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Impacts of Mexico's payments for ecosystem services programme

October 2015

Impact Evaluation Report 20

Environment

International Initiative for Impact Evaluation

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List of abbreviations and acronyms

CONAFOR	National Forestry Commission (Comisión Nacional Forestal de México)
CONAPO	National Population Council (Consejo Nacional de Población)
CRP	Conservation Reserve Program
FCA	Forest conservation activities
ICC	Intra-cluster correlation
INE	National Ecology Institute (Instituto Nacional de Ecología)
LEDAPS	Landsat Ecosystem Disturbance Adaptive Processing System
NASA	National Aeronautical and Space Agency
NDVI	Normalized Difference Vegetation Index
PCA	Principal components analysis
PES	Payments for ecosystem services
PSAH	Payments for hydrological services (Pago por Servicios Ambientales Hydrológicos)
REDD	Reduced emissions from deforestation and degradation
SLCP	China’s Sloped Land Conversion Program
USGS	United States Geological Survey
VCT	Vegetation change tracker

Executive summary

This document summarizes current findings from an evaluation of Mexico's National Payments for Hydrological Services from 2003 to 2010, carried out by researchers at the University of Wisconsin-Madison, Duke University, and Amherst College. We thank the Mexican National Forestry Commission for generous sharing of data and time contributed to the project. Our evaluation seeks to understand the environmental and socioeconomic impacts of the program, with the goal of extracting lessons learned and identifying room for possible future improvement. This section summarizes our major findings and recommendations.

Mexico's federal payments for hydrological services program (PSAH) began in 2003 and pays landowners to maintain forest cover under five-year contracts. Between 2003 and 2011, the Mexican National Forestry Commission (CONAFOR) allocated approximately US$450 million to enroll more than 2.6 million hectares of land in the program. The goals of the PSAH program include "compensating land owners for the environmental services provided by their forest lands" (CONAFOR 2012), and in 2006 were modified to include poverty alleviation (McAfee and Shapiro 2010). Landowners may enroll a portion of their property and must maintain existing forest cover within the enrolled parcel, but can make changes to land cover in other parts of their property. Verification of forest cover is made by satellite image analysis or ground visits. Participants are removed from the program if CONAFOR finds deforestation due to conversion to agriculture or pasture within the enrolled area. Payments are reduced if forest is lost due to natural causes such as fire or pests (Muñoz-Piña *et al.* 2008).

Program overview and analysis of enrolment

Findings: An analysis of program selection criteria and the characteristics of lands enrolled suggests the program has met the dual goals of targeting funds to areas of ecological and social priority. Specifically:

- On average, land enrolled between 2004 and 2010 had similar risk of deforestation, higher hydrological priority, and similar degree of marginality to all forested lands in the country. That is to say, land which was enrolled was broadly representative of available land.
- Looking at the evolution of the program over time, targeting to high deforestation risk and more marginalized areas has improved substantially between 2004 and 2010 due to changes in the program rules and the eligible zones resulting in the selection of higher risk and more poor recipients from within the applicant pool.

Recommendations: One potential means of improving the ecological impact of the program would be to select properties with even higher risk of deforestation, as the average risk of deforestation among enrolled properties remains somewhat below the national average across all forested lands. Two possible ways to do this would be to target further on the basis of multiple characteristics which determine avoided deforestation (in addition to the National Ecology Institute's [INE] risk numbers) or to raise the payment amounts.

Environmental impacts

Findings: A comparison of forest cover across time between program beneficiaries and rejected applicants using coarse-resolution satellite data suggests that the program has significantly reduced forest loss compared to what would have been expected in the absence of the program.

Environmental impact using NDVI

- Both enrolled and unenrolled properties show decreases in normalized difference vegetation index (NDVI) over the period examined. However the program appears to reduce the temporal change in NDVI by around 62% relative to the counterfactual trend in the control group. This suggests that the program either reduces deforestation or degradation in enrolled properties, although it does not seem to entirely eliminate the overall downward NDVI trend.
- We find significant heterogeneity in avoided NDVI loss impacts, with larger impacts in communally held lands, on land of lower slope and closer to cities, and in less poor municipalities.

Recommendations: Together, these results indicate a moderate avoided deforestation impact, with room for stronger impacts through improvements in targeting of payments. Our analysis indicates only limited potential for changes in targeting that could produce more avoided deforestation without compromising social goals. Specifically:

- More avoided deforestation could be gained by additional targeting to high quality lands (for instance near urban areas and with lower slope), but these changes would likely make the program less progressive.
- More avoided deforestation might also be achieved by raising payments in order to induce enrollment of land at a higher risk of deforestation. This could increase positive wealth impacts but would mean higher payments to fewer individuals unless the program budget is also expanded.
- Our results indicate that one possibility for a "win-win" on both dimensions is additional targeting of payments to communally owned properties, which are poorer on average and also show higher avoided deforestation impacts. CONAFOR has already moved in this direction, and we recommend keeping this change.

Socioeconomic impacts

Findings: A comparison of household and community survey responses from 2008 beneficiaries and rejected applicants to the program suggests generally neutral or positive socioeconomic impacts of the program. Specifically:

Wealth impacts

- We find that all households on average are gaining in material wealth over time, but wealth increases for beneficiaries are not significantly larger than those for non-beneficiaries.

Labor, production, and credit impacts

- Overall, the program has not significantly affected agriculture or livestock livelihoods. The majority of beneficiaries originally employed in agriculture, livestock or forestry remain employed in those categories and the overall percentages of people employed in each sector are very similar across time.
- Production of food crops, including staple crops, does not decrease on average or show different general trends between beneficiaries and non-beneficiaries, suggesting that the program does not compromise food security.
- Both beneficiaries and non-beneficiaries show intensification of agriculture and rising value per hectare of production across time. Reported prevalence of land clearing for cultivation is also not significantly different across beneficiaries and non-beneficiaries.
- Livestock production trends are generally not significantly different between beneficiary and non-beneficiary households. We do however see an increase in the average number of livestock owned by beneficiary common property households, possibly indicating a positive impact on assets not captured by the previous analysis. Private property households overall showed decreases in livestock production and land used—but trends were very similar across beneficiaries and non-beneficiaries.
- With respect to investment and credit, we find tentative evidence that the program may have made credit more available for some households. There is less borrowing among private property beneficiaries, and we see some increased production of cash crops among poor common property households. Common property households who were not investing in new crops or livestock infrastructure at baseline are more likely to invest in 2011 if they were beneficiaries. The program appears to have helped *ejidatario* households in which the program funds were distributed as lump-sum transfers and private property households to keep their children in school longer.

