PRELIMINARY DRAFT

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Incentivizing conservation of de facto community-owned forests*

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November 17, 2020

Abstract

Payments for Environmental Services (PES) are a nature conservation policy in which landowners receive financial compensation conditional on verified environmental service delivery. PES contracts have been found to be effective in inducing conservation on private lands, as the agent signing the contract is also the one ensuring the environmental service delivery. If land is (de facto) collectively owned, offering collective conservation payments may give rise to strong free-riding incentives. We implement a Randomized Controlled Trial in arid Burkina Faso, aimed at stimulating reforestation in community-managed forest areas, to test the relative effectiveness of two community PES payment schemes – a linear group payment scheme, in which group payments increase linearly with tree survival rates, and a threshold group payment scheme. Contrary to standard economic theory we find that linear payments give rise to higher tree survival rates than threshold group payments. We use both field-experimental evidence as well as lab-experimental results to explore the mechanisms giving rise to this surprising result.

Keywords: Forest conservation, payments for environmental services, randomized controlled trial, threshold payments, social dilemma games, coordination games.

*We thank the Climate Investment Fund for their financial support, and Burkina Faso's Forest Investment Program (FIP) for their generous collaboration in the implementation of this research. We also thank Jonas Guthoff for his excellent research assistance, and participants of the 2019 Bioecon and 2020 EAERE conferences as well as seminar participants at Tilburg University for their constructive comments. The findings, interpretations, and conclusions expressed in this paper are entirely those of the authors. They do not necessarily represent the views of the World Bank and its affiliated organizations, or those of the Executive Directors of the World Bank Group, or the governments they represent. All remaining errors are our own. Please send all correspondence to d.p.vansoest@tilburguniversity.edu.

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; Pagiola *et al.*, 2002; Sohngen and Mendelsohn, 2003; Buys, 2007; 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; Watson *et al.*, 1996; Turner *et al.*, 2007; Rosa *et al.*, 2016; Busch *et al.*, 2019). Not surprisingly, stimulating forest conservation in the tropical zone is a key element of the International Panel on Climate Change (IPCC)'s 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.

One available forest conservation policy is Payments for Environmental Services (PES), 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). Samii *et al.* (2014a) report the results of a meta-analysis on the effectiveness of PES. Even though the available evidence base is still quite limited (and by and large consists of observational studies using matching protocols), they conclude 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.

PES schemes are not the only available forest conservation policy. 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 countereffective. 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.[1]

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 land owner) is also the one who can ensure

[1] PES 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 Alpízar, 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).

that the necessary actions are taken to meet the payment criteria. Whether PES payment schemes are likely to provide equally strong conservation incentives on (de facto) commonly owned resources (like forests on communal lands), is not obvious. Here, (changes in) conservation status 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).[2]

In this paper we aim to contribute to the quest for optimal PES design by comparing the environmental outcomes of two different payment mechanism aimed at fostering forest conservation in (de facto) commonly-owned forests. One scheme offers payments that increase linearly in the conservation outcome. This linear payment scheme provides strong conservation incentives in the context of (de facto) privately-owned land, and according to Kaczan *et al.* (2017) it is the scheme that is typically implemented in practice. In the context of collective payments, however, the linear payment scheme 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 amount paid depends on whether the environmental outcome is better than a specific threshold level.

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

Threshold 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 (Barrett, 2016). 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. This holds for each community member, and hence threshold group payments change the nature of the interaction from a social dilemma into a coordination game. We develop motivating theory (presented in full in Appendix A) in which we show that threshold group payments are indeed expected to provide better environmental outcomes than linear group payments, but only if there is not too much uncertainty regarding the relationship between maintenance effort and tree survival rates.

Our study thus aims to contribute to the discussion on optimal PES policy design to induce conservation on commonly-owned land. We do so by implementing 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 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. Our results are mixed. Consistent with theory, we find that threshold 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. Contrary to our theoretical predictions, however, 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 this surprising result, 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 the study they implemented in Laos, 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 the effectiveness of collective PES payments crucially depends on the (strength of the) community's governance structure in place. This finding corroborates the earlier results of a lab-in-the-field study in Cambodia, implemented by Travers *et al.* (2011). 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, increase 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. Our findings suggest that feedback mechanisms that minimize outcome uncertainty might be required for achieving the potential of threshold-based payments for addressing the social dilemma inherent to collective PES schemes.

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 payment scheme performed worse than the linear payment scheme. Section 5 presents the results of the laboratory experiment, and section 6 concludes.

2 Experimental design

2.1 Intervention description and conceptual framework

Our project focused on using PES payments to increase the survival rates of young trees that were recently planted as part of a reforestation project on degraded forest lands. The campaign started with, in total, about 33,500 new trees being planted on 66 reforestation sites across 11 protected forests in July/August 2017. Subsequently, community members of villages surrounding these project forests were randomly selected, from a pool of volunteers, to receive a PES contract for the maintenance of, on average, about 500 trees that were recently planted on well-defined plots within nearby degraded forest land. They were informed that the amount of money their group would be entitled to depended on the number of trees that are still alive at the beginning of the next rainy season (nine months after the trees had been planted), and that 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.

