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Evaluating the permanence of forest conservation following the end of payments for environmental services in Uganda

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Abstract

A cluster randomized controlled trial evaluating a Payments for Environmental Services (PES) conservation program in Uganda that ran from 2011 to 2013 found that the program reduced deforestation from 9.1 percent tree loss in the control villages to 4.2 percent tree loss in the treatment villages. This study looks at the longer term impacts using satellite images collected nearly four years later. It finds that deforestation resumed among former PES recipients once payments ended. The rate of deforestation among former PES recipients was slightly lower than among control group member, so that the gap in forest cover (and, hence, in carbon emissions) between former PES recipients and control group members persisted, and even grew slightly larger—treatment villages did not *catch up* with the control villages in terms of deforestation. This indicates that the delay in carbon emissions *during* the program has continued. The cost-effectiveness of PES as a means of reducing carbon emissions depends crucially on whether, or to what extent, the reduction in deforestation proves long lasting. Under the observed trends, PES is estimated to have a benefit-cost ratio of about 15.

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1. Introduction

Payments for Environmental Services (PES) programs have become a common approach to forest conservation, often with World Bank support. These programs make conditional payments to landholders who conserve forests or other environmentally-desirable land uses, thus encouraging them to do so. PES programs are generally intended to be long-term programs, as the incentive they provide to conserve would cease when payments do. But what happens if payment do cease, by design or because of insufficient funding?

A cluster randomized controlled trial evaluating the Budonga-Budoma PES conservation program implemented in Hoima district and northern Kibaale district in Uganda from 2011 to 2013 found that the program reduced deforestation substantially: from 9.1 percent tree loss in the control villages to 4.2 percent tree loss in the treatment villages. This effect size is equivalent to an increase in tree cover, relative to the control, of 5.5 ha per village, or 0.33 ha per private forest owner (PFO), resulting in a delay in the emission of 184 metric tonnes of carbon dioxide (tCO_2) per eligible forest owner (Jayachandran and others, 2017).

This result suggests that PES can be a very cost-effective means of reducing deforestation and avoiding carbon emissions. The same study shows, however, that the program's cost-effectiveness depends crucially on whether, or to what extent, the reduction in deforestation proves long lasting. If treated forest owners resume typical deforestation rates without 'catching up' on foregone deforestation, the program's benefit-cost ratio would be 14.8. Conversely, if they 'catch up' on foregone deforestation within 4 years, the benefit-cost ratio drops to 2, and if treated forest owners engage in a surge of deforestation immediately after the program ends, then program benefits would be less than program costs.

In this paper, we return to the same study site using satellite imagery from December 2016 to assess whether the forest area that was conserved under the PES program remained conserved three years once payments ceased, and if not the rate and extent to which deforestation occurred. To our knowledge, no study of the permanence of the results of a conservation-oriented PES program has ever been conducted.[1] The only assessments of the permanence of PES impacts have been in the context of programs focusing on restoration.[2] These assessments have found that land use changes induced by PES persisted after payments ended (Pagiola and others, 2016a, 2016b). However, restoration-oriented PES projects are qualitatively different, so these results cannot be applied to conservation-oriented programs.

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[1] Grosjean and Kontoleon (2009) assess the long-term permanence of China's Sloping Land Conversion Program, but use stated preference techniques to try to predict whether the program's effects would prove permanent, rather than observations of actual post-program behavior.

[2] Most PES programs focus on conservation: they pay landholders to preserve existing forest (or other valuable natural ecosystems), under the assumption that forests are less profitable than alternatives, and thus would likely not be conserved in the absence of PES. Other PES programs focus on restoration: they pay landholders to restore or establish forest, and usually focus on land uses that are expected to be more profitable to landholders than alternative practices (such as agroforestry or silvopastoral practices), and usually only provide short-term payments. Wunder (2005) calls programs that focus on restoration "asset-building", in contrast to "use-restricting" conservation-focused programs.

It is important to bear in mind that this study is does not conduct an impact evaluation per se, but rather assesses the extent to which that impact proved to be long lasting ('permanent'). We use the same treatment and control groups as in the original study, and measure forest cover changes in the same way.

2. Assessing the impact of payments of environmental services

In a PES program, landholders are offered payments conditional on conserving or restoring their forests or other valuable ecosystems (Wunder, 2015; Engel and others, 2008). The basic theory of change is that payments induce conservation by increasing the returns that landholders receive from forests relative to those of alternative land uses. Participants only receive the payments once tree cover has been verified.[3]