Forest management impacts

- The program has clearly had a positive impact on the level and type of forest management implemented by beneficiary landowners, which is likely to improve ecological services.
- The program has increased training in forest management and activities devoted to forest management; such skill training is likely to have long-term benefits that extend beyond the program.
- The program has significantly increased the time spent in activities related to preventing and combating forest fires, patrolling against illegal logging and poaching, pest control, and erecting fences to limit access by grazing animals. The time dedicated to this work is likely to have long-term benefits for forest health.
- Rules governing forest use have increased over time, but households in beneficiary communities are only slightly more likely than households in non-beneficiary communities to feel that it is more difficult to access the forest than in the past.

Application and implementation costs

- Our survey data indicate considerable costs to applicants both from applying to the program and implementing forest management activities.
- Application costs are relatively small compared to the overall payments, but the full costs of additional labor used for implementation of forest management plans are large compared to overall payments.

Perceived benefits of the program

- Beneficiaries of the program were generally aware of the program and were positive about the perceived impacts of the program.
- Most beneficiaries perceive the main benefits of the program to be extra income/employment and support for forest conservation.
- A high proportion of both *ejidos* (federally recognized common property holdings with land tenure and governance rights granted to a set number of households) ,and private property beneficiaries reported that they would like to re-enroll in the program after the five-year contract is complete.
- Beneficiaries and non-beneficiaries alike are skeptical of the potential to directly sell ecosystem services to private parties when the program ends.

Recommendations: Although the lack of substantial increases in production or investment is somewhat disappointing from a poverty alleviation/income generation standpoint, it is reassuring that trends are generally similar between beneficiaries and non-beneficiaries. This suggests the program has not had negative impacts and has largely preserved livelihood strategies that would have been chosen in the absence of the program. It is also reassuring in terms of possible concerns about substitution slippage or "leakage" of deforestation to non-enrolled areas of the property (Alix-Garcia *et al.* 2012), since we don't see additional expansion of production that might require new clearing on other parts of the same properties. In addition, the results do give a clear indication that the program has been successful in promoting increased forest management activities and education and that beneficiary perceptions of the social and ecological impacts of the program are generally positive. These results suggest that continuation or expansion of the program without major changes is justified from both ecological and social standpoints.

The large estimates for labor costs involved in implementing forest management activities suggest that the costs of participation deserve more attention. While payments were originally justified on the basis of opportunity cost, the survey results suggest that the greatest costs to beneficiaries are due to the labor requirements of increased forest management. This may justify an increase in the size of payments in the future if budgets will support them. Program rules were changed in 2010 to decrease the amount and types of forest management required in order to decrease the beneficiary's labor costs, so it would also be important to evaluate whether these changes were successful before deciding on further action.

Further recommendations

The final section of the report focuses both on some of the questions brought up by CONAFOR during the course of the project, and technical challenges that we have faced.

Current payment scheme and opportunity costs: We consider the revenues per hectare in both agricultural and cattle-raising activities across the different forest types in our sample. Under the assumption that costs are distributed in similar ways across forest types, the current relatively high payments to mixed mesophytic forests are justifiable, though earnings appear to be much higher in coniferous regions relative to rainforest, which is in contrast with the current payment scheme.

Selection index and weighting: We observe that the selection criteria for PSAH have changed significantly over time, and note that it is difficult to establish the impact of so many changes happening both simultaneously and in consecutive years. Recent years have seen the addition of a significant number of environmental criteria. Under the current selection system, the importance of these far outweigh those given to criteria that correspond more closely to the stated goals of the program—poverty alleviation and avoided deforestation. This could undermine program effectiveness. We suggest an alternative weighting scheme that allows for the continued addition of individual targeting criterion without compromising program goals.

Challenges in satellite image interpretation: The availability of free satellite images covering the entire world presents a significant opportunity for researchers. In addition, new, higher resolution images are readily available for monitoring and evaluation of land-use change. However, our experience has shown that there are significant challenges to monitoring deforestation in mountainous, cloudy regions of Mexico. These are complicated by issues of phenology in areas with significant variation in forest type in small areas. Methodologies to resolve these issues are not yet available, and this will present a significant challenge to implementing REDD (reduced emissions from deforestation and degradation) type projects in tropical regions in the near future.

1. Introduction

1.1 Global importance of PES

Given the expected negative impacts of climate change (e.g. Schlenker *et al*. 2005; Tol 2009; Dell *et al.* 2012), policymakers have become increasingly concerned with the ex-post evaluation of policies which purport to mitigate greenhouse gas emissions (e.g. Martin *et al.* 2011; Li *et al.* 2013; Davis *et al.* 2013). Among the suite of options, policies for reducing emissions from deforestation and forest degradation, or REDD, have been a center piece of international climate change negotiations and are expected to play a significant role in reducing the approximately 20% of global emissions due to land-use change (Stern 2008; IUCN 2009; United Nations 2009). Future financial flows from developed to developing countries for REDD programs are predicted to be close to US$30 billion a year (UN-REDD 2011). To reach REDD goals, many countries will employ direct payments to landowners: Mexico, Costa Rica, Ecuador, and Brazil have already established national or state-level payments for avoided deforestation programs and others are experimenting with similar programs (Jindal *et al*. 2008; Wunder and Wertz-Kanounnikoff 2009; UN-REDD 2011). However, despite their popularity with policymakers, rigorous empirical evidence on the impacts of such Payments for Environmental Services (PES) programs is extremely limited.

Environmental services are the benefits provided by healthy ecosystems, including carbon sequestration, watershed protection, and biodiversity conservation. Although property owners benefit from environmental services, the majority of benefits accrue to external parties. This difference in private and social benefits results in a classic market failure: without changes in the structure of incentives, landowners will provide too few of these socially valuable services.