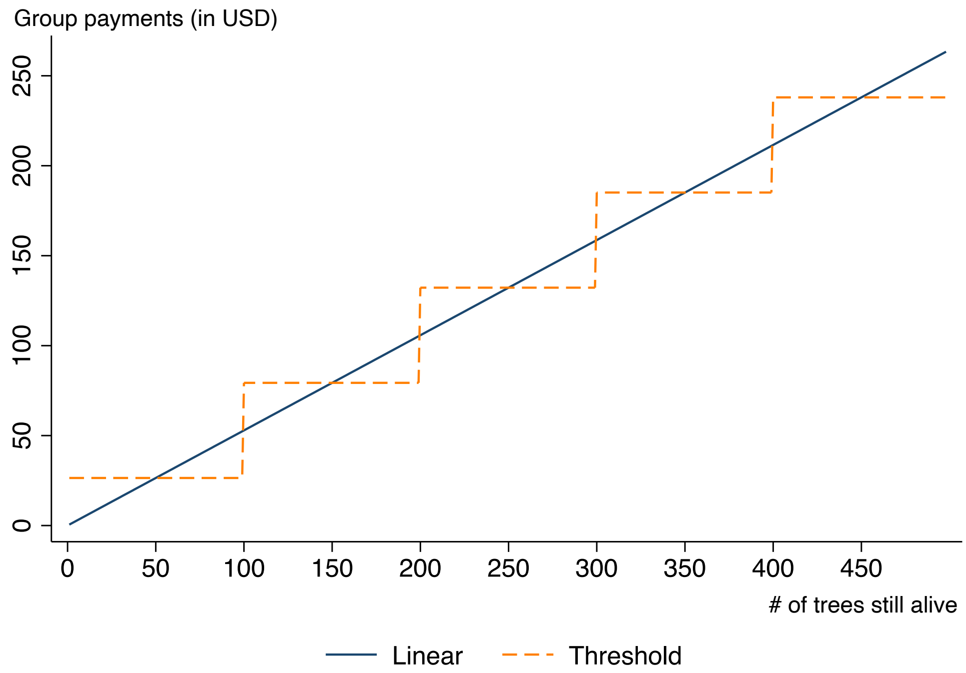
Two different payment schemes were implemented. The linear group payment scheme consisted of paying maintenance groups 300 FCFA (about 53 dollar cents[3]) for each tree that is still alive at endline. In the threshold group payment scheme the amount of money maintenance groups would receive depended on the highest threshold level met by the endline number of trees still alive 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.

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.[4] 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 that with linear group payments the privately optimal effort level is lower than the socially optimal one,

[3] At endline the official exchange rate was $1.77 for 1000 FCFA.

[4] Our data suggest that participation in non-farm employment is very low in the study area.

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 payment scheme.



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.

As shown in Appendix A, replacing linear payments by threshold payments changes the nature of the game from a social dilemma into a coordination game. In the threshold payment scheme, group payments only fall if the extra tree that dies results in the number of trees still alive falling 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 6000 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) marginal benefits of effort to its marginal costs. With well-behaved cost functions and with a linear group payment scheme, 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, if the costs of effort are quadratic and with $n > 1$ agents in a group, each agent's dominant strategy is to put in 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. Whether agents are willing to exert effort in the threshold group payment scheme depends on whether the agent's costs of providing effort to make the number of living trees pass the threshold are smaller than the extra amount of money she will receive at that higher level (compared to the payments she receives if the threshold is not crossed). The larger the aggregate amount of effort put in by their fellow group members, the more likely it is that the extra benefits associated with reaching the next threshold are larger than the costs of the amount of effort the agent needs to put into maintenance to reach that next threshold. Each agent's willingness to contribute thus crucially depends on how much effort her fellow group members are willing to supply.

So under what circumstances does the threshold group payment scheme provide better or worse incentives to keep trees alive than the linear group payment scheme? Without loss of generality, we assume that it takes one unit of effort to keep one tree alive, and we assume that the costs of effort are quadratic. We then 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.

We prove that, for the parameters implemented in the RCT (a maximum number of trees that can be kept alive equal to 500, maintenance groups consisting of 5 members, payoff-equivalent payment schemes, 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 uncertainty 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 marginal benefits of putting in effort to the marginal costs of doing so; with mean-preserving uncertainty, the dominant strategy remains unchanged.

Uncertainty does, however, affect the willingness of an agent to provide effort in the threshold group payment scheme. While Barrett and Dannenberg (2014) document that uncertainty can cause a coordination game to collapse into a social dilemma game, we find that outcomes with threshold group payments can become even worse than those with linear group payments. 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. For the lowest threshold 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); the likelihood that eliminating risk is optimal is smaller the higher the targeted threshold level. In addition, the larger the uncertainty, the expected marginal benefits of putting in effort are also smaller. 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 high enough, it may not be an equilibrium to eliminate all risk for even the lowest threshold, and the expected marginal benefits of putting in effort to increase the probability of meeting the lowest thresholds may be so low that the equilibrium effort level is lower than the Nash equilibrium effort level in the linear payment scheme.

2.2 Implementation of the treatments

We implemented the two treatments as follows. In 11 of Burkina Faso's protected forests, consisting in total of 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 were of a variety of indigenous species, and the same varieties of trees species were planted in each of the two plots in each block. For each of the 33 blocks, members of the adjacent communities were informed of the opportunity to participate in our tree maintenance program, in which groups of community members would be made responsible for the survival of the trees on the plot that was assigned to them, and who would receive a financial payment nine months later (at the beginning of the next rainy season) depending on the number of trees that were still alive at that moment. In principle, all community members aged 18 or older and who were able to take care of the trees, were eligible to participate in the program. Of those eligible for and interested in participating, we randomly selected five individuals to form the group that would be remunerated for the number of surviving trees using the linear payment scheme, and another five individuals who would be compensated on the basis of the threshold payment scheme. Finally, the two groups in each block were randomly assigned one of the two reforestation plots in their block.

Upon completion of the recruitment and assignment process, each maintenance group was assembled on the reforestation plot assigned to them. The group members received instructions regarding tree maintenance[5] and they were also informed of the mechanism via which they, as a group, 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 on beforehand.

