2012). Does Community Forest Management provide global environmental benefits and improve local welfare? *Frontiers in Ecology and the Environment*, **10** (1), 29–36.
- BOZA, M. A. (1993). Conservation in action: past, present, and future of the national park system of costa rica. *Conservation biology*, **7** (2), 239–247.
- BURIVALOVA, Z., MITEVA, D., SALAFSKY, N., BUTLER, R. and WILCOVE, D. (2019). Evidence types and trends in tropical forest conservation literature. *Trends in ecology & evolution*, **34** (7), 669–679.
- BUSCH, J., ENGELMANN, J., COOK-PATTON, S. C., GRISCOM, B. W., KROEGER, T., POSSINGHAM, H. and SHYAMSUNDAR, P. (2019). Potential for low-cost carbon dioxide removal through tropical reforestation. *Nature Climate Change*, **9** (6), 463–466.
- CAREY, J. (2020). News feature: The best strategy for using trees to improve climate and ecosystems? go natural. *Proceedings of the National Academy of Sciences*, **117** (9), 4434–4438.
- CHHATRE, A. and AGRAWAL, A. (2008). Forest commons and local enforcement. *Proceedings of the national Academy of sciences*, **105** (36), 13286–13291.
- COPPOCK, D., CROWLEY, L., DURHAM, S., GROVES, D., JAMISON, J., KARLAN, D., NORTON, B., RAMSEY, D. and TREDENNICK, A. (2020). Large investments in agro-pastoral namibia enhance collective action but fail to alter livelihoods, cattle productivity, or rangeland condition. *Science*.
- ENGEL, S., PAGIOLA, S. and WUNDER, S. (2008). Designing payments for environmental services in theory and practice: An overview of the issues. *Ecological economics*, **65** (4), 663–674.
- *et al.* (2016). The devil in the detail: a practical guide on designing payments for environmental services. *International Review of Environmental and Resource Economics*, **9** (1-2), 131–177.

- FEENY, D., BERKES, F., MCCAY, B. J. and ACHESON, J. M. (1990). The tragedy of the commons: twenty-two years later. *Human Ecology*, **18** (1), 1–19.
- FERRARO, P. J. (2001). Global habitat protection: limitations of development interventions and a role for conservation performance payments. *Conservation Biology*, **15** (4), 990–1000.
- GÄCHTER, S., HUANG, L. and SEFTON, M. (2016). Combining “real effort” with induced effort costs: the ball-catching task. *Experimental Economics*, **19** (4), 687–712.
- GELMAN, A. and CARLIN, J. (2014). Beyond power calculations: Assessing type s (sign) and type m (magnitude) errors. *Perspectives on Psychological Science*, **9** (6), 641–651.
- HAYES, T., MURTINHO, F. and WOLFF, H. (2017). The impact of payments for environmental services on communal lands: an analysis of the factors driving household land-use behavior in ecuador. *World Development*, **93**, 427–446.
- HUCK, S., NORMANN, H.-T. and OECHSSLER, J. (2004). Two are few and four are many: number effects in experimental oligopolies. *Journal of Economic Behavior & Organization*, **53** (4), 435–446.
- IMBENS, G. W. and RUBIN, D. B. (2015). *Causal inference for statistics, social, and biomedical sciences: An introduction*. Cambridge University Press.
- ISAAC, R. M., SCHMIDTZ, D. and WALKER, J. M. (1989). The assurance problem in a laboratory market. *Public Choice*, **62** (3), 217–236.
- JAYACHANDRAN, S., DE LAAT, J., LAMBIN, E. F., STANTON, C. Y., AUDY, R. and THOMAS, N. E. (2017). Cash for carbon: A randomized trial of payments for ecosystem services to reduce deforestation. *Science*, **357** (6348), 267–273.
- KACZAN, D., PFAFF, A., RODRIGUEZ, L. and SHAPIRO-GARZA, E. (2017). Increasing the impact of collective incentives in payments for ecosystem services. *Journal of Environmental Economics and Management*, **86**, 48–67.
- , SWALLOW, B. M. *et al.* (2013). Designing a payments for ecosystem services (pes)