PES programs aim to correct this externality problem by giving payments or in-kind compensation to landowners in exchange for land-use practices that protect or enhance environmental services. They are a form of “incentive-” or “market-based” policy for environmental protection (Jack *et al.* 2008). In contrast with traditional command-and-control style regulations, incentive-based policies can broaden participation and increase the flexibility of environmental protection, often making them more cost-effective and politically feasible than traditional environmental regulation (Stavins 2003). PES programs have been implemented worldwide and continue to grow in scope and scale. Major national programs include the US Conservation Reserve Program (CRP) (Sullivan *et al.* 2004), China’s Sloping Land Conversion Program (Uchida *et al.* 2007), and national PES programs in Costa Rica and Mexico. There are also literally hundreds of individual community-scale projects worldwide (Landell-Mills and Porras 2002; Pagiola *et al*. 2005; Wunder 2008; FAO 2007).

1.2 Knowledge gaps

Proponents of PES argue that payments can induce landholders to change behavior and protect resources that would have been degraded. Skeptics contend that current PES programs pay landholders who would have undertaken conservation regardless of payments or whose low potential profits meant little deforestation risk. Section 2 reviews the relevant research findings to date. There has been no rigorous quantitative evaluation of the environmental effectiveness of Mexico's program and little assessment of similar programs. As highlighted by Pattanayak *et al.* (2010) and Wunder (2008), rigorous evaluations of PES programs are extremely limited, but essential for increasing the efficiency-scarce funds dedicated to conservation projects.

Although the primary goal of the PSAH program is to decrease deforestation, PES programs have also been promoted for their potential to increase incomes of the rural poor. PES has been widely promoted as an instrument for both environmental protection *and* poverty alleviation (e.g. Landell-Mills and Porras 2002; Turpie *et al*. 2008; Lipper *et al*. 2009). Hence, there has been significant discussion in the literature of potential poverty effects of PES programs. The presumed mechanism behind this assertion is either that payments exceed the opportunity costs of enrolling forested land, or that they encourage the development of alternative income sources. Much of this work has been well reviewed in Bulte *et al.* (2008), Lipper *et al.* (2009), and Palmer and Engel (2009). Earlier work has suggested that there are some potential situations in which the poor might benefit from PES and that there may be tradeoffs in targeting. However, robust conclusive evidence on either point is still lacking.

Our evaluation sheds new light on this question by carefully examining the potential socioeconomic and social benefits of Mexico's program. Mexico's PSAH program began in 2003 and pays landowners to maintain forest cover under five-year contracts. The assumption driving the program is that forest helps increase water infiltration and reduce the speed of runoff, thus leading to healthier watershed function. Between 2003 and 2011, CONAFOR allocated approximately US$450 million to enroll more than 2.6 million hectares of land in the program, making it one of the largest PES in the world, along with the US Conservation Reserve Program, China's Sloped Land Conversion Program (SLCP), and Costa Rica's Payments for Ecosystem Services Program. The goals of the PSAH program include "compensating land owners for the environmental services provided by their forest lands" (CONAFOR 2012) and in 2006 were modified to include poverty alleviation (McAfee and Shapiro 2010).

Landowners may enroll a portion of their property and must maintain existing forest cover within the enrolled parcel, but can make changes to land cover in other parts of their property. Verification of forest cover is made by satellite image analysis or ground visits. Participants are removed from the program if CONAFOR finds deforestation due to conversion to agriculture or pasture within the enrolled area. Payments are reduced if forest is lost due to natural causes such as fire or pests (Muñoz-Piña *et al*. 2008).

1.3 Evaluation questions

Given the gaps in understanding of both environmental and socioeconomic impacts of PES, the evaluation questions driving this study fall under three different headings: environmental effectiveness, socioeconomic impacts, and policy implications:

1) Environmental effectiveness: The primary goal of the PSAH program is to maintain forest cover in order to enhance hydrological services. Our evaluation therefore aims to answer the following questions:

a. Did property owners who received payments reduce their rates of deforestation on enrolled properties (compared to what would have happened if they had not received payments)?
b. How does the program's effectiveness in preventing deforestation vary according to the socioeconomic and geographic characteristics of the recipients, such as degree of initial levels of poverty, distance to markets, and private vs. communal land ownership?
c. Did the program cause significant displacement, or "leakage" of deforestation from enrolled properties to nearby un-enrolled properties, possibly undermining environmental benefits?

2) Socioeconomic impacts: Although the primary goal of the program is environmental, PES programs have been promoted in Mexico and elsewhere for their potential to improve incomes for rural communities, particularly for the rural poor. We therefore aim to answer:

a. Are there significant socioeconomic benefits of the program for participating communities or households?
b. How do program socioeconomic impacts vary according to such factors as region, initial levels of poverty, distance to markets, private vs. communal land ownership, and institutional capacity?
c. Are the observed socioeconomic and behavioral impacts likely to be sustained after payments end?

3) Policy implications: Mexico's program has the potential to serve as an important model for global efforts to scale up PES programs generally and as part of REDD initiatives. Our project therefore also seeks to respond to the following questions:

a. What does Mexico's experience suggest about meeting dual goals of environmental and socioeconomic benefits? Can PES improve the livelihoods of the rural poor while enhancing environmental services?
b. What does the observed heterogeneity of socioeconomic and environmental impacts suggest about possible targeting strategies? Do we see important tradeoffs from increased targeting on land quality, initial levels of poverty, or land tenure type?
c. What lessons can we draw from Mexico's experience for the design of international REDD agreements? For example, what do the costs of transacting with small landholders and of monitoring and evaluation tell us about the feasibility of other REDD programs? What do measured “leakage” amounts suggest about the advantages of national versus regionally targeted programs?