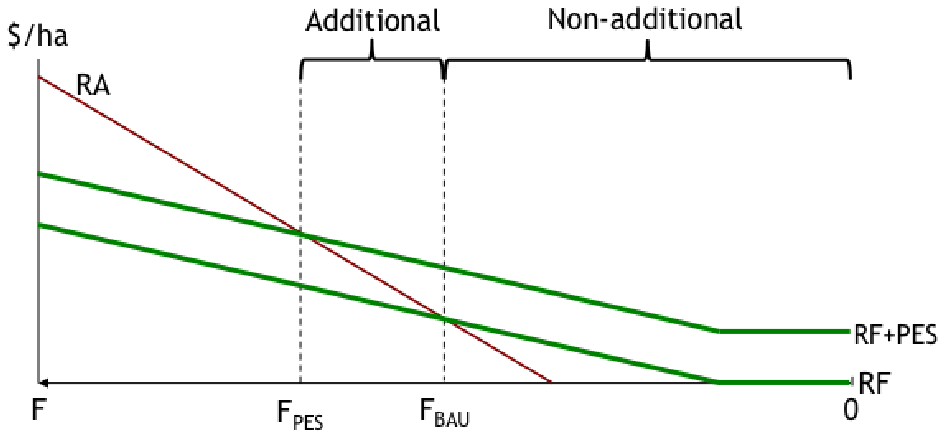

Figure 1. Effect of PES on deforestation

Figure 1 uses a simple von Thunen diagram to illustrate the logic of PES. The RF curve shows net returns (or 'rents') to landholders from conserving forests, which might include sustainable harvest activities such as collection of non-timber forest products or firewood. The RA line shows returns to landholders from agricultural uses of the same land. Traditionally, the horizontal axis represents distance from the city center, in order to capture the idea that rents to agriculture are higher near major markets, but it can also represent other characteristics which monotonically decrease profitability, such as land slope. Landholders would tend to deforest where returns to agriculture exceed those of conserving forests: in other words between F (the edge of the forest frontier closest to markets) and F_{BAU}, where BAU refers to "business as usual." A PES payment would increase the net benefits that landholders receive from forests, as shown by the RF+PES line. A greater number of landholders would thus find it to be in their interest to conserve forests, reducing the area of deforestation decreases to just F to F_{PES}. Thus, by offering PES, the expected deforestation is reduced by the amount of F_{BAU}–F_{PES}.

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[3] As such, PES is very similar to a Conditional Cash Transfer (CCT) program conditioned on conservation rather than education or health.

The original study confirmed this hypothesis: it found that forest owners who received payments to conserve their forests did so, reducing their forest cover loss significantly compared to forest owners in the control group.

PES programs are an increasingly important tool for forest conservation and restoration, including in many World Bank and FCPF projects.[4] As with many other conservation instruments, there has been considerable debate as to the effectiveness of PES in reducing deforestation (Ferraro and Pattanayak, 2008; Pattanayak and others, 2010; Miteva and others, 2012; Börner and others, 2017). Only a few impact evaluations have been conducted to date, however, generally using matching techniques to construct a control group (Sills and others, 2008; Arriagada and others, 2012; Honey-Rosés and others, 2011; Alix-Garcia and others; 2012; Robalino and Pfaff, 2013), but in one case using a regression discontinuity approach (Alix-Garcia and others, 2018).

These analyses have focused on whether PES programs have proven to be *additional*: that is, to have resulted in higher levels of forest conservation than would have occurred in the absence of the PES program. As shown in Figure 1, payments offered to forests to the right of F_{BAU} would go to forests that would have been conserved even in the absence of PES, and so would not result in any additional forest cover (nor, consequently, in any additional environmental services).

Beyond additionality, a key concern of conservation-oriented PES programs is whether forest conservation will persist after payments end: whether the program's effects will be *permanent*.[5] The logic of PES suggests that once payments cease, forests would once again be less profitable than alternative uses, and so would likely no longer be conserved.[6] Conservation-focused PES programs generally avoid this problem by making PES contracts renewable indefinitely. For many reasons, however, payments may not in fact persist. In some cases, funding is simply insufficient to allow contracts to be renewed[7]; in others, changing program priorities may result in some of a program's contracts not being renewed. Likewise, for programs that rely on prioritization criteria to choose their participants, a changing mix of applicants may result in some prior participants not being able to renew their contracts. The question of permanence is, thus, a common one for conservation-oriented PES programs.

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[4] Projects with PES components are currently under implementation in Brazil (Espírito Santo, São Paulo), Colombia, Mexico, Nicaragua, Ghana, Madagascar, and Albania, and are under preparation in other countries. Several BioCarbon Fund projects also rely on PES to achieve their objectives. PES programs are also being considered by many countries being supported by the Forest Carbon Partnership Facility (FCPF).

[5] We use the term "permanence" as it is the term used in the carbon sequestration literature.

[6] Indeed, a finding that former participants continue conserving forests even after payments cease would suggest that the PES program had lacked additionality: that the forests are not in fact less profitable than alternative land uses and so would have been conserved even without PES. This could be the case either because forests are in fact sufficiently valuable to landholders (for example, they may be the sources of a variety of products such as timber, fuelwood, or forage, or may protect water sources that the landholders themselves depend upon) or because the alternative land uses are very unprofitable (for example, if soils are poor, slopes are steep, or plots are very isolated).

[7] Because of government-wide budget cuts, for example, funding for Mexico's PES program fell from over USD50 million a year in 2016 to less than USD16 million in 2017, which reduced annual enrolment (including renewals) from almost 600,000 ha to less than 170,000 ha.