- program to reduce deforestation in tanzania: An assessment of payment approaches. *Ecological Economics*, **95**, 20–30.
- KERR, J., VARDHAN, M. and JINDAL, R. (2014). Incentives, conditionality and collective action in payment for environmental services. *International Journal of the Commons*, **8** (2).
- LE QUÉRÉ, C., ANDREW, R., FRIEDLINGSTEIN, P., SITCH, S., HAUCK, J., PONGRATZ, J., PICKERS, P., KORSBAKKEN, J., PETERS, G., CANADELL, J. *et al.* (2018). Global carbon budget 2018. *Earth System Science Data*, **10**, 2141–2194.
- MACKENZIE, I. A., OHNDORF, M. and PALMER, C. (2012). Enforcement-proof contracts with moral hazard in precaution: ensuring ?permanence?in carbon sequestration. *Oxford economic papers*, **64** (2), 350–374.
- MCNEELY, J. A. (1993). Economic incentives for conserving biodiversity: lessons for africa. *Ambio*, pp. 144–150.
- NARLOCH, U., PASCUAL, U. and DRUCKER, A. G. (2012). Collective action dynamics under external rewards: experimental insights from andean farming communities. *World Development*, **40** (10), 2096–2107.
- OECD (2010). *Paying for Biodiversity: Enhancing the Cost-Effectiveness of Payments for Ecosystem Services*. Paris: OECD.
- OSTROM, E. (1990). Governing the commons: The evolution of institutions for collective action. *American Political science review*, **86** (1), 248–249.
- PAGIOLA, S., HONEY-ROSÉS, J. and FREIRE-GONZÁLEZ, J. (2016). Evaluation of the permanence of land use change induced by payments for environmental services in quindío, colombia. *PloS one*, **11** (3), e0147829.
- PEARCE, D., BARBIER, E. and MARKANDYA, A. (2013). *Sustainable development: economics and environment in the Third World*. Routledge.
- PERSSON, U. M. and ALPÍZAR, F. (2013). Conditional cash transfers and payments for

- environmental services? a conceptual framework for explaining and judging differences in outcomes. *World Development*, **43**, 124–137.
- REUTEMANN, T., ENGEL, S. and PAREJA, E. (2016). How (not) to pay — field experimental evidence on the design of redd+ payments. *Ecological Economics*, **129**, 220 – 229.
- SALK, C., LOPEZ, M.-C. and WONG, G. (2017). Simple incentives and group dependence for successful payments for ecosystem services programs: Evidence from an experimental game in rural Lao PDR. *Conservation Letters*, **10** (4), 414–421.
- SAMII, C., LISIECKI, M., KULKARNI, P., PALER, L. and CHAVIS, L. (2014a). Effects of payment for environmental services (PES) on deforestation and poverty in low and middle income countries: A systematic review. *Campbell Systematic Reviews*, **11**, 95pp.
- , —, —, — and — (2014b). Effects of decentralized forest management (DFM) on deforestation and poverty in low and middle income countries: A systematic review. *Campbell Systematic Reviews*, **10**, 88pp.
- SIMPSON, R. D. and SEDJO, R. A. (1996). Paying for the conservation of endangered ecosystems: a comparison of direct and indirect approaches. *Environment and development economics*, pp. 241–257.
- STERN, N. H., PETERS, S., BAKHSHI, V., BOWEN, A., CAMERON, C., CATOVSKY, S., CRANE, D., CRUICKSHANK, S., DIETZ, S., EDMONSON, N. *et al.* (2006). *Stern Review: The economics of climate change*, vol. 30. Cambridge University Press Cambridge.
- TRAVERS, H., CLEMENTS, T., KEANE, A. and MILNER-GULLAND, E. (2011). Incentives for cooperation: The effects of institutional controls on common pool resource extraction in cambodia. *Ecological Economics*, **71**, 151–161.
- WADE, T. I., NDIAYE, O., MAUCLAIRE, M., MBAYE, B., SAGNA, M., GUISSÉ, A. and GOFFNER, D. (2018). Biodiversity field trials to inform reforestation and natural resource management strategies along the african great green wall in senegal. *New forests*, **49** (3), 341–362.