1.4 Study design

Mexico’s PSAH is not a randomized program, and was in fact well-established before we began our evaluation. Therefore, the study design used here is quasi-experimental and exploits the rather large pool of applicants to the program each year and the fact that there are more qualified applicants than available funding. To evaluate environmental and socioeconomic impacts of the program, we compare the behavior over time of program beneficiaries to matched applicants who were rejected from the program. A key advantage of using controls drawn from the applicant pool is that all owners have demonstrated their (otherwise unobservable) desire to enroll in the program, revealing that their expected participation costs are sufficiently low to motivate application, and perhaps that they share a “conservation oriented” inclination. However, even with program applicants as controls, there still may be other remaining characteristics which could be correlated with selection into the program and changes over time in deforestation. To address this problem, we investigated the selection process, pre-match data on the basis of relevant characteristics, and estimate panel regressions, including appropriate controls. Our preferred specification includes property-level fixed effects, in order to control for any unobservable fixed characteristics of the parcels.

In order to understand how PSAH participation affects forest cover (measured by the greenness of vegetation) we use new annual data on mean dry season NDVI from 2003 to 2011, and program data on applicants from 2004 to 2009. Poverty alleviation potential is assessed by analyzing municipal-level poverty for all applicants and new household survey data for 2008 applicants. Impacts are established by comparing changes in household consumption and investment decisions from 2007 to 2011 between recipients and matched rejected applicants. In order to assess the socioeconomic impacts of the PSAH program, we conducted a national-level field survey of a sample of beneficiary and matched non-beneficiary applicants from the 2008 program cohort. Surveys in communal properties were implemented with both heads of households and community leaders and with private property household heads. Case studies were also conducted in 18 of the survey sites with in-depth interviews conducted with CONAFOR employees, intermediary agents, and participants.

1.5 Overview and sources

This report is broadly divided into six sections, plus annexes, following the format suggested by 3ie. This section and the following provide an overview of the questions confronted by the evaluation, in addition to providing context for the policy intervention. Section 3 presents a theory of change that frames much of the analysis presented here. Section 4 shows a rather extensive analysis of the program rollout and targeting strategies over time. Much of the work in section 4 is taken directly from a working paper produced under the auspices of this project, entitled “Adaptive Management in Mexico’s Payments for Hydrological Services Program Improves Targeting for Environmental and Social Goals.” This paper is currently under revision. Section 5 shows the heart of the impact evaluation. The overall sections on environmental impacts and wealth tradeoffs come from a paper which is currently under revision, “Only one Tree from each Seed? Environmental Effectiveness and Poverty Alleviation in Programs of Payments for Ecosystem Services.” Subsequent parts of section 5, including many of the basic summary statistics, were first presented to CONAFOR in November in 2012, in a report entitled “Evaluation of CONAFOR’s Payments for Hydrological Services Program, 2003–2010,” which has subsequently been translated into Spanish. The sections on spillovers, also in section 5, are a combination of information that was published in *Land Economics* in 2012 (Alix-Garcia *et al.* 2012), and work in progress. Section 6 discusses policy recommendations that were given to CONAFOR in the 2012 report, in addition to challenges that we have confronted in the evaluation in general, which we hope will be of some use to policy designers of future PES programs.

2. Context

2.1 Program background

Annual payment rates for the cohorts we study (2004–2009) are given in Table 2.1. They correspond to approximately US$27 per hectare for general forest types and approximately US$36 for cloud forest. The initial rates were based on estimates of the average per hectare opportunity cost of growing maize. They have since been adjusted to match inflation and are currently set as a multiple of 6.5–8.5 times the federal minimum daily wage. Our survey data indicates that payments are significant in relation to income. On average, annual per capita payments for households in common properties were approximately US$130, which is greater than one month’s minimum wage. For private property households, the average per household payments were approximately US$3,050 per year, which is 12% of household income given the estimated income brackets of the private property households.[1]

Table 2. 1: PSAH payment rates per hectare 2004–2009 (in Mexican pesos)

Payment Rates	2004	2005	2006	2007	2008	2009
Rate per hectare cloud forest	400	400	413.70	429.85	447.02	465.80
Rate per hectare for other forest types	300	300	316.35	328.71	341.84 394.43 for oak forest	356.20 411.00 for oak forest
Daily minimum wage in the federal district	45.24	46.80	48.67	50.57	52.59	54.80

PSAH rates from 2006 onward are set using multiples of the minimum wage in the Federal District, at the rate of 8.5* min wage for cloud forest, 7.5*min wage for oak forest, and 6.5*min wage for other forest.

More than half of the program participants live in communally held and governed structures, including ejidos, which are federally recognized common property holdings with land tenure and governance rights granted to a set number of households, and *comunidades*, which are indigenous lands. The Mexican ejidos and comunidades resulted from the land reform that extended from the end of the 1910 revolution until the early 1990s. During this time, an area equivalent to half the country was redistributed (Assies 2008). Ejidos are composed of two different kinds of property rights over land: private parcels and commons. Private land is mostly used for agricultural activities, while the commons are mainly dedicated to pasture and forest. Many people who are not full ejido members live within these communities, usually descendants of the original members who

[1] The mean per capita payment in common property communities is 1,539 pesos. This was calculated taking into account the annual payment each community receives from the PSAH program, excluding payments for technical support. This number is a lower bound as it includes the total population in the community, including children and older adults. The final amount was converted to US$ using the exchange rate reported for July 15, 2011 (11.72 pesos/US$). The monthly minimum wage was calculated taking into account the daily minimum wage reported by CONASAMI. The average daily minimum wage in 2011 for the whole country was 58.1 pesos. Assuming 20 working days within a month, the monthly minimum wage is 1,161 pesos. Using the previous exchange rate, this is equivalent to US$ 99. For private households, the mean payment per year is 35,777 pesos. Given the exchange rate, this is equivalent to US$ 3,053. Since the survey does not have information about households' income, we use income data coming for the National Income and Expenditures survey (ENIGH), collected by INEGI in 2010, and assume that private households in our sample are located in the upper 3 deciles of the income distribution. According to ENIGH, the average quarterly income for the upper 3 deciles is 72,398 pesos, so an average annual income ~ 289,593 pesos. Therefore, the PSAH payments represent 12% of this total annual income.

are denied membership rights by the legal restriction on inheritance to only one child. Non-members do not formally have voting rights or land, but in practice they often farm on lands ceded by others or illegally taken from the commons. We may therefore expect possibly differential impacts on individuals with and without full membership rights to land. There is also likely to be significant heterogeneity depending upon the community-level decision of how payments are distributed within the common properties (see preliminary analysis by Yañez-Pagans 2013). Below we focus on average impacts on households and for differences between members and non-members, although some estimations will take into account differences in transfer schemes. Detailed modeling and analysis of possible internal community dynamics is left for future work.