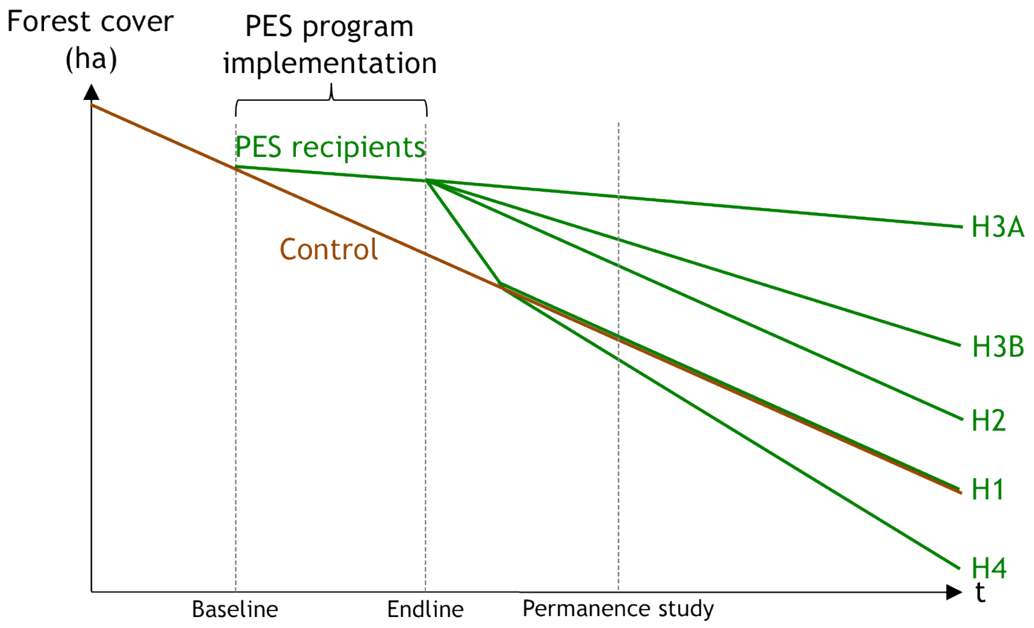

Figure 2: Possible post-PES scenarios

Our hypothesis is that previously treated forest owners will resume deforesting after payments end. We wish to confirm this but also, and most important, assess *how* permanence fails. Several hypotheses of how forest cover may evolve after payments end are possible, as illustrated in Figure 2 below, which depicts forest cover in the treatment and control groups (vertical axis) over time (horizontal axis):

- Former participants may 'catch up' the foregone deforestation, and may do so quickly or slowly (H1) so that after a few years they are indistinguishable from the control group.
- Former participants may simply revert to the previous rates but without 'catching up' the foregone deforestation (H2), in which case there is a 'permanent' delay in deforestation. Even that difference would have a big impact on economic returns to PES programs.
- In a best-case scenario, participation in a PES program changes forest owners' conservation behavior, so that they continue conserving even once payments cease. A strong form of this hypothesis is that they now conserve as much as during the PES program (H3A); a weaker form is that they conserve less than during the PES program, but more than prior to the PES program (H3B).[8]
- In a worst-case scenario, former participants catch up on foregone deforestation and then continue deforesting at a higher rate than prior to the PES program (H4).[9]

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[8] This change in behavior may result from changes in perception of the value of forests, or from the cash income from PES allowing participants to invest in more sustainable land uses or in non-farm activities.

[9] This may occur if participation in PES 'crowds out' any conservation motivation that landholders might have had, so that they now expect to be paid even for conservation they previously undertook on their

The cost-effectiveness of conservation-oriented PES programs depends heavily on which of these scenarios is realized. An improved understanding of permanence' could affect both the design of PES programs and the decision to adopt them in the first place. It is currently thought that conservation-oriented PES programs require long-term payments, which restricts their application. A finding that impacts are at least partly permanent would relax this restriction, while a finding that participants immediately revert to past behavior and 'catch up' on foregone deforestation would confirm it, and may lead to other instruments being preferred when long-term funding is not available. A finding that participation in PES 'crowds out' conservation would lead to PES having to be used with great caution.

3. Study context

Forests cover an eighth of Uganda's land area, concentrated in the western region. Uganda's annual deforestation rate between 2005 and 2010 was 2.7 percent, the third highest in the world (FAO, 2010). The pace of deforestation is even faster on privately-owned land, which represents about 70 percent of Uganda's forests (NEMA, 2008). As in much of Africa, the main drivers of deforestation in the study region are subsistence agriculture and domestic demand for timber and charcoal (Fisher, 2010).

The Budonga-Budoma Program was among the first PES programs in Africa. It was designed and implemented by the Chimpanzee Sanctuary and Wildlife Conservation Trust (CSWCT), a Ugandan non-profit organization, and implemented in 60 villages in Hoima district and northern Kibaale district in western Uganda. As in much of Africa, the main drivers of deforestation in the study region are subsistence agriculture and domestic demand for timber and charcoal (Fisher, 2010). Trees are often sold by eligible PFOs to timber and charcoal dealers and feed into a national market, with much of the end use in urban areas.

To participate in the program, CSWCT offered PFOs 70,000 Ugandan shillings (UGX), or approximately USD28 (in 2012 prices), per year per hectare of private forest on the condition that they cease deforesting. Participants had to enroll all their primary forest. The PES project lasted two years, from 2011-2013, and cash was paid out at the end of each year. Community monitors employed by CSWCT were responsible for assessing PFO compliance with the contract. Altogether, 180 PFOs in the study sample enrolled in the PES program, corresponding to 32 percent of eligible PFOs in the sample in treatment villages.

4. Experimental design and data

The Budonga-Budoma PES Program was the first conservation PES program to be evaluated using a randomized controlled trial (RCT). 121 villages were randomly assigned to 60 treatment and 61 control villages. All treatment villages received the same PES program. See Jayachandran and others (2017) for full details.

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own initiative, or if cash income from PES allows participants to deforest more rapidly (for example, by buying chainsaws).