Although trees were planted in two reforestation plots in each of the 33 forest blocks, 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

[5]Activities that are effective in increasing survival rates include cleaning the area under the trees, setting up firebreaks and keeping out wildlife and livestock. Watering is also an option, but the endline survey indicated that this was not implemented very often. All groups received instructions on how to implement these activities.

security reasons in the form of armed unrest. We thus have endline survey data for and tree survival information on just 31 blocks (consisting of 62 reforestation plots). That means that we ended up with, in total, 310 individuals participating in our RCT, five in each of the 62 maintenance groups. Of those 310, we were able to obtain baseline and endline information for 309 and 290, respectively. Table 1 presents the characteristics of the participants that ended up in each of the two treatment arms, as well as the outcomes of the balance tests.

Table 1: Summary statistics of characteristics of the maintenance groups in the two treatment groups, and associated balance test.

Variable	(1) Linear group payments treatment N	(1) Linear group payments treatment Mean/SE	(2) Threshold group payments treatment N	(2) Threshold group payments treatment Mean/SE	(3) Total N	(3) Total Mean/SE	T-test P-value (1)-(2)	Normalized difference (1)-(2)
Female	146	0.158	144	0.118	290	0.138	0.331	0.114
		(0.030)		(0.027)		(0.020)		
Participant's age	146	38.712	144	40.729	290	39.714	0.110	-0.188
		(0.908)		(0.870)		(0.631)		
Household head	146	0.623	144	0.722	290	0.672	0.073*	-0.210
		(0.040)		(0.037)		(0.028)		
Primary school completed, or better	146	0.185	144	0.167	290	0.176	0.684	0.048
		(0.032)		(0.031)		(0.022)		
Owns land	146	0.801	144	0.868	290	0.834	0.127	-0.179
		(0.033)		(0.028)		(0.022)		
Land area (acres)	146	12.897	144	14.507	290	13.697	0.847	-0.023
		(5.117)		(6.575)		(4.152)		
Agricultural income (in k FCFA)	143	3.29e+05	143	3.61e+05	286	3.45e+05	0.597	-0.063
		(47368.018)		(36383.046)		(29826.348)		
Value of livestock (in k FCFA)	146	2.25e+06	144	1.80e+06	290	2.02e+06	0.583	0.065
		(7.61e+05)		(3.13e+05)		(4.13e+05)		
Member, Forest Management Group	146	0.603	144	0.549	290	0.576	0.353	0.109
		(0.041)		(0.042)		(0.029)		
Lives close to reforestation area	146	0.130	144	0.125	290	0.128	0.896	0.015
		(0.028)		(0.028)		(0.020)		
Disposes of means of transport	146	0.849	144	0.889	290	0.869	0.320	-0.117
		(0.030)		(0.026)		(0.020)		

Notes: The value displayed for t-tests are p-values. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

As shown in Table 1, most of our participants are male, with an average age of about 40 years. More than 60% are the head of their household, and less than 20% completed primary education or higher. Most participants own at least some land (outside the protected forests), and the area they can cultivate is, on average, about 16 acres. Agricultural income is about 340,000 FCFA (about $ 600) per annum, and non-agricultural income is a non-negligible share of total income (200,000 CFA, or about $ 440). More than half of the participants are member of a Forest Management Group (FMG).[6] Relatively few live close to the reforestation area they are supposed to manage, but most of them have access

[6] In 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 (part of the) forest that had been assigned to the community. FMG members are thus community members with prior experience with forest management activities. Because selection into the RCT of eligible community members was random, some but not all participants are also FMG members.

to some means of transportation to visit their plot (typically a bicycle or a moped).

Comparing the values of the two groups, differences between them are typically small, and (as shown in the third column) statistically insignificant.[7] This conclusion is reinforced by comparing normalized differences for each of the characteristics. Normalized differences are generally preferred to *t*-tests because they provide a scale-free comparison (Imbens and Rubin, 2015; Imbens and Wooldridge, 2009; Abadie and Imbens, 2011). As shown in the last column of Table 1, all normalized differences are below 0.16, and hence well below the literature's standard cut-off value of 0.25.

3 Empirical approach

We thus ended up with tree survival data for 62 plots, 31 in each treatment arm. Our randomization procedure allows us to treat the observed tree survival rates of the two treatments in the same block as matched pairs, and to 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.

Our study is thus adequately powered to provide reliable estimates of possible treatment differences – but only just so. Financial and 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, it does not speak 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 with than without financial incentives. Reforestation occurred on degraded lands within protected forests quite distant from the settlements, and hence the non-monetary local benefits of reforestation are likely to be negligible. We observe an average survival rate around 34 percent, substantially higher

[7]Balance tests were also implemented 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 are significantly different at 10 percent, or lower.

than is typical in such dry agro-ecological conditions (Carey, 2020).[8]

We assess the impact of the threshold versus the linear group payment scheme on both intermediate and ultimate measures of cooperation. Theory suggests that, unless uncertainty is too high, threshold 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 also 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 individual trees (independent of whether or not they were planted close to another sapling), and verify the status of each tree (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

[8] For 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)

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.

4 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 (columns (7) and (8)). Regarding the former, we use two types of regression specifications. The simplest version merely consist of regressing the relevant dependent variables on the treatment indicator in the presence of 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. These regression results are presented in columns (1), (3) and (5) of Table 2. The other version includes, in addition to the treatment dummy as well as block fixed effects, a series of individual characteristics (gender, age and the size of land holdings) as controls. Because outcomes may be more similar within forests than between forests, standard errors are clustered at the forest level. The results using this regression model are presented in columns (2), (4) and (6) of Table 2.