- WATSON, R. T., ZINYOWERA, M. C. and MOSS, R. H. (1996). *Climate change 1995. Impacts, adaptations and mitigation of climate change: Scientific-technical analyses*. Cambridge: Cambridge University Press.
- WILEBORE, B., VOORS, M., BULTE, E. H., COOMES, D. and KONTOLEON, A. (2019). Unconditional transfers and tropical forest conservation: evidence from a randomized control trial in sierra leone. *American Journal of Agricultural Economics*, **101** (3), 894–918.
- WILSON, E. O. *et al.* (1988). The current state of biological diversity. *Biodiversity*, **521** (1), 3–18.
- WORLD BANK (2018). *Evaluating the permanence of forest conservation following the end of payments for environmental services in Uganda*. World Bank Working Paper AUS 0000379.
- WUNDER, S. (2005). Payments for Environmental Services: Some nuts and bolts, CIFOR Occasional Paper 24, Bogor, Indonesia: CIFOR.
- (2015). Revisiting the concept of payments for environmental services. *Ecological Economics*, **117**, 234 – 243.
- , ENGEL, S. and PAGIOLA, S. (2008). Taking stock: A comparative analysis of payments for environmental services programs in developed and developing countries. *Ecological Economics*, **65** (4), 834–852.

Appendix A Theoretical predictions

Consider a group of $n > 1$ individuals, who are identical in all respects. The group is offered a contract that specifies the amount of money the group is entitled to depending on the number of trees that are still alive at a specific future date (i.e., at endline). The payment is to be shared equally among all members of the group. Using $Q \geq 0$ to denote the number of trees still alive at endline, the group payment is $B = B(Q)$. Each individual group member receives B/n , independent of the amount of effort she put in. Let us use $\bar{Q} > 0$ to indicate the total number of trees that have been planted (and hence the maximum number of trees that can be kept alive). For ease of exposition we assume that there are no non-monetary benefits associated with tree survival.¹²

Tree survival rates are a function of both conservation effort and luck. Without loss of generality, we assume that it takes one unit of effort to keep one tree alive, and that uncertainty is additive. The tree survival production function is thus $Q = \sum_{i=1}^n z_i + \epsilon$, where z_i is the amount of effort put in by group member i to keep trees alive and ϵ is a stochastic term drawn from a uniform distribution with support $[-A, +A]$. To facilitate notation, let us use $Z = \sum_{i=1}^n z_i$ to denote the total amount of effort put in by the group, and $Z_{-i} = \sum_{j \neq i} z_j$ the total amount of effort put in by all group members other than member i . We assume that the conservation costs incurred by group member i are a quadratic function of the amount of effort she put in:

$$c_i(z_i) = cz_i^2/2. \tag{A1}$$

We consider two types of conservation contracts. The payment scheme in the linear group payment contract is $B = bQ$, with b denoting the group's payment per tree that is still alive at endline. The amount a group receives under the threshold group payment contract depends on whether the number of trees still alive is above or below a threshold level. Using $h = \{0, 1, \dots, H\}$ to enumerate thresholds from lowest to highest¹³ and using

¹²Including non-monetary conservation benefits would complicate the analysis without yielding any additional insights. The reason is that these benefits are very likely independent of the payment scheme in place. Including them in the analysis would affect the equilibrium number of trees kept alive, but not the difference therein between the two payment schemes.

¹³Strictly speaking $h = 0$ is not a threshold. Allowing h to be equal to 0 facilitates notation in the

Q_h to denote the critical number of trees still alive associated with threshold h , group payments are equal to $B = B_h$ if $Q_h \leq Q < Q_{h+1}$. More specifically, suppose that the H thresholds are set equidistantly on support $[0, \bar{Q}]$ so that they are set at intervals of $\bar{Q}/(H+1)$ trees.

The payments received by groups remunerated under the linear or the threshold group payment contract depend on the per-unit payment b , the vector of threshold group payments B_h , and on the vector of associated threshold levels Q_h . The two schemes can be made ex-ante payoff equivalent by ensuring that, for all $h = \{0, 1, \dots, H\}$, the threshold group payment B_h is equal to the (unweighted) average payments in the linear group payment scheme for all tree survival outcomes between $\frac{h\bar{Q}}{(H+1)}$ and $\frac{(h+1)\bar{Q}}{(H+1)}$. Solving $B_h = \frac{1}{\bar{Q}/(H+1)} \int_{\frac{h\bar{Q}}{H+1}}^{\frac{(h+1)\bar{Q}}{(H+1)}} bQ \, dQ$, we have

$$B_h = b(h + 0.5) \frac{\bar{Q}}{H+1} \quad \forall \quad h = \{0, 1, \dots, H\}. \quad (\text{A2})$$

For a graphical representation of the linear and threshold group payment schemes, see Figure 1.