For the original study, two types of data were collected, at baseline in 2011 and endline in 2013. First, high-resolution satellite imagery (taken by the QuickBird satellite) of the study region was procured. On average, the program had been in place for 1.5 years at the time of the endline satellite imagery. Second, a quantitative survey instrument was administered to the sample of private forest owners. The satellite images were used to construct the primary outcome: area of tree cover.[10] The quantitative survey was used for secondary outcomes such as self-reported tree-cutting, activities related to the forest such as patrolling it and granting others' access to it, and proxies for well-being such as consumption and child health.[11]

For this study, forest cover in December 2016—three years after the PES payments ceased—was analyze, using a newly acquired set of satellite images. This satellite imagery included 2-m spatial resolution multispectral (blue, green, red, and near infrared bands) imagery from GeoEye 1 and WorldView 3 satellites. Input imagery covered an area of 1,054 km^2 and it was organized in 6 mosaics. All processing was carried out at the mosaic level. The mosaics were subsequently combined together to create a wall to wall map of the study area.

The imagery was used to create a very-high resolution tree cover map (see Appendix Figure 1). For this purpose, we applied a region growing algorithm (region-based segmentation). Region growing procedures group pixels into larger regions based in predefined criteria for growth. The approach starts with a set of seed pixels to which adjacent pixel are appended based on some predefined characteristics. In our case, both seeds and regions were defined based on multispectral criteria. These criteria were grounded on a training dataset created from visual interpretation of multi temporal very high-resolution data (Google Earth) and reinforced by visual interpretation of Sentinel 2 imagery for the period. The region growing process was followed by a series of morphological operations (erosion-dilation) to further refine tree cover mapping.

Clouds and cloud shadows introduce noise and can compromise the automatic detection of tree cover in the satellite imagery. Thus, previous to tree cover mapping, clouds and cloud shadows were masked out in successive and separate region growing procedures based on a single spectral band (blue band for clouds and NIR for cloud shadows).

Tree cover information for areas covered by clouds and cloud shadows was obtained from a Sentinel 2 mosaic (10-m spatial resolution) for the study area using imagery from the same acquisition window as the VHR dataset and applying a supervised

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[10] We do not use the restricted definition of forest based on a minimum contiguous area covered by trees, as we are interested in the total effect on tree cover, inclusive of possible shifting of tree-clearing from 'official' forest to other land.

[11] Surveyors for the original study's survey were carefully screened and underwent two weeks of training, on the specific survey instruments, on the ethics of human subjects research, and on general tips to improve the quality of data collection. The surveyors worked in small teams, each with a supervisor who was available to answer questions. 'Back-checkers' did second visits to some households to double-check a subset of questions to ensure that the surveyors were collecting data accurately. A field research assistant who oversaw the fieldwork checked the data daily for to ensure data quality. The census was collected on paper and then transcribed. The baseline and endline surveys were collected using smartphones. No additional surveys were conducted for this study.

classification approach (classification tree). Additionally, a similar approach was implemented to mask out vegetated surfaces (wetlands) that due to spectral similarities could not be precisely separated in the VHR dataset.

Finally, while the baseline and follow up images were taken at different times of the year, the impact of seasonality is limited since trees, given their deeper radical system, have normally access to ground water resources and have a more stable phenological cycle throughout the year. Tree cover is the study area fall into the medium altitude–moist evergreen and semi-deciduous forest categories and a large proportion of their trees have leaves throughout the year. As a consequence, the spectral signal of the trees is sufficiently different from those of other vegetated surfaces even in the dry season and thus seasonality should not have a major impact in the quality of the tree cover map. In any case, program impacts are measured as differences in tree cover between treatment and control villages, and thus rely on images taken at the same time across villages.

As shown in Appendix Table 1, the characteristics of the households at the time of the baseline household survey were balanced across the treatment and control villages. In levels, the mean (median) self-reported land area owned per PFO was 10.8 (5.3) ha, and the average forest area 2 ha. Given the USD28 per ha payment, PFOs were eligible to receive, on average, approximately USD56 per year for conservation, equal to 5 percent (16 percent) of mean (median) annual household income. The original study also demonstrated that there was no selective attrition on a range of baseline variables.

5. Empirical Strategy

We follow the same empirical strategy as in the original study and estimate intent-to-treat (ITT) parameters for changes in forest cover since baseline, both at the village aggregate level and the PFO level. We estimate the following ordinary least squares regression to quantify the impacts of the PES program:

$$\Delta TreeCover_j = \alpha + \beta Treat_j + X_{1j} \cdot \delta + X_{2j} \cdot \mu + \varepsilon_j. \quad (1)$$

The outcome is the change in the area of tree cover between baseline and the 5.5 year follow up in village *j*. The regressor of interest is *Treat*, which equals 1 in the treatment villages and 0 in the control villages. We control for the vector X_1, which encompasses variables related to the stratification procedure, in all specifications: subcounty fixed effects and four village-level variables used to balance the randomization: number of PFOs, average household earnings per capita, distance to a road, and average land size. In addition, we include (village aggregate) baseline forest cover of sampled PFOs in all estimations to improve precision.[12] X_2 are additional control variables we include in our preferred specification, namely 1990 and 2010 Landsat-based measures of photosynthetic vegetation to control for any pre-trends in deforestation and dummy variables for the date of the baseline satellite image. We also examine heterogeneity by several baseline characteristics.

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[12] The original study results are not affected by this inclusion: original coefficient estimates are nearly identical and generally measured with (marginally) more efficiency. Results are available on request.

For efficiency, we weight the regressions by the proportion of the land that is visible in the image (as opposed to cloud-covered). In essence, we have an aggregate outcome (total trees on the whole parcel of land) and have a sampling rate that varies across forest owner. Here, the sampling rate is not a choice by the data collectors, but is caused by cloud cover. In such a scenario, weighting by the sampling rate improves efficiency. The estimations are based on standard errors clustered by village.