2.2 Literature

Previous literature addressing the environmental effectiveness of national PES programs indicates small or modest benefits of these programs. Much of this literature focuses on the US Conservation Reserve Program, one of the earliest national-scale programs which directly incentivized individual landowners for conservation actions (Sullivan *et al*. 2004; Feng *et al*. 2005; Lubowski *et al*. 2006). Using a structural model and county-level data, Goodwin and Smith (2003) find significant reductions in soil erosion as a result of the US CRP. Previous studies on SLCP (Uchida *et al*. 2005; Xu *et al.* 2006) also indicate that programs in China have achieved significant soil conservation benefits on the basis of modeling using household surveys on participant behavior and targeting criteria.

Few previous studies directly evaluate effectiveness using a comparison group of properties to estimate what would have happened in the absence of the program (Pattanayak *et al*. 2010). When we began the study, the only evaluations of national PES programs using direct control group comparisons that we are aware of are from Costa Rica (Sills *et al*. 2007, 2008; Arriagada *et al*. 2008; Pfaff *et al*. 2009; Robalino *et al*. 2007; Sanchez-Azofeifa 2007). These studies generally find little or no impacts, possibly because the overall rate of deforestation slowed in Costa Rica around the same time that the program was introduced. An exception is new work by Arriagada *et al.* (2012) which indicates significant avoided deforestation impacts of Costa Rica's program in the Sarapiquí region, where deforestation rates were generally higher. Mexico, in contrast, continues to experience significant rates of deforestation (FAO 2005). The small number of studies which discuss Mexico's national payments for ecosystem services program (Muñoz-Piña *et al*. 2008; Alix-Garcia *et al*. 2005, 2008a,b; Corbera and Brown 2009; McAfee and Shapiro 2010) describe important debates and changes about targeting strategy but do not directly estimate program effectiveness by measuring deforestation and using matched controls. Other ongoing work in Mexico in this vein includes a new paper by Honey-Roses *et al*. (2011) which uses spatial matching to evaluate the effectiveness of payments coupled with protected area designation near a monarch butterfly reserve. The paper finds that these conservation measures resulted in additional protection of 3–16% of high quality forest habitat and 0–2.5% of lower quality forest.

Previous research on PES suggests significant heterogeneity in environmental effectiveness across space (Pfaff and Robalino 2012), and several papers have pointed out the potential theoretical irreconcilability between cost-effective avoided deforestation and poverty reduction if the forest at greatest risk is not owned by the poorest households.[2]However, actual evidence on household impacts or tradeoffs is limited, primarily due to data availability (see references in Uchida *et al.* 2009, Pattanayak *et al.* 2010; Arriagada and Perrings 2011). Previous work on SLCP, which pays for reforestation, does not suggest major tradeoffs between environment and development goals (Uchida *et al*. 2007, 2009; Gauvin *et al.*2010). Gauvin *et al.* (2010) comes close to this evaluation aims, but due to data limitations simulates the SLCP's ability to achieve both poverty and environment goals based on baseline profiles of beneficiaries versus non-beneficiaries. In contrast, our work evaluates results based on changes over time between enrolled and rejected applicants. In summary, the wealth impacts of payments for avoided deforestation programs have not yet been rigorously evaluated, nor compared to environmental impacts.

3. Theory of change

In order to illustrate the problem faced by the program managers in designing payments for avoided deforestation, we discuss a simple rent-driven model of land use (see,for example, Chomitz and Gray 1996;Samuelson *et al.* 1983;Pfaff 1999; Robalino 2007;Angelsen 2010;Pagiola and Zhang 2010; Pfaff *et al.* 2011). Figure 1 shows a graphical representation. Assume that there is a set of landholders, varying in land characteristics (q_i), where these represent geographic factors which decrease productivity and/or increase costs, such as slope, altitude, and distance to city. This metric is arranged along the x-axis such that the highest rents are to the left. Each landholder seeks to maximize rents and can choose to allocate his land to either agriculture or forest activities depending on the relative return to the two uses.[3] By assumption, returns to agriculture on high quality land are greater than returns to standing forest, while returns to forest on low

[2] These include: Pagiola *et al.* (2005), Pfaff *et al.* (2007), Alix-Garcia *et al.* (2008), Bulte *et al.* (2008), Jack *et al.* (2008), Zilberman *et al.* (2008), Leimona *et al.* (2009), Pattanayak, Wunder and Ferraro (2010), and Pfaff and Robalino (2012).