Finally, recall that we assume that in either payment scheme each individual group member receives a share of $1/n$ of the group payments, independent of the amount of effort they put in in keeping trees alive. Each individual group member's (expected) payoff function is then

$$\pi_i = E(B)/n - 0.5cz_i^2, \quad (\text{A3})$$

with $B = bQ$ or $B = B_h$ (if $Q_h \leq Q < Q_{h+1}$), depending on the payment scheme in place.

We are now ready to determine which of the two group payment schemes, the linear one or the threshold one, is predicted to induce the highest survival rates. We do so first assuming that the relationship between effort and tree survival is deterministic ($A = 0$),

 remainder of this Appendix.

and then we analyze how outcomes may differ when allowing for uncertainty ($A > 0$).

A.1 Equilibrium survival rates in the two schemes under certainty

In this subsection we abstract from the any uncertainty regarding the relationship between the total amount of effort and the number of trees surviving ($A = 0$). We first derive the standard game-theoretic predictions regarding equilibrium effort for the linear group payment scheme. Absent uncertainty, we have $Q = \sum_{i=1}^n z_i$. A group's net benefits are equal to $b \sum_{i=1}^n z_i - \sum_{i=1}^n 0.5cz_i^2$ while the net benefits for each individual group member are equal to $\frac{b}{n} \sum_{j=1}^n z_j - 0.5cz_i^2$. Using subscript L to denote outcomes for the linear group payment scheme and superscript D to denote the deterministic case, the socially optimal (SO) and Nash equilibrium (NE) individual effort levels are, respectively, $z_L^{D,SO} = b/c$ and $z_L^{D,NE} = b/(nc)$. Taking into account that $Q \leq \bar{Q}$, the socially optimal and Nash equilibrium group effort levels are

$$Z_L^{D,SO} = \min \left[\frac{nb}{c}, \bar{Q} \right] \quad (\text{A4})$$

and

$$Z_L^{D,NE} = \min \left[\frac{b}{c}, \bar{Q} \right], \quad (\text{A5})$$

respectively.

Equations (A4) and (A5) indicate that the choice of \bar{Q} (relative to n , b and c) is not innocuous. For the linear group payment scheme to be a social dilemma in the deterministic case, we need to have that $\bar{Q} > b/c$ (see (A5)), and preferably we would set $\bar{Q} = nb/c$ (see (A4)). In the RCT we are free to choose b and n , but we have no reliable estimate of the value of c . The choice of \bar{Q} (again relative to n , b and c) also affects the analysis of the threshold group payment scheme, and then especially so in combination with the choice of the number of thresholds, H . The combination of \bar{Q} and H should be such that at least one non-trivial threshold ($h \geq 1$) is an equilibrium of the

threshold group payment scheme. For any n , b and c , if \bar{Q} is very high and H is very low, the costs of putting in effort to reach the first threshold, $\bar{Q}(H + 1)$, may be larger than the benefits of doing so – as benefits are linear and the costs are quadratic in effort. As we will prove below, the threshold game has at least one non-trivial equilibrium if $\bar{Q} \leq \frac{2}{3} \frac{nb}{c}(H + 1)$. And the relative values of \bar{Q} and H also determine whether it is ever optimal for an agent to not only supplement the rest of the group’s effort to reach the first threshold above $Z_{-i} \equiv \sum_{i \neq j} z_j$, but also two or more. For expositional simplicity, we assume that $\bar{Q}/(H + 1)$ needs to be sufficiently large such that it is never optimal for an agent to single-handedly raise the threshold level achieved by two or more units. A necessary condition for this to be the case is that $\bar{Q} > 2b(H + 1)/(nc)$.¹⁴

Combining conditions $\bar{Q} \leq \frac{2}{3} \frac{nb}{c}(H + 1)$, $\bar{Q} > b/c$ and $\bar{Q} > 2b(H + 1)/(nc)$, we have $\frac{2}{3} \frac{nb}{c}(H + 1) \geq \bar{Q} > \max\left[\frac{b}{c}, \frac{2(H+1)b}{n}\right]$. Regarding the RHS of this condition, our RCT’s parameterization of $H = 4$ and $n = 5$ implies that we have $2(H + 1) > n$, and hence the above boils down to the following condition:

$$\frac{2}{3} \frac{nb}{c}(H + 1) \geq \bar{Q} > \frac{2(H + 1)b}{n} \frac{1}{c}. \quad (\text{A6})$$