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

	Input measures of cooperation						**Output 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^{+}	0.950^{+}	0.140	0.163^{*}	-0.054^{+}	-0.109^{**}	-0.077^{*}	-0.095^{**}
	(0.393)	(0.580)	(0.095)	(0.088)	(0.032)	(0.046)	(0.041)	(0.040)
Constant	5.290^{***}	6.239^{***}	3.995^{***}	4.294^{***}	0.179^{***}	0.152^{**}	0.453^{***}	0.426^{***}
	(0.191)	(0.834)	(0.046)	(0.276)	(0.016)	(0.052)	(0.062)	(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	No	Yes	No	Yes	No	Yes	No	Yes
Bloc fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	No	No

Robust standard errors, clustered at the forest level in Models (1)-(6) and at the block level in Models (7) and (8), are presented in parentheses.
The participants' characteristics controlled in the regressions include gender, age, and land area.
$^{+}$ $p < 0.15$, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

The results are interesting. 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 groups report having met significantly more frequently with their fellow group members (on average 6.1 times, versus 5.2 times in the linear payments group), and this difference only just fails to be significant at the 10% level in regression (1); $p = 0.106$. Controlling for individual characteristics increases the size of the coefficient on the treatment indicator, but also its standard error; see (2).

While we find (weak) evidence of the threshold 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 (at $p = 0.098$) when controlling for individual characteristics; see (4). 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 (as we have $p = 0.043$ in specification (6)). So we also find that the process of cooperation was assessed to be more equitable in the threshold group payment treatment than with linear payments.

We thus find that the threshold payments resulted in better scores for our three measures of cooperation than linear payments (with the differences being significant at $p < 0.106$, or better). But did this 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 7.6 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 ($p = 0.021$).

5 Mechanisms

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. These outcomes are surprising. Before delving in potential mechanisms, we calculate the probability of incorrectly concluding that the linear group payments outperform threshold group payments. Conditional on having the opposite outcome, we can estimate the probability that we incorrectly conclude that the linear payment scheme outperforms the threshold scheme. Suppose that, in fact, the threshold payment scheme outperforms the linear 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.

So what are the potential mechanisms via which the threshold scheme did not yield higher survival rates than the linear payment scheme? We hypothesize two. First, survival rates were measured at endline, and the survey questions 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. Second, and in line with the theory presented in Appendix A, coordination in threshold games becomes more difficult when there is uncertainty regarding the probability of accidentally crossing the target threshold; see also the discussion in Section 2.1. In the following two subsections we aim to test the relevance of each of the two.

5.1 The dynamics of cooperation

Survival rates were measured at endline, and the survey questions analyzed above asked for an overall evaluation of the process of cooperation. The reported outcomes may, however, hide important differences in the dynamics of cooperation over time. In the survey we asked participants how they evaluate 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 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 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 payment scheme. Focusing on those who reported a change in cooperation over time, we find 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) Linear group payments treatment Mean/SE	N	(2) Threshold group payments treatment Mean/SE	t-test p-value (1)-(2)	Chi2 p-value
Good cooperation throughout	146	0.664 (0.039)	144	0.597 (0.041)	0.237	0.236
Zero cooperation throughout	146	0.021 (0.012)	144	0.014 (0.010)	0.664	0.663
Cooperation changed over time	146	0.274 (0.037)	144	0.306 (0.039)	0.555	0.553
- improved over time	40	0.650 (0.076)	44	0.818 (0.059)	0.082*	0.080
- worsened over time	40	0.350 (0.076)	44	0.182 (0.059)	0.082*	0.080

5.2 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 with certainty, the lower the amount of effort risk-neutral agents are likely to be willing to invest in keeping trees alive.[9] We cannot measure risk itself, but we can analyze whether the endline numbers of trees alive are bunched around the various thresholds. If agents 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 payment plots with a number of surviving trees just above each threshold, and relatively few threshold payment plots with a number of surviving trees just below each threshold.

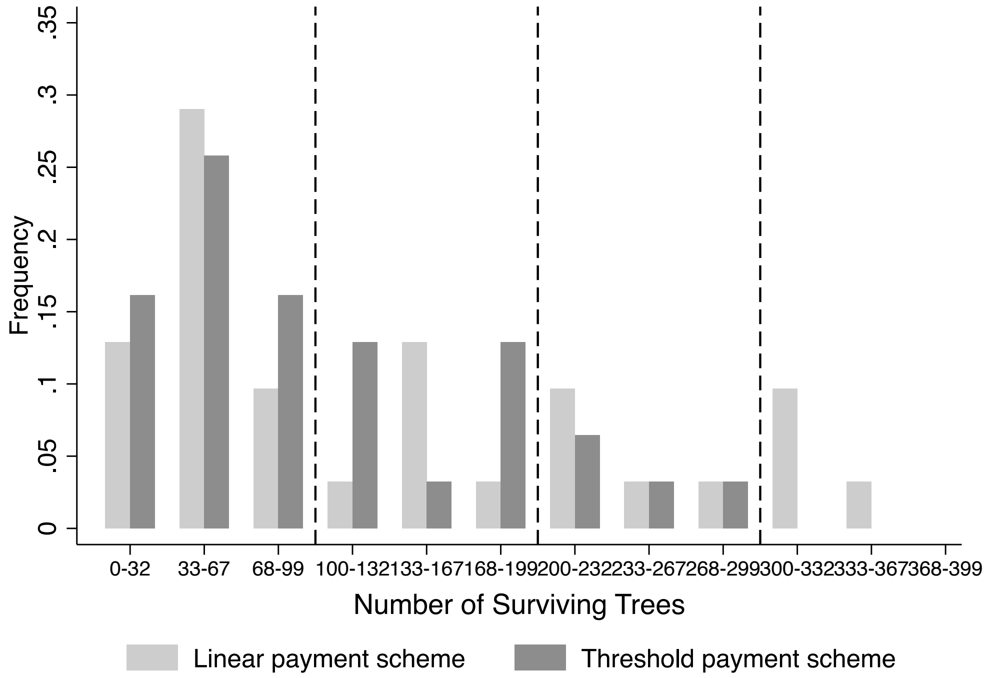
Figure 2 presents the distribution of the observed survival rates in the threshold payment scheme vis-à-vis the payment thresholds, and the distribution of the observed survival rates in the linear payment scheme. The bin size is 33, and hence we can distinguish plots with between 0 and 32 surviving trees above the threshold, those with between 1 and 33 surviving trees below the threshold, and those being 33 or more trees away from the nearest threshold.