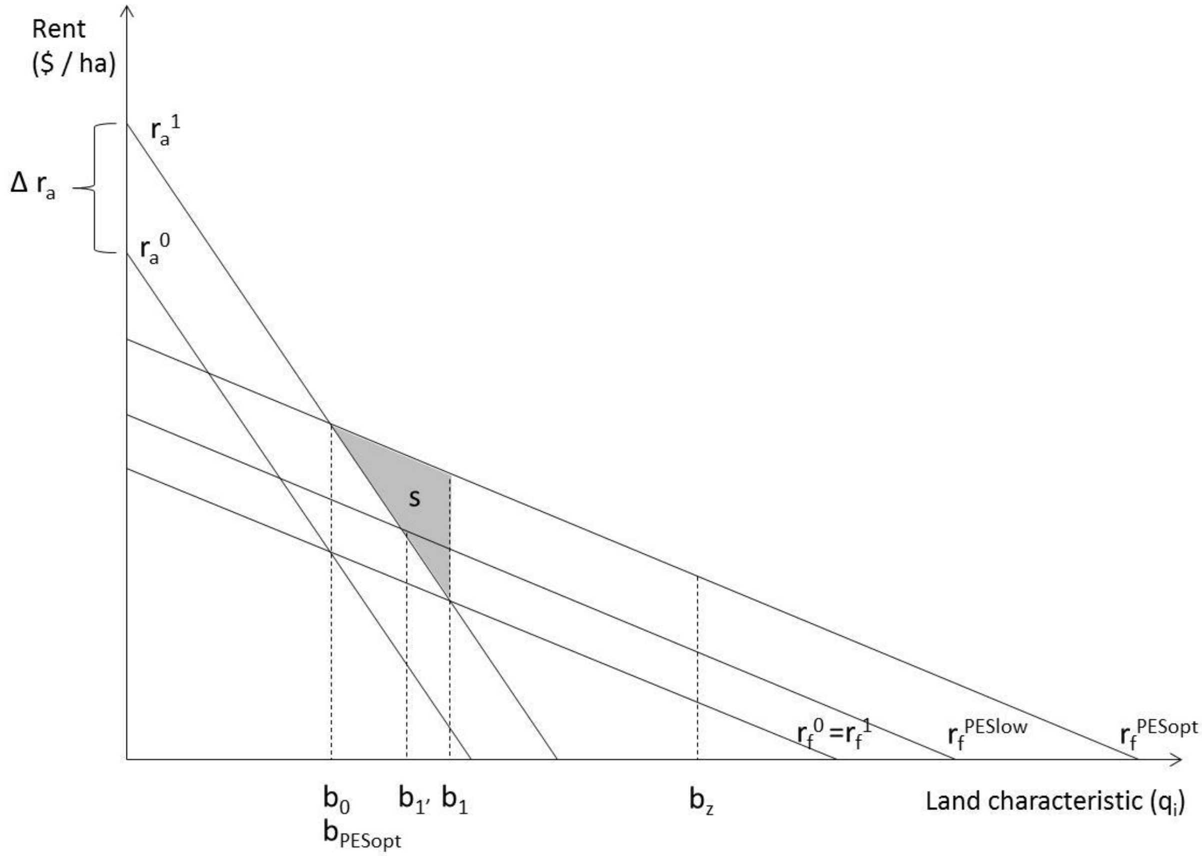
[3] Forest loss and degradation in Mexico are due to both human-induced change, primarily the expansion of agricultural or pastoral activities and logging, and to natural causes including fires, pests, disease, drought, and storm damage (Deininger and Minten 1999, 2002; Alix-Garcia *et al.* 2005; Bray and Klepeis 2005; Alix-Garcia 2007; Díaz-Gallegos *et al*. 2009). We prefer this model for simplicity but note that it emphasizes the agricultural and pastoral drivers of deforestation. Where illegal logging or natural causes of deforestation are significant, community decisions to protect forests may be also explained by the benefits generated by forest (including timber or non-timber forest products or local erosion control) relative to the costs of patrolling and maintaining the forest.

quality land are higher than for agriculture. At time t=0, the initial rent curve for forest is r_f^0 and for agriculture is r_a^0. The initial equilibrium agriculture-forest boundary point for each characteristic, holding the others constant, is at b^0, where agricultural rents equal forest rents. Land to the left of this point is in agricultural use and land to the right in forest use.

Deforestation between t=0 and t=1 is motivated by an increase in the rents to agriculture from r_a^0 to r_a^1 (for instance because of population growth or increasing consumption of land-intensive goods as the population grows richer). Without any policy intervention, the rent curve for agriculture shifts up and the agriculture-forest boundary point moves to b^1. Deforestation will happen on parcels between b^0 and b^1; these are the parcels "at risk."[4]

[4] We confirm the expected patterns using data from Mexico's Forest Monitoring. Probit models indicate that deforestation between 2003 and 2009 is indeed strongly predicted by slope, distance to the nearest locality with population greater than 5,000, and elevation with the expected signs.

Figure 1: Economic framework: rent model of PES



Graphical rent model. X-axis indicates land characteristics (q_i) which affect productivity and costs such as slope, altitude, and distance to city. Y-axis indicates rents from agricultural or forest land use.

3.1 PES payments and avoided deforestation

Now assume the regulator acts at time t=0 to combat this expected deforestation by offering to pay landowners who maintain forest cover. Assume that due to feasibility or political reasons, he can only offer a fixed payment amount for each hectare of land (as was the case in Mexico's PSAH program from 2003 to 2010). However, the regulator may establish "eligible zones" for the program in order to target high-risk areas. Looking at Figure 1, it is clear that in order to achieve full avoided deforestation, at least budgetary expenditure,[5] the regulator should choose a payment greater than or equal to the change

[5] Note that an efficient PES program would maximize environmental net benefits; these benefits might depend on land quality so full avoided deforestation might not be economically efficient. For simplicity, we assume uniform environmental benefits across land quality and focus on the cost-effectiveness of the program. Note however that cost-effectiveness cannot be assessed simply by comparing budgetary outlays to amount of deforestation avoided. The true costs of the program should include the administrative and transactions costs

in the agricultural rents (Δr_a) and should set eligibility from b^0 to b^1. Assuming that there is no leakage or slippage,the rent curve for forest would shift up to r_f^{PESopt} so that the boundary between agriculture and forest would remain at b^0.

From this framework we see that the key to gaining high environmental effectiveness at low cost is to enroll only the high risk of deforestation properties. To do this we need both adequate payments and properly targeted eligible zones. If payments are set too low, the regulator fails to attract land at high risk of forest loss (for example, the forest rent curve shifts up to r_f^{PESlow}, the agriculture-forest boundary shifts to $b^{1'}$, and avoided deforestation is only between $b^{1'}$ and b^1). If the eligible zones are too large (for example, between b^0 and b^z), then many payments will go to landowners who would not have deforested even in the absence of payments (those between b^1 and b^z).[6]

3.2 PES payments and socioeconomic gains

This framework also demonstrates that it is the underlying correlation between risk of deforestation and poverty which determines environment-development tradeoffs. First, if lower land quality or higher costs are correlated with higher poverty, then the land at highest risk of deforestation (b^0 to b^1) is owned by landowners in the middle of the wealth range. Therefore if regulators target to maximize environmental effectiveness –by setting the eligible zone b^0 to b^1– the poorest landowners are excluded from participation. Opportunities to improve environmental effectiveness and also participation by the poor exist only where poverty is not well-correlated with the risk of deforestation. In Mexico, two possibilities are given by variation in property rights and regional differences. Tenure arrangements are a complex function of historical developments (Alix-Garcia 2008b) not driven by geography alone. In our data, common properties show both a higher rate of deforestation and lower wealth than private properties. Regional variation also could provide scope for targeting if poorer regions have higher deforestation risk. Finally, if the correlation between deforestation threat and poverty is imperfect, the regulator can prioritize poor households within the set of properties with high deforestation risk.