We assume that condition (A6) holds throughout the remainder of this analysis. So how likely is it that it also holds in our RCT? Given our parameter values, the second inequality in this equation dictates that \bar{Q} should be at least twice as large as the Nash equilibrium number of trees surviving in the linear group payment scheme (which equals b/c), implying a survival rate of less than 50%. And regarding the first inequality in (A6), we have that \bar{Q} should not be larger than $2(H + 1)/3$ times the socially optimal number of trees surviving (which is equal to nb/c). Given that $H = 4$ in our RCT, this condition is very likely to be met too. So, despite the fact that we do not know c , our parameterization is such that condition (A6) is very likely to be met in practice. Or, in words, the parame-

¹⁴This can be inferred as follows. Suppose that $Z_{-i} = \left(\frac{h+1}{H+1}\right)\bar{Q} - \nu$, where ν is infinitely close to zero. Agent i can ensure private gains equal to $\left(\frac{B_{h+1}}{n} - \frac{B_h}{n}\right) \frac{b\bar{Q}}{n(H+1)}$ by putting in $z_i = \nu \approx 0$ to reach threshold $h + 1$, and it would be privately optimal to put in the additional $\bar{Q}/(H + 1)$ units of effort to reach threshold $h + 2$ if $B_{h+2}/n - 0.5c\left(\frac{\bar{Q}}{H+1}\right)^2 \geq B_{h+1}/n$. Using (A2) and solving, we have that a necessary condition for agents to be unwilling to unilaterally raise the threshold reached by two or more levels is that $\frac{b}{n} \frac{\bar{Q}}{H+1} < 0.5c\left(\frac{\bar{Q}}{H+1}\right)^2$, or $\bar{Q} > 2b(H + 1)/(nc)$.

ters are chosen such that (i) the linear group payment scheme poses a social dilemma, (ii) it may be privately optimal for a group member to independently supplement the efforts by others to reach the next threshold, but not to put in additional effort to reach two or more additional thresholds, and (iii) at least one non-trivial threshold, $h \geq 1$, is an equilibrium in the threshold group payment scheme.

We now derive the socially optimal and (the set of) Nash equilibrium outcomes in the presence of threshold group payments. Because costs are assumed to be quadratic in effort, net group benefits associated with reaching threshold h are maximized if each agent puts in a share of $1/n$ of the total amount of effort needed to reach that threshold: $z_i = \left(\frac{h}{H+1}\right)\frac{\bar{Q}}{n}$. Threshold $h = h^{D,SO}$ is the socially optimal threshold if

$$B_{h^{D,SO}} - 0.5c \sum_{i=1}^n \left(\left(\frac{h^{D,SO}}{H+1} \right) \frac{\bar{Q}}{n} \right)^2 > B_{h^{D,SO}+1} - 0.5c \sum_{i=1}^n \left(\left(\frac{h^{D,SO}+1}{H+1} \right) \frac{\bar{Q}}{n} \right)^2. \quad (\text{A7})$$

Substituting (A2) into (A7) and solving, the socially optimal threshold equals

$$h^{D,SO} = \left\lfloor \frac{nb}{c\bar{Q}/(H+1)} - \frac{1}{2} \right\rfloor, \quad (\text{A8})$$

where $\lfloor x \rfloor$ denotes the first integer number below x . From this expression we infer that $h^{D,SO} \geq 1$ if $\frac{2}{3}\frac{nb}{c}(H+1) \geq \bar{Q}$ – see the first inequality in (A6). Also note that if \bar{Q} happens to be chosen such that it is equal (or at least sufficiently close) to the socially optimal aggregate effort level with linear group payments ($\bar{Q} = Z_L^{D,SO} = nb/c$), we have that $h^{D,SO} = \lfloor H + \frac{1}{2} \rfloor$. Or, in words, if \bar{Q} is equal to the social optimum aggregate effort level in the linear group payment scheme, then it is also socially optimal to reach the highest threshold (H) in the threshold group payment scheme. More generally, substituting (A4) into (A8), the socially optimal effort level with threshold group payments is at the highest threshold equal to or below the linear group payments' socially optimal group effort.