Figure 2 shows little evidence of observed survival rates 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 survival rates in the linear payment scheme. If anything, there are more linear payment plots with just over 200 or just over 300 surviving trees than in the threshold payment treatment. And although there are more threshold payment plots with just above 100 trees surviving than linear payment plots, the former are also quite over-represented in the range just below the threshold of 100 surviving trees.

Visual inspection of the distributions in Figure 2 thus suggests that the threshold group payment scheme was not effective in preventing the number of surviving trees falling below the various thresholds. Plots in the threshold group payment treatment are

[9] In 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.

Figure 2: The distribution of observed survival rates in the linear and threshold payment schemes, vis-à-vis the payment thresholds.



not more likely to have surviving tree numbers in the terciles just above a threshold (up to 32 above the threshold) than linear group payment plots. Only 33% of the plots in the threshold payment scheme have surviving tree numbers in the terciles above any of the thresholds, compared to 39% in the linear payment scheme ($p = 0.729$, according to a χ^2 test).

Not having been able to stay above the threshold does not necessarily mean that the groups in the threshold payment scheme have not tried it, and maybe they were unlucky with their tree survival rates just falling below a threshold. So are the plots in the threshold group payment treatment are 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 payment scheme?[10] We find that 68% of the threshold payment plots ended up with surviving tree

[10] If 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 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 the marginal benefits of maintenance effort are very low. Direct financial incentives to keep threes alive are also zero in the bottom tercile (the one

numbers in a tercile just above or just below any of the three thresholds, compared to 52% of the plots in the linear 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.

6 Supporting evidence from a laboratory experiment

We thus find supporting evidence for both mechanisms proposed in Section 4 as to why the linear group payment scheme was found to give rise to significantly higher survival rates than the threshold group payment scheme. Maintenance groups in the threshold group payment scheme may have been too late in establish 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) information on survival rates made it more difficult to coordinate, and given that participants reported that cooperation improved over time, (ii) the thresholds ultimately resulted in more cooperation, but too late to actually improve survival outcomes.

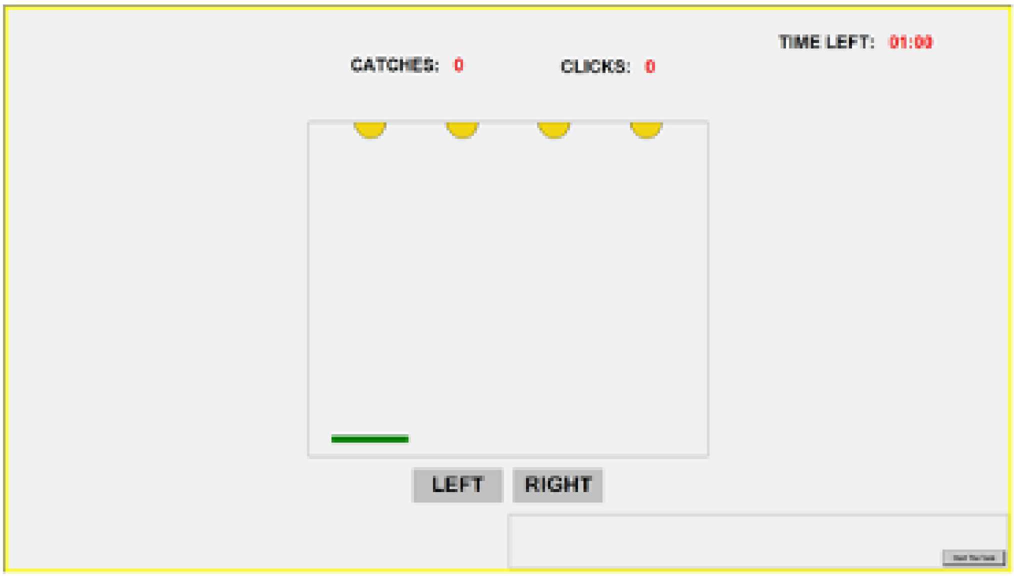
To complement the insights from the field experiment, we implement a laboratory experiment that mimics some of the essential features of the field, while allowing for monitoring of changes in cooperation over time as well as manipulating the amount of information participants have on real-time survival 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" suitable as a workhorse for a variety of (individual and multi-person) experimental paradigms, including social dilemma games. Real effort games have the advantage of increased realism to the interaction while still maintaining considerable control over the (material) costs of effort.

The ball-catching task as developed by Gächter *et al.* (2016) is as follows. In the task, a subject has a fixed amount of time to catch balls that fall randomly from the top of the

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 payment plots should be overrepresented.

screen by using mouse clicks to move a tray at the bottom of the screen. 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 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: Screen shot of the ball-catching task as developed by Gächter *et al.* (2016).



6.1 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 Payments without Information); one trial task was followed by three paid tasks. The money earned in each of the three paid tasks depended on the number of balls caught in the last period of the task. Because balls that are not caught in one period were not dropped in the next, payments were thus based on the total number of balls surviving all three periods of the task.

In the linear 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 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 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 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 x $(50h + 25)$.Whether or not the threshold group payment treatment results in higher survival rates than the linear 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 implemented three tasks, each lasting three periods. We thus have information on 1152 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, within parentheses, the total number of observations (over all periods, tasks and subjects) in each of the four treatments in the laboratory experiment.