We also estimate regressions where the unit of observation is the PFO, using a proxy for the land owned by the PFO.

6. Results

Most of the baseline satellite images were taken in May-June 2011, whereas the most recent images were taken in December 2016, a difference of approximately 5.5 years. We first present the village-level results, which are the preferred results because they account for any within village level spillovers. Since baseline, forest cover in the control villages declined by 46.6 percent (a change of 0.629 log points), equivalent to an annualized rate of deforestation of 7.2 percent.[13] As shown below in Table 1, this is slightly higher than the rate of deforestation limited around the sampled PFO homes.

Table 1: Longer-term effects of PES program on village tree cover, from baseline (2011) to follow-up (2016)

Variables	(1) *Change in village tree cover (ha)*	(2) *Change in village tree cover (ha)*	(3) *Change in IHS village tree cover (ha)*
Treatment	31.485**	15.300	0.159**
	(13.920)	(10.186)	(0.075)
Observations	121	121	121
Stratification controls	Yes	Yes	Yes
Additional baseline controls	No	Yes	Yes
R-squared	0.257	0.683	0.408
Mean in the control group	-83.697	-83.697	-0.629

The point estimates in column 3 of Table 1 show that treatment villages have significantly more forest cover: 0.159 log points. This implies that forest cover in treatment villages declined by 37.4 percent, a (significant) difference of 9.2 percentage points with control villages, almost identical to the treatment effect at the sample PFO level, and equivalent to an annualized rate of deforestation of 5.9 percent since baseline. In other words, there is no evidence that within village displacement of tree cutting from the areas around the PFO homesteads is off-setting the PES program's permanent impact, just as there was no evidence of such displacement in the short-run analysis.

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[13] Note that in Tables 1 and 2 we compare the entire period from baseline (in 2011) to follow-up (in 2016),

Table 2 below shows the impact of the PES program on forest cover within the area around the homesteads of PFOs and explores heterogenous treatment effects.

Table 2: Long-term effects of PES program on PFO tree cover from baseline (2011) to follow-up (2016)

Variables	(1) *Change in PFO forest cover (ha)*	(2) *Change in PFO forest cover (ha)*	(3) *Change in (IHS) PFO forest cover (ha)*	(4) *Change in (IHS) PFO forest cover (ha)*	(5) Change in (IHS) PFO forest cover (ha)
Treatment	0.367*	0.416**	0.143**	0.139	0.136
	(0.193)	(0.186)	(0.069)	(0.095)	(0.137)
Treatment x had loan at baseline				-0.062	-0.120
				(0.071)	(0.074)
Treatment x opinion at baseline: deforestation causes problems				0.091	0.089
				(0.075)	(0.074)
Treat x Trusts fellow community members					-0.142**
					(0.069)
Treatment x Sold forest products					0.216***
					(0.076)
Treatment x Older than median age (45 years)					-0.072
					(0.075)
Treatment x Expenditure deciles					0.005
					(0.015)
Observations	995	995	995	993	992
Stratification controls	Yes	Yes	Yes	Yes	Yes
Additional baseline controls	No	Yes	Yes	Yes	Yes
R-squared	0.853	0.897	0.488	0.492	0.503
Mean in the control group	-1.855	-1.855	-0.492	-0.492	-0.492

Notes: Standard errors are heteroskedasticity-robust in all columns 1-3 and clustered by village. Asterisks denote significance: * p < .10, ** p < .05, *** p < .01. All regressions and means are weighted by the proportion of available tree-classification data for the observation. All columns include subcounty fixed effects, the four village-level baseline variables used to balance the randomization, and the PFO baseline forest cover. Columns 2, 3, and 4 also control for dummy variables for the date of the baseline satellite image, and for 1990 and 2010 area covered by photosynthetic vegetation within the PFO land circles.

The first two columns show the results in levels (hectares of tree cover), and the next two columns show the proportional effects. To interpret the proportional results, note that over this period, forest cover on the area around the homesteads of sampled PFOs in control villages declined by 38.9 percent (a change of 0.492 log points)[14],

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[14] Circles of land around the PFO homestead GPS location were drawn, equal to twice the size of the reported land area.

equivalent to an annualized rate of 6.1 percent per year. Column 3 shows the inverse hyperbolic sine (IHS) tree cover, which approximates the log function (and accommodates zeros, unlike the log function). Column 3 is our preferred specification because the levels estimations (columns 1 and 2) are by design more sensitive to the tails of the distribution, which capture the changes on the few very large private forest areas. The significant treatment coefficient point estimate in column 3 shows that sample PFOs in treatment villages have 0.143 log points more forest cover 5.5 years later. This implies that forest cover declined by 29.5 percent on sampled PFOs in treatment villages, a difference of 9.4 percentage points with control villages, and equivalent to an annualized rate of deforestation of 4.8 percent.

Column 4 tests for heterogeneous 'permanence' effects using interactions between treatment assignment and baseline characteristics, controlling for main effects. The PES program may have prompted PFOs with access to credit (72 percent of sample PFOs) to smooth consumption, for example when faced with a health shocks, by borrowing instead of cutting down trees to pay health bills; after the PES program, they may have persisted in this behavior, permanently reducing the rate at which they cleared forests. Thus, this access to credit might make scenario H3 more likely. Another hypothesis is that the PES program crowded out intrinsic motivation to preserve the forests, leading to scenario H4. We test this idea using PFOs' belief that deforestation has negative effects on their community (54 percent of sample PFOs) as a proxy for their initial intrinsic motivation. However, neither of these interactions are significant.