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of running and participating in the program, and any distortionary effects of raising the program revenue on top of the opportunity costs implied by our diagram.

[6] Note that this model is consistent with previous empirical and theoretical research suggesting heterogeneity in PES impacts across space. Arriagada *et al.* (2011) find larger avoided deforestation impacts of Costa Rica's PES program in the Osa region, where threats to forest are high. Wünscher *et al.*'s (2008) simulation shows that the avoided deforestation benefits of PES in Costa Rica could be increased by targeting based on landowners' participation costs, with higher payments to attract those with larger costs. Consistent with this, Pfaff *et al.* (2011) find that efforts to better target Costa Rica's PES payments starting in 2000 did improve avoided deforestation impacts from 2000 to 2005. Alix-Garcia *et al*. (2012) find more avoided deforestation where baseline poverty rates are lower and Honey-Roses *et al*. (2011) find larger impacts of PES in protecting high quality habitat in the Monarca reserve.

This framework also implies a likely tradeoff between socioeconomic gains and environmental effectiveness. The surplus rent received by landowners equals (at most) the payments minus the opportunity cost of land use (transaction costs and maintenance costs lower the surplus). With the "optimal" PES policy (payments = Δr_a and an eligible zone from b^0 to b^1), the total surplus gained by landowners is thus triangle(s) in Figure 1. Note that the amount of surplus gained by individual landowners increases as rents decrease; so we expect to see greater socioeconomic impacts of the program where risk of deforestation is lower. More positively, this framework does imply that if rents are negatively correlated with wealth and there is a fixed per hectare payment, PES should be progressive within the set of households that do receive payments. With this simple framework in mind, we turn to the data on Mexico's program.

4. Program implementation

Mexico's PSAH differs from many of the interventions studied at 3ie, in that it has been in place since 2004. While this history reduces the opportunity to experiment within the program, it also affords us the insight of temporal trends from programmatic data to describe the interaction of changing program rules with outcomes. The program grants five-year renewable contracts to both individual and communal landowners. Landowners may enroll a portion of their property and must maintain existing forest cover within the enrolled parcel, but can make changes to land cover in other parts of their property. Verification of forest cover is made by satellite image analysis or ground visits. Landowners are removed from the program if CONAFOR finds deforestation due to conversion to agriculture or pasture within the enrolled area. Payments are reduced if forest is lost due to natural causes such as fire or pests (Muñoz-Piña *et al.* 2008). Mexico's PSAH program goals include "maintaining forest functions that provide environmental services" and "compensating land owners for the environmental services provided by their forest lands" (CONAFOR 2012). Starting in 2006, program goals were modified to include poverty alleviation in addition to environmental services (Shapiro and Castillo 2012).

4.1 Methods of analysis of implementation

Criteria for the selection of areas to enroll in the program have changed several times since 2003. To categorize these changes, we reviewed annually published rules of operation released by CONAFOR from 2003 to 2011. To understand what types of land were enrolled in the program, we constructed three samples of randomly selected points: (1) Points within enrolled PSAH properties; (2) Points within all forest areas across Mexico, as defined by INEGI's Series III vegetation layer; and (3) Points within rejected PSAH applicant properties. This enables us to assess how representative PSAH is of the universe of forested land in Mexico. Shapefiles of enrolled and rejected PSAH program areas for 2004–2010 and databases of program information were provided by CONAFOR. Forest type classifications were created from the INEGI's Series III landuse layer from 2002. Shapefiles used to create variables were provided by or sourced from INEGI, CONAGUA, INE, and CONABIO.

4.2 Selection criteria

Table 4.1 summarizes the enrollment criterion over time from 2003 to 2011. In addition to these criteria, properties enrolled in the PSAH program must be within eligible zones as determined by CONAFOR; these zones expanded considerably between 2004 and 2009, but are currently being prioritized and downsized (Figure 2). Prior to 2006, the primary criteria for selection were being located within an eligible zone and having the minimum percentage of forest cover. In the first three years of the program, total land area in the eligible zones was relatively small, requiring that enrolled areas be upstream from urban areas of >5,000 and be located on an overexploited aquifer. Given the high demand for the program and evolving priorities, in 2006 multiple social and environmental selection criteria (for example, degree of marginalization, female applicant, existing forest management plan, etc.) were added to refine the selection process. Applicants to the program were assigned points based on several criteria (Table 4.1). In the same year, the selection criteria for the eligible zones were also updated. Between 2006 and 2011, further selection parameters were added according to lessons learned and shifts in program mandates and priorities.

Table 4. 1: Selection criteria for PSAH program participants, 2003–2011, from the yearly program rules released by CONAFOR

* indicates a required criterion; □indicates an enrollment priority

Geographic Selection Criteria	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Within a protected natural area				□	□	□	□	□	□
Within zones related to water provision for urban centers with population >5,000 or within boundaries of CONAFOR priority mountains	*	*	*	□	□	□	□	□	
Within an area of high surface water scarcity				□	□	□	□	□	□

Located in an overexploited aquifer	*	*	*	□	□	□	□	□	□
Within area of high risk of deforestation as classified by INE				□	□	□	□	□	□
Area contains high biomass density determined by ECOSUR							□	□	□
Area has low rate of anthropogenic soil degradation							□	□	□
In a watershed where there are others with local payments for environmental services								□	□
Participant Selection Criteria	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
No active legal battle over enrolled land	*	*	*	*	*	*	*	*	*
Not enrolled in any other CONAFOR PSA programs				*	*	*	*	*	*
Priority to applicants with land of highest % forest cover	□	□	□	□	□	□	□	□	□
Applicant presents a forest management plan at time of application				□	□	□	□	□	□
Applicants in municipality with majority				□	□	□	□	□	□

indigenous population									
Applicants from marginalized areas defined by CONAPO				□	□	□	□	□	□
Applicant is a woman						□	□	□	□
Applicant presents a pending contract with an ecosystem service buyer				□	□	□	□	□	
Applicant submits with other owners whose lands are adjacent					□	□	□	□	
Land Requirements									
Land area	50–4000 ha			20–3000 ha			100–200 ha per individual; 200–3000 ha per community		
Forest cover	80%			50%					

Table 4.2 shows the total number of properties and area enrolled in the program across time as well as the number of rejected applicants and the area that they proposed to enroll.