Threshold	**Information**	
	Yes	No
Yes	360	252
No	252	288

(a) Subject - Period - Task level

Threshold	**Information**	
	Yes	No
Yes	10	7
No	7	8

(b) Group level

6.2 Results of the laboratory experiment

We first check whether there are any treatment differences between the threshold and linear 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 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	75.524	0.501
	(2.574)	(3.459)	
No	73.417	71.625	0.663
	(3.360)	(2.465)	
p-value	0.859	0.351	

Notes: We report standard errors in parantheses

To uncover any differences in the underlying dynamics, we run panel 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: 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***	137.8***
	(9.446)	(8.120)
Period 2	-37.17***	-47.57***
	(3.862)	(4.213)
Period 3	-51.96***	-62.62***
	(4.374)	(3.923)
Threshold	13.13	-7.286
	(12.89)	(10.93)
Threshold × Period 2	-6.976	14.40***
	(5.078)	(4.617)
Threshold × Period 3	-16.80**	4.486
	(6.027)	(5.999)
Observations	135	153
Adjusted R^2	0.543	0.549
Task FE	Yes	Yes

Robust standard errors clustered at the group level.
The participants' characteristics controlled in the regressions include gender, age, and land area.

Column (1) of Table 6 thus presents the outcomes of the linear and threshold 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 same information when this information is provided. Because the linear 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. Column (2) of Table 6 presents the outcomes of the linear and threshold payment games when subjects are informed of the total number of balls caught in the previous period of the current task.

We find the following. As shown in column (1) of Table 6, average group effort in the linear group payment treatment starts at between 130 and 140 clicks in the first period of a task in that treatment, and subsequently falls quite substantially over the remaining periods of the task. This is in line with the self-assessed development of cooperation in the linear group payment treatment in the field; if survey respondents stated that group effort changed over time, the change was in most instances negative – cooperation was perceived to worsen (see Table 3). Column (1) of Table 6 also shows that group effort in the threshold group payment treatment is not significantly different from that in the linear payment treatment, except for the third and last period. Without information threshold payments are thus unlikely to be able to sustain cooperation above and beyond that in the linear 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 this information does not increase effort; if anything, learning how much effort the rest of the group did in the previous period (and presumably comparing it to one's own effort in that 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 information is provided in a task (i.e., in period 2), as it results in a significant 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.

Adding up the relevant coefficients implies that effort is decreasing over time in the threshold payment group too, but less fiercely so than with the linear payment scheme in place. We thus find that providing information on current conservation levels (compared to the nearest threshold), does result in an increased effort to prevent crossing that next threshold.

7 Conclusions

In this paper we tested whether threshold group payments give rise to better conservation outcomes than linear group payments. We show that making 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. We embed a Randomized Controlled Trial in a large-scale reforestation project in rural Burkina Faso, and test whether threshold group payments give rise to higher tree survival rates than linear payments. The results of our study are surprising as we find evidence for the opposite – actual trees survival rates turn out to be higher with linear than with threshold group payments. 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 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 with threshold payments initial survival rates are lower but that they are also declining less fast over time than in the linear payment scheme. The laboratory experiment also provides (suggestive) evidence for the claim that threshold payments might have outperformed the linear 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 payments were less effective than linear payments, more field tests (possibly with group sizes larger than the five persons per group in our RCT) are needed to determine whether threshold payments are inferior to linear payments, and to further improve our understanding of the underlying dynamics.

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Appendices

A Theoretical predictions

Consider a group (or community) consisting of $n > 1$ individual members, who are identical in all respects. The group is offered financial compensation depending on the number of trees that are still alive at a specific future date (i.e., at endline), and which 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 amount of money B the group is entitled to is thus $B = B(Q)$, and 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.[11]

Group members can increase the tree survival rates by putting in effort, but (bad) luck may also affect tree survival. Without loss of generality, we assume that it takes one unit of effort to keep one tree alive, and also 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 costs of effort of keeping tree alive are a quadratic function of effort and are equal to $0.5cz_i^2$.

The amount of payments (B) a group receives at endline depends on the number of trees that are still alive at that moment (Q). The linear group payments scheme pays an amount $B = bQ$ with b denoting the group's payment per tree that is still alive at endline. With threshold group payments, the amount received by a group depends on whether the number of trees still alive is larger or smaller than a threshold level.

[11] This is unlikely to be the case in the real world. But then it is also true that these non-monetary benefits are likely to be independent of the financial payment scheme in place. That means that including non-monetary benefits would affect the number of trees still alive at endline, but not the difference therein between the two payment schemes.

Using $h = \{0, 1, \ldots, H\}$ to enumerate thresholds from lowest to highest[12] and using 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.[13] To ensure payoff equivalence between the linear and threshold group payment schemes, we set group payments B_h such that, for all $h = \{1, 2, \ldots, H\}$, they are the same as the (unweighted) average payments in the linear 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 that the linear and threshold payment schemes can be made (ex-ante) payoff equivalent by setting

$$B_h = b(h + 0.5)\frac{\bar{Q}}{H+1} \quad \forall \quad h = \{0, 1, ..., H\}. \tag{A1}$$

For a graphical representation of the linear and threshold 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 payoff function is then

$$\pi_i = B/n - 0.5cz_i^2, \tag{A2}$$

with $B = bQ$ or, if $Q_h \leq Q < Q_{h+1}$, $B = B_h$ – 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 ($A = 0$),

[12] Note that we allow h to have value 0, even though strictly speaking $h = 0$ is not a threshold. This facilitates notation in the remainder of this Appendix.

[13] With $\bar{Q} = 500$ trees and $H = 4$ thresholds, the threshold levels are at 100, 200, 300 and 400 trees.