Having determined $h^{D,SO}$ we now determine which of the H thresholds are Nash equilibrium outcomes of the threshold group payment game, and also whether the threshold group payment scheme is likely to give rise to higher effort levels (and hence survival

rates) than the linear group payment scheme. To do so, we first derive the maximum amount of effort an agent is willing to put in to reach the next threshold, as well as the set of Nash equilibrium outcomes. For $(\frac{h}{H+1})\bar{Q} > Z_{-i} \geq (\frac{h-1}{H+1})\bar{Q}$ individual i is willing to put in $z_i = (\frac{h}{H+1})\bar{Q} - Z_{-i} \geq 0$ if $B_h/n - 0.5c((\frac{h}{H+1})\bar{Q} - Z_{-i})^2 \geq B_{h-1}/n$. Solving and focusing on the set of symmetric equilibria, we find that all

$$h^{D,SO} = \left[0, \dots, h^{D,MAX}\right] \quad \text{with} \quad h^{D,MAX} = \left\lfloor \sqrt{\frac{2(H+1)nb}{\bar{Q}c}} \right\rfloor \quad (\text{A9})$$

are Nash equilibrium outcomes of the threshold group payment game.

So under what circumstances do equilibrium threshold levels exist with aggregate effort levels that are higher than the aggregate Nash equilibrium effort of the linear group payment scheme? Because $\sqrt{\frac{2(H+1)nb}{\bar{Q}c}} \geq h^{D,MAX} \geq \sqrt{\frac{2(H+1)nb}{\bar{Q}c}} - 1$ (with at least one of the inequalities being strict), a sufficient condition for the threshold group payment scheme to outperform the linear group payment scheme is that $\left(\sqrt{\frac{2(H+1)nb}{\bar{Q}c}} - 1\right)\frac{\bar{Q}}{H+1} > \frac{b}{c}$, or

$$\sqrt{\frac{2(H+1)nb}{\bar{Q}c}} > 1 + \frac{b(H+1)}{c\bar{Q}}. \quad (\text{A10})$$

The closer $(H+1)/\bar{Q}$ is to zero, the more likely it is for (A10) to hold. Using (A6), we know that if (A10) holds for $\frac{H+1}{\bar{Q}} = \frac{3c}{2nb}$, it holds for all $(H+1)/\bar{Q}$ that satisfy (A6). Substituting $\frac{H+1}{\bar{Q}} = \frac{3c}{2nb}$ into (A10) and solving yields the condition that $n \geq \lfloor \frac{1.5}{\sqrt{3}-1} + 1 \rfloor = 3$, and this condition is indeed met for our parameterization.¹⁵

A.2 Equilibrium survival rates in the two schemes under uncertainty

The outcome that survival rates are higher with threshold group payments than with linear group payments does not necessarily hold, however, if the relationship between (aggregate) effort and the number of trees surviving is stochastic (i.e., when $A > 0$). In that case we have $Q \in [Z - A, Z + A]$, with $A > 0$. Given profit function (A3) (which

¹⁵To verify the claim that the threshold group payment scheme outperforms the linear group payment scheme for all values of \bar{Q} that meet (A6), we check whether it also holds for \bar{Q} at the lower bound of (A6): $\frac{H+1}{\bar{Q}} = \frac{nc}{2b}$. Substituting this value into (A10) and solving, we have that $n > 2$. As $\frac{1.5}{\sqrt{3}-1} > 2$, we have that if condition (A10) is met for $\frac{H+1}{\bar{Q}} = \frac{3c}{2nb}$, it holds for all values of (A6).

implicitly assumes risk neutrality), the Nash equilibrium effort level does not change in case of linear group payments. An individual agent then maximizes $bE(Q)/n - 0.5cz_i^2$, or $b(Z_{-i} + z_i)/n - 0.5cz_i^2$. Using superscript U to denote outcomes in case of $A > 0$ and assuming that (A6) continues to hold, the aggregate Nash equilibrium effort level with linear group payments is equal to

$$Z_L^{U,NE} = \frac{b}{c}, \quad (\text{A11})$$

and the expected number of trees kept alive is equal to b/c as well.

In case of threshold group payments, uncertainty about the relationship between effort and the number of trees still alive does affect the (expected) private benefits of contributing to reaching a threshold. Consider the case where $(\frac{h}{H+1})\bar{Q} > Z_{-i} > (\frac{h-1}{H+1})\bar{Q}$. The private decision problem for an individual agent to contribute to reaching the next threshold is then whether $P(Q \geq (\frac{h}{H+1})\bar{Q})B_h/n + (1 - P(Q \geq (\frac{h}{H+1})\bar{Q}))B_{h-1}/n - 0.5cz_i^2 > B_{h-1}/n$, or, using (A6),

$$P\left(Q \geq \left(\frac{h}{H+1}\right)\bar{Q}\right) \frac{b}{n} \frac{\bar{Q}}{H+1} - \frac{c}{2} z_i^2 \geq 0. \quad (\text{A12})$$