Column 5 expands the heterogenous effects, again controlling for main effects. The coefficients for the treatment interactions with loan and with attitudes toward deforestation remain insignificant. Of the newly added interaction terms, baseline consumption (as measured by expenditure deciles) and age (as measured by being above the median age of 45 years) also do not have a significant interaction coefficient estimates.[15] We do find that the positive treatment effect disappears among PFOs (54 percent of sample PFOs) who expressed trust in their fellow community members at baseline.[16] This finding is not the result of a differential treatment effect on trust overall. At the 2 year follow up survey, community trust levels remained identical between treatment and control PFOs. On the other hand, column (5) shows that there is a significantly positive (and large) interaction effect among PFOs (65 percent of sample PFOs) who sold forest products in the year prior to baseline. This result is intuitive, as the PES program will have substituted income from tree cutting to income from the PES program itself.

7. Discussion

The original study found that the PES program had reduced the rate of tree loss from 9.1 percent in control villages to 4.2 percent in the treatment villages after a period of 1.5 years, a difference of 4.9 percentage points. As expected, deforestation resumed after payments ended. By the time of the follow up, three years later, control

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[15] We do not test for gender as only 6 percent of household heads are female.

[16] The question was phrased a: "In general, would you say that most members of your community can be trusted? (Yes = 1)"

villages had experienced a cumulative 46.6 percent decline in forest cover since the baseline, compared with 37.4 percent in treatment villages (Figure 3). Table 3 shows these results in terms of annualized rates of tree loss. During the PES project, PES recipients deforested at an annual rate of 2.8 percent, compared to 6 percent for the control group. In the four years of the post-PES period, deforestation by former PES recipients accelerated again, at an annual rate of 7.4 percent, compared to 8.3 percent for the control group.

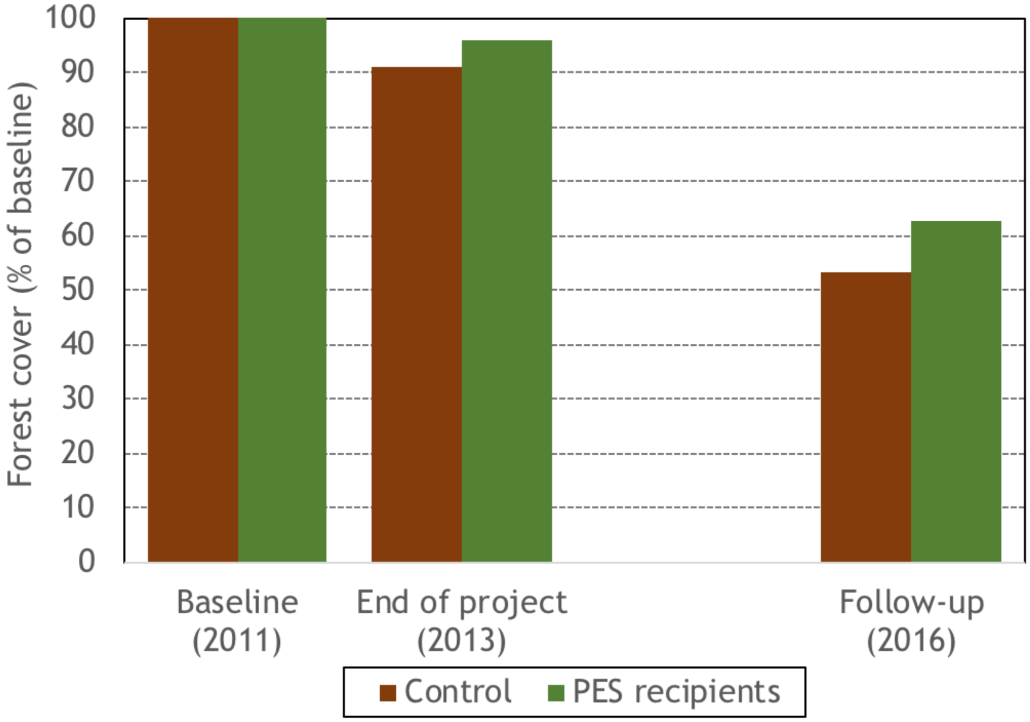

Figure 3: Loss of tree cover during and after the PES project

Table 3: Annualized rate of tree cover loss
(% per year)

Time period	*Control*	*Treatment*	*Difference*
Baseline – End of project (1.5 years total)	6.0	2.8	3.2
End of project - Follow up (4 years total)	8.3	7.4	0.9

These results show that former treatment villages resumed deforesting after the payments ended, but that they did not *catch up* with the control villages in terms of deforestation. In fact, the gap in tree cover between PES recipients and control villages has grown from 4.9 percentage points at the time payments ended to 9.2 percentage points at the time of the follow-up. Note, however, that we cannot statistically rule out that the gap simply persisted and did not grow. Thus, while the rate of deforestation by former PES recipients after the end of payments has become quite similar to that of the control group, a gap has persisted. In terms of the hypotheses set out in Figure 2, the results are closest to hypothesis H2 or H3B; the point estimates are suggestive of H3B, but we do not have the statistical power to distinguish between H3B and H2.