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

A.1 The case of $A = 0$

Let us 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 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 $z_L^{D,SO} = b/(nc)$. Taking into account that $Q \leq \bar{Q}$, the socially optimal and Nash equilibrium group effort levels are

$$Z_L^{D,SO} = min\left[\ \frac{nb}{c}, \bar{Q}\ \right] \tag{A3}$$

and

$$Z_L^{D,NE} = min\left[\ \frac{b}{c}, \bar{Q}\ \right], \tag{A4}$$

respectively.

Equations (A3) and (A4) indicate that the choice of $\bar{Q}$ (relative to n, b and c) is not innocuous. For the linear payment scheme to be a social dilemma in the deterministic case, we need to have that $\bar{Q} > b/c$ (see (A4)), and preferably we would set $\bar{Q} = nb/c$ (see (A3). While we can choose b and n ourselves, we have no information on 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 ($h \geq 1$) should be an equilibrium of the threshold 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 $\bar{Q} > b/c$, $\bar{Q} \leq \frac{2}{3}\frac{nb}{c}(H+1)$ and $\bar{Q} > 2b(H+1)/(nc)$, we have $\frac{2}{3}\frac{nb}{c}(H+1) \geq \bar{Q} > max\left[\frac{b}{c}, \frac{2(H+1)}{n}\frac{b}{c}\right]$. Regarding the RHS of this condition, our RCT's parameterisation of $H = 4$ and $n = 5$ implies that we have $2(H+1) > n$, and hence the above boils down to the following condition:

$$\frac{2}{3}\frac{nb}{c}(H+1) \geq \bar{Q} > \frac{2(H+1)}{n}\frac{b}{c}. \tag{A5}$$

We assume that condition (A5) holds throughout the remainder of this analysis. So how likely is it that it also holds in our RCT? 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 payment scheme (which equals b/c), implying a survival rate of less than 50%. And regarding the first inequality in (A5), 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 (A5) is very likely to be met in practice. Or, in words, the parameters are chosen such that (i) the linear payment scheme poses a social dilemma, (ii) it may be optimal for an agent to independently supplement the efforts by others to reach the next threshold, but not to

[14] This can be inferred as follows. Suppose that $Z_{-i} = (\frac{h+1}{H+1})\bar{Q} - \nu$, where ν is infinitely close to zero. Agent i can ensure private gains equal to $\frac{B_{h+1}}{n} - \frac{B_h}{n} = \frac{b\bar{Q}}{n(H+1)}$ 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 $B_{h+2}/n - 0.5c\big(\frac{\bar{Q}}{(H+1)}\big)^2 \geq B_{h+1}/n$. Using (A1) 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 $\frac{b}{n}\frac{\bar{Q}}{H+1} < 0.5c\big(\frac{\bar{Q}}{H+1}\big)^2$, or $\bar{Q} > 2b(H+1)/(nc)$.

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. As shown by equation (A2), threshold payments B_h increase linearly with the threshold reached, while the costs of the required effort increase quadratically. That means that the socially optimal threshold in the deterministic case, $h^{D,SO}$ (which may be equal to 0), is the one where the group is better off at $h = h^{D,SO}$ than at $h = h^{D,SO} + 1$:

$$B_{h^{D,SO}} - 0.5c\sum_{i=1}^{n}\left(\left(\frac{h^{D,SO}}{H+1}\right)\frac{\bar{Q}}{n}\right)^2 > B_{h^{D,SO}+1} - 0.5c\sum_{i=1}^{n}\left(\left(\frac{h^{D,SO}+1}{H+1}\right)\frac{\bar{Q}}{n}\right)^2. \quad \text{(A6)}$$

Because costs are quadratic in effort, group benefits are maximized if each agent puts in $1/n^{th}$ of the total amount of effort needed to reach threshold h $\left(i.e., \left(\frac{h}{H+1}\right)\frac{\bar{Q}}{n}\right)$. Substituting (A1) into (A6) and solving, the socially optimal threshold equals

$$h^{D,SO} = \left\lfloor \frac{nb}{c\bar{Q}/(H+1)} - \frac{1}{2} \right\rfloor, \quad \text{(A7)}$$

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 (A5). 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 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 (A3) into (A7), the socially optimal effort level with threshold payments is at the highest threshold equal to or below the linear 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 $\left(\frac{h}{H+1}\right)\bar{Q} > Z_{-i} \geq \left(\frac{h-1}{H+1}\right)\bar{Q}$ individual i is willing to put in $z_i = \left(\frac{h}{H+1}\right)\bar{Q} - Z_{-i} \geq 0$ if $B_h/n - 0.5c\left(\left(\frac{h}{H+1}\right)\bar{Q} - Z_{-i}\right)^2 \geq B_{h-1}/n$. Solving and focusing on the set of symmetric equilibria, we find that all

$$h^{D,SO} = \left[0, .., h^{D,MAX}\right] \quad \text{with} \quad h^{D,MAX} = \left\lfloor \sqrt{\frac{2(H+1)}{\bar{Q}} \frac{nb}{c}} \right\rfloor \tag{A8}$$

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 $\sqrt{\frac{2(H+1)}{\bar{Q}} \frac{nb}{c}} \geq h^{D,MAX} \geq \sqrt{\frac{2(H+1)}{\bar{Q}} \frac{nb}{c}} - 1$ (with at least one of the inequalities being strict), a sufficient condition for the threshold group payment scheme to outperform the linear payment scheme is that $\left(\sqrt{\frac{2(H+1)}{\bar{Q}} \frac{nb}{c}} - 1\right)\frac{\bar{Q}}{H+1} > \frac{b}{c}$, or

$$\sqrt{\frac{2(H+1)}{\bar{Q}} \frac{nb}{c}} > 1 + \frac{b}{c} \frac{(H+1)}{\bar{Q}}. \tag{A9}$$

The closer $(H+1)/\bar{Q}$ is to zero, the more likely it is for (A9) to hold. Using (A5), we know that if (A9) holds for $\frac{H+1}{\bar{Q}} = \frac{3c}{2nb}$, it holds for all $(H+1)/\bar{Q}$ that satisfy (A5). Substituting $\frac{H+1}{\bar{Q}} = \frac{3c}{2nb}$ into (A9) and solving yields the condition that $n > \frac{1.5}{(\sqrt{3}-1)}$, and this condition is indeed met for our parameterization.[15] So if condition (A5) is met and absent any uncertainty regarding the relationship between effort and the number of trees surviving, survival rates are predicted to always be higher with threshold group payments than with linear group payments.