As the actual number of trees surviving is assumed to be uniformly distributed on support $[Z - A, Z + A]$, member i can eliminate all risk of reaching threshold h by putting in $z_i(h) = \left(\frac{h}{H+1}\right)\bar{Q} + A - Z_{-i}$. Using $z^{Risk}(h)$ to denote the maximum amount of effort each individual member is willing to contribute to reaching threshold h if not all risk can be eliminated (to be derived below), each member's maximum effort level is equal to

$$z_T^{MAX} = \min \left[\left(\frac{h}{H+1}\right)\bar{Q} + A - Z_{-i}, z^{Risk}(h) \right]. \quad (\text{A13})$$

To determine $z_i^{Risk}(h)$, let us first derive the probability that threshold h is passed:

$$P\left(Q \geq \left(\frac{h}{H+1}\right)\bar{Q}\right) = \frac{1}{2A} \int_{\frac{h\bar{Q}}{H+1}}^{Z+A} 1 \, dv = \frac{1}{2A} \left[Z + A - \left(\frac{h}{H+1}\right)\bar{Q} \right]. \quad (\text{A14})$$

Substituting equation (A14) into (A12), taking the first derivative equal to zero and setting it equal to zero, the maximum amount of effort member i wants to put in to increase the probability of passing the next threshold is $z_i^{Risk} = \frac{1}{2A} \left(\frac{\bar{Q}}{H+1}\right) \frac{b}{nc}$. That means that, using (A13), we have $z_T^{U,MAX}(h) = \min\left[\left(\frac{h}{H+1}\right)\bar{Q} + A - Z_{-i}, \frac{1}{2A} \left(\frac{\bar{Q}}{H+1}\right) \frac{b}{nc}\right]$. Focusing on the set of symmetric equilibria, we thus have

$$z_T^{U,MAX}(h) = \min\left[\frac{1}{n} \left(\left(\frac{h}{H+1}\right)\bar{Q} + A\right), \frac{1}{2A} \left(\frac{\bar{Q}}{H+1}\right) \frac{b}{nc}\right]. \quad (\text{A15})$$

From (A15) we can infer that increased uncertainty (a higher A) reduces the set of equilibrium thresholds because of two reasons. First, the amount of effort that is needed to eliminate all risk increases in A , and hence an equilibrium in which a threshold is met with certainty is less likely to exist the higher is A . Second, if it does not pay to eliminate all risk, the marginal benefits of putting in effort to increase the probability of reaching the threshold are declining in A ; z_i^{Risk} is smaller the larger is A .

So what are the (symmetric) equilibrium threshold levels of the threshold group payment scheme? From (A15) it is clear that only the lowest thresholds may be equilibria that can be met with certainty; higher thresholds may still be achievable, but only probabilistically. That means that (A15) implies that $h^{U,NE} = [0, \dots, \lfloor \frac{1}{2A} \frac{b}{c} \rfloor]$ are equilibria of this game, where the lower threshold levels may be the ones in which joint effort eliminates all risk, but with the higher ones being reached only probabilistically.

So under what conditions does uncertainty result in aggregate effort being lower with threshold group payments than with linear group payments? If A is such that equilibria exist in which all risk is eliminated, threshold group payments still outperform the linear group payment scheme. If A is such that eliminating all risk is not an equilibrium for any of the thresholds, the maximum aggregate effort equals $Z_T^{U,MAX} = \lfloor \frac{1}{2A} \frac{b}{c} \rfloor \frac{\bar{Q}}{H+1} \leq \frac{1}{2A} \frac{b}{c} \frac{\bar{Q}}{H+1}$. A sufficient condition for the linear group payment scheme to outperform the threshold group

payment scheme is that $Z_T^{U,MAX} < \frac{b}{c} = Z_L^{U,NE}$, and this is the case if $A > \frac{1}{2}(\frac{\bar{Q}}{H+1})$. That is, if uncertainty about the number of trees surviving is such that even targeting a survival rate in the top half of a threshold band ($Z \in [(\frac{h+0.5}{H+1})\bar{Q}, (\frac{h+1}{H+1})\bar{Q}]$) does not guarantee that h is achieved with certainty, aggregate effort is lower than the Nash equilibrium effort level with linear group payments.