The original study presented several cost-benefit scenarios (Table 4). The best estimate of total program costs of averted emissions at scale-up—incentive payments to forest owners plus program administration costs—was USD0.46/tCO_2. We compared the amount paid to avert CO_2 emissions to the value of CO_2 benefits using the middle estimate of the social cost of carbon used by the United States Environmental Protection Agency (EPA) for 2012: USD39 per averted tCO_2 (in 2012 prices). Further, because the PES program was only in place for two years, our cost-benefit scenarios compared the effects representing different durations of a *delay* in CO_2 emissions.

Table 4: Cost-benefit analysis

Scenario	*Benefit (USD/tCO₂)*	*Cost (USD/tCO₂)*	*Benefit-cost ratio*
S1 (a). Base case: Program effects undone over 4 years	1.11	0.46	2.4
S1 (b). Program effects undone immediately	0.37	0.46	0.8
S2. Deforestation resumes at normal rate (permanent delay)	0.74	0.05	14.8

Source: Based on Jayachandran and others (2017).

Notes: This table compares the costs of the PES program to the social benefit of delayed CO_2. The base case assumes (i) an average 3-year delay in deforestation (treatment effects undone over 4 years); (ii) no further treatment effects during the 0.5 years between endline QuickBird data collection and program end; (iii) average time from tree-cutting to CO_2 emissions of 10 years; and (iv) a monitoring rate of 2 spot checks per monitor per day. Row 2 modifies (a) to assume a 1-year delay in deforestation (treatment effects undone immediately when the program ends). Row 3 modifies (a) to assume the averted deforestation and all subsequent deforestation are delayed by the 2-year duration of the program.

The results from our follow up study most closely resemble scenario 2: deforestation resumes at a normal rate (permanent delay) after the program ends, which has a benefit-cost ratio of 14.8. Note that for this scenario to indeed hold, the annualized rate of deforestation in treatment villages should not begin to exceed that of control villages in the years ahead. On the other hand, our finding that the annualized rate of deforestation between the endline in 2013 and the most recent follow up in 2016 continues to be lower between treatment than control indicates that the benefit-cost ratio of this scenario may actually be conservative still.

These results should not be interpreted as suggesting that offering only short-term payments in a conservation-oriented PES program is desirable. As can be seen in Figure 3, former PES recipients resumed deforesting following the end of payments. Although former PES recipients deforested at a slightly lower rate (relative to the control group) than prior to the PES program, forest cover fell rapidly. What these results suggest is that, when long-term conservation payments are for some reason not possible, short-term payments may be preferable to doing nothing.

These results thus do not modify the guidance that PES programs should generally continue payments indefinitely when the objective is long-term forest conservation. This is particularly true when watershed protection and/or biodiversity conservation are the primary desired benefits of conservation. However, when emissions reductions are the primary desired benefit, a short-term PES program may be preferable to doing nothing, as it would result in a permanent delay in emissions reductions. If the program's costs are sufficiently low, this delay might well be sufficient to make the program cost-effective even though deforestation resumes after payments end.

As with all studies, external validity must be approached with caution. The study area is not unusual in an African context, but is less representative of, say, a Latin American context, where 'villages' are not a significant mode of organization. The study area's deforestation rates appear high when compared to national rates, but are not unusual for areas with ongoing deforestation. The particular payment rules used by the PES program are within the range of those used by other such projects, but not identical. In particular, PES programs such as those of Costa Rica and Mexico offer much longer payment periods for forest conservation (5 years, renewable indefinitely) (Pagiola, 2008; Muñoz-Piña and others, 2008). If payments do affect perceptions of forest conservation (either positively or negatively, by 'crowding out' conservation motivations) or if they relax constraints to undertaking other activities (whether environmentally-benign or harmful), it is plausible that a longer exposure to payments would increase the magnitude of the effect. Caution is also warranted because this is the first evaluation of a PES program using an RCT, and this study would be the first to examine the permanence of a conservation-focused PES program.