[15]To verify the claim that the threshold payment scheme outperforms the linear payment scheme for all values of $\bar{Q}$ that meet (A5) if the condition holds for the upper bound value of (A5)), we check whether it also holds for $\bar{Q}$ at the lower bound of (A5): $\frac{H+1}{\bar{Q}} = \frac{nc}{2b}$. Substituting this value into $\sqrt{\frac{2(H+1)}{\bar{Q}} \frac{nb}{c}} > 1 + \frac{b}{c} \frac{(H+1)}{\bar{Q}}$ and solving, we have that $n > 2$. As $\frac{1.5}{(\sqrt{3}-1)} > 2$, we have that $n > \frac{1.5}{(\sqrt{3}-1)}$ is indeed a sufficient condition for (A9) to hold.

A.2 The case of $A > 0$

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. In that case we have $Q \in [Z - A, Z + A]$, with $A > 0$. Given profit function (A2) (which 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 (A5) continues to hold, the aggregate Nash equilibrium effort level with linear payments is equal to

$$Z_L^{U,NE} = \frac{b}{c}, \tag{A10}$$

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 $\left(\frac{h}{H+1}\right)\bar{Q} > Z_{-i} > \left(\frac{h-1}{H+1}\right)\bar{Q}$. The private decision problem for an individual agent to contribute to reaching the next threshold is then whether $P\left(Q \geq \left(\frac{h}{H+1}\right)\bar{Q}\right)B_h/n + \left(1 - P\left(Q \geq \left(\frac{h}{H+1}\right)\bar{Q}\right)\right)B_{h-1}/n - 0.5cz_i^2 > B_{h-1}/n$, or, using (A5),

$$P\left(Q \geq \left(\frac{h}{H+1}\right)\bar{Q}\right)\frac{b}{n}\frac{\bar{Q}}{(H+1)} - \frac{c}{2}z_i^2 \geq 0. \tag{A11}$$

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

$$z_T^{MAX} = min\Bigg[\bigg(\frac{h}{H+1}\bigg)\bar{Q} + A - Z_{-i}, z^{Risk}(h)\Bigg]. \tag{A12}$$

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

$$P\Bigg(Q \geq \bigg(\frac{h}{H+1}\bigg)\bar{Q}\Bigg) = \frac{1}{2A}\int_{\frac{h\bar{Q}}{(H+1)}}^{Z+A} 1 \quad dv = \frac{1}{2A}\Bigg[Z + A - \bigg(\frac{h}{H+1}\bigg)\bar{Q}\Bigg]. \tag{A13}$$

Substituting $E(B) = P\Bigg(Q \geq \bigg(\frac{h}{H+1}\bigg)\bar{Q}\Bigg)B_h - \Bigg(1 - P\Bigg(Q \geq \bigg(\frac{h}{H+1}\bigg)\bar{Q}\Bigg)\Bigg)B_{h-1}$ into (A2), setting the first derivative equal to zero and assuming symmetry, the maximum amount of effort member i wants to put in to increase the probability of passing the next threshold is $z^{Risk} = \frac{1}{2A}\bigg(\frac{\bar{Q}}{H+1}\bigg)\frac{b}{nc}$. That means that, using (A12), we have $z_T^{U,MAX}(h) = min\Bigg[\bigg(\frac{h}{H+1}\bigg)\bar{Q} + A - Z_{-i}, \frac{1}{2A}\bigg(\frac{\bar{Q}}{H+1}\bigg)\frac{b}{nc}\Bigg]$. Focusing on the set of symmeteric equilibria, we thus have

$$z_T^{U,MAX}(h) = min\Bigg[\frac{1}{n}\Bigg(\bigg(\frac{h}{H+1}\bigg)\bar{Q} + A\Bigg), \frac{1}{2A}\bigg(\frac{\bar{Q}}{H+1}\bigg)\frac{b}{nc}\Bigg]. \tag{A14}$$

From (A14) 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 (A14) it is clear that only the lowest thresholds (such as $h = 0$ or $h = 1$) may be met with certainty; higher thresholds may still be achievable, but only probabilistically. That means that (A14) implies that $h^{U,NE} = \big[0, .., \lfloor \frac{1}{2A}\frac{b}{c} \rfloor\big]$ 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 payments than with linear payments? If A is such that it is optimal to eliminate all risk, threshold payments still outperform the linear payment scheme. If A is such that eliminating all risk is not an equilibrium for any of the thresholds, the maximum aggregate effort equals $Z_T^{U,MAX} = \left\lfloor \frac{1}{2A} \frac{b}{c} \right\rfloor \frac{\bar{Q}}{H+1} \leq \frac{1}{2A} \frac{b}{c} \frac{\bar{Q}}{H+1}$. 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 $A > \frac{1}{2} \left(\frac{\bar{Q}}{H+1} \right)$. 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 $\left(Z \in \left[\left(\frac{h+0.5}{H+1} \right) \bar{Q}, \left(\frac{h+1}{H+1} \right) \bar{Q} \right] \right)$ does not guarantee that h is achieved with certainty, aggregate effort is lower than the Nash equilibrium effort level with linear group payments.