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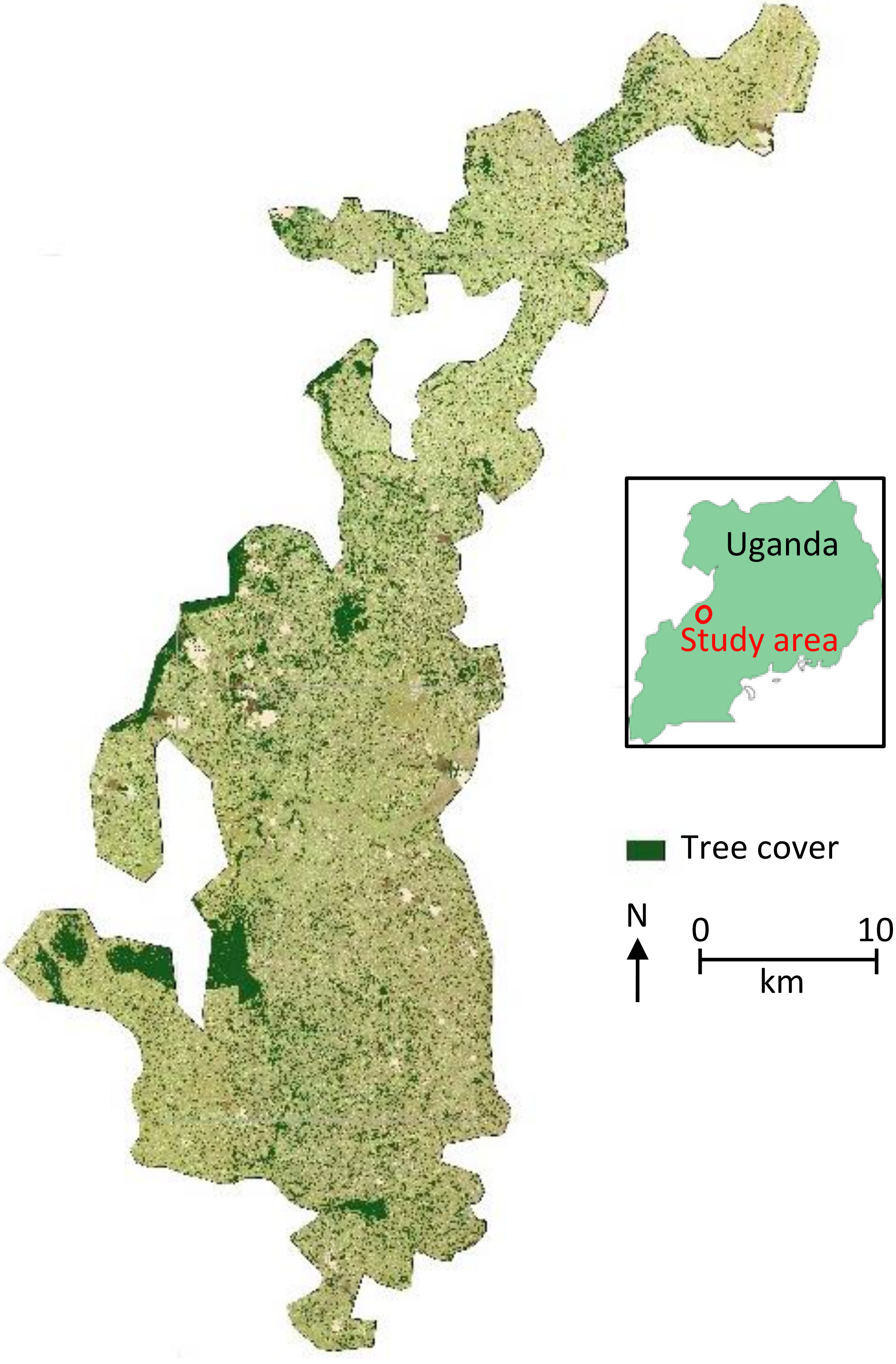
Appendix Table 1: Descriptive statistics of the households in the treatment and control villages and randomization balance

	Treatment	Control	Std. diff.
Household head's age	47.499	47.589	0.003
	[13.605]	[14.659]	
Household head's years of education	7.715	7.931	-0.056
	[4.003]	[4.187]	
IHS of self-reported land area (ha)	4.062	4.004	0.053
	[1.021]	[0.968]	
Self-reported forest area (ha)	1.727	2.068	-0.042
	[3.318]	[12.413]	
Cut any trees in the last 3 years	0.845	0.858	-0.031
	[0.362]	[0.350]	
Cut trees to clear land for cultivation	0.236	0.241	-0.016
	[0.425]	[0.428]	
Cut trees for timber products	0.704	0.721	-0.037
	[0.457]	[0.449]	
Cut trees for emergency/lumpy expenses	0.250	0.292	-0.088
	[0.433]	[0.455]	
IHS of total revenue from cut trees	1.238	1.397	-0.085
	[2.118]	[2.248]	
Rented any part of land	0.163	0.198	-0.091
	[0.370]	[0.399]	
Dispute with neighbor about land	0.218	0.206	0.035
	[0.413]	[0.405]	
Involved in any environmental program	0.100	0.111	-0.035
	[0.301]	[0.315]	
Agree: Deforestation affects the community	0.539	0.548	-0.014
	[0.499]	[0.498]	
Agree: Need to damage environment to improve life	0.064	0.043	0.089
	[0.245]	[0.204]	
Tree cover in land circle (ha)	4.355	3.845	0.050
	[12.466]	[9.178]	
Weighted tree cover in land circle (ha)	4.403	3.999	0.057
	[11.643]	[8.252]	
% of land circle with tree cover	0.199	0.209	-0.044
	[0.161]	[0.157]	
% change in vegetation, 1990-2010	0.035	0.037	-0.016
	[0.066]	[0.058]	
Observations (forest owners)	564	535	
Number of villages	60	61	

Source: Jayachandran and others (2017).

Notes: The table reports subsample means with standard deviations in brackets. The last column reports the regression-adjusted difference in mean between the treatment and control subsample divided by the pooled standard deviation, and an asterisk denotes that this difference has a p-value less than 0.10. The standardized difference and p-value are based on a regression with sub-county fixed effects, with clustering at the village level. IHS denotes the inverse hyperbolic sine transformation of the variable. Weighted forest cover is the mean weighted by the proportion of the forest owner's land with valid satellite data.



Appendix Figure 1: Tree cover in the study area at time of follow-up study

Appendix

All subjects provided informed consent to participate in the original study. For the original study, the project received ethical approval from the Uganda National Council for Science and Technology. UNCST approval covers the period of field activities in Uganda, from 2010 through 2013. When the project began, the lead PI (Jayachandran) was at Stanford University and the project was approved by Stanford University’s Institutional Review Board (IRB). After Jayachandran moved to Northwestern University in 2011, the project was approved by Northwestern’s IRB. Northwestern IRB approval is required throughout the period when data are analyzed and thus the project is currently covered by IRB approval and will continue to be so. We submitted a modification of the Northwestern IRB protocol to include the follow-up satellite imagery.