Figure 2: PSAH eligible zones, 2004–2010

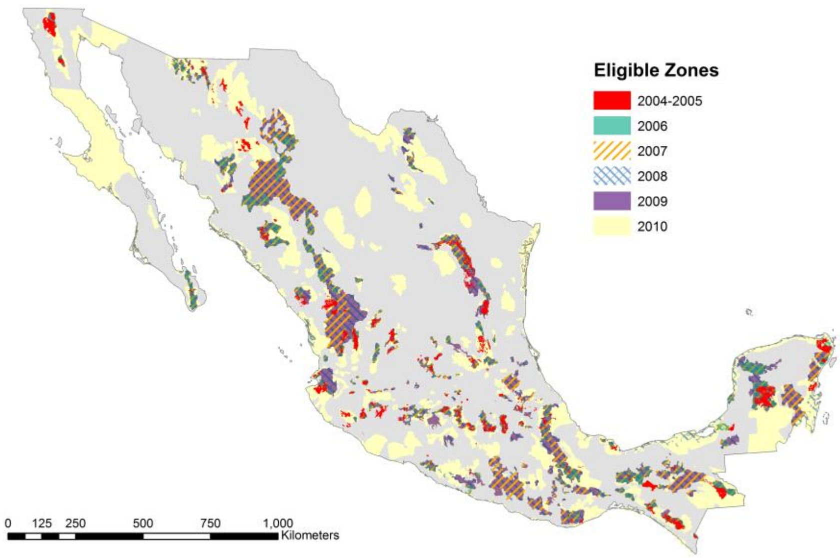


Table 4. 2: Total number of properties and land area enrolled in the PSAH program, 2003–2011, as indicated by yearly databases from CONAFOR

Year	Number enrolled	Area enrolled (ha)	5-year payments ($ MXN)	Number rejected	Area rejected (ha)
2003	271	126817.97	191999999.98		
2004	352	178676.17	288000000.00	209	256153.9139
2005	257	338045.15	515235160.43	226	212401.6118
2006	241	127015.76	204002584.94	380	492151.0063
2007	816	545576.96	925890661.30	889	878131.8602
2008	727	324154.77	662811103.64	2032	985468.0117
2009	410	320196.09	675478056.55	925	634332.5348
2010	688	508979.23	1116221417.27	1410	1196186.697
2011	217	195043.99	422569218.81	n/a	n/a
Totals	3979	2664506.09	5002208202.92	6071	4654825.636

There are three main reasons for rejection: (1) having all the qualifications but being rejected for lack of funding due to program budget constraints (~40% of sample); (2) failing to meet the geographic requirements, such as having less forest cover than is required or being located outside of the eligible zones (~30%); (3) lacking complete paperwork or necessary documentation (~30%). Some landowners choose to reapply in future years while others are rejected and do not reapply. We use these groups to test the robustness of our environmental impact results below.

4.3 Targeting for hydrological services and avoided deforestation

Table 4.3 shows the mean values for multiple land characteristics of the enrolled properties, all forested lands in Mexico, and rejected applicant properties from 2004 to 2010. The statistics clearly indicate that CONAFOR has been successful in targeting areas of particular environmental concern and with high demand for hydrologic services. Relative to all forested points, points within enrolled PSAH areas are more frequently located within overexploited aquifers, priority mountain areas, and protected natural areas. The mean surface water availability for PSAH points is .15 standard deviations lower than that for all forested points. In addition, PSAH points are on average located .15 standard deviations closer to localities with a population over 5,000, where demand for greater water availability and hydrologic services is likely higher (Table 4.3).

Means of these variables for the sample of points in areas that applied to the program but were rejected indicate that this successful targeting is occurring at two stages during the enrollment process: recruitment and selection. Rejected points are more frequently located within overexploited aquifers and protected natural areas than all forested points and have lower surface water availability, indicating that applicants to the PSAH program are already to some extent targeted on the basis of environmental criteria and demand for hydrologic services. Relative to rejected applicants, enrolled PSAH areas are even more frequently in environmental priority areas and have even lower surface water availability, indicating that targeting succeeds during this phase of the enrollment process as well.

Table 4. 3: Summary statistics for random samples of points within enrolled PSAH areas, all forests, and rejected PSAH areas, including the normalized differences between enrolled PSAH points and rejected and all forested points (program data from 2004–2010)

Variable	Mean for enrolled PSAH points (n=20037)	Mean for all forested points (n=44104)	Mean for all rejected points (n=26228)	Normalized difference (enrolled PSAH vs. all forested)	Normalized difference (enrolled PSAH vs. rejected PSAH)
Slope (grade)	12.1	10.3	11.9	0.136	0.020
Elevation (m)	1500	1160	1480	0.260	0.015
Surface water availability	6.84	7.18	6.88	-0.159	-0.017
Overexploited aquifer	0.156	0.074	0.114	0.183	0.088

Km to locality w/ op. > 5000	33.0	38.1	38.6	-0.144	-0.160
Risk of deforestation	2.49	2.85	2.40	-0.183	0.052
Priority mountain	0.255	0.068	0.112	0.371	0.266
Protected natural area	0.142	0.071	0.080	0.164	0.139
Municipal poverty index, 2000	0.264	0.239	0.251	0.017	0.008
Majority indigenous	0.375	0.248	0.244	0.196	0.202
Communally held property	0.878	0.604	0.812	0.465	0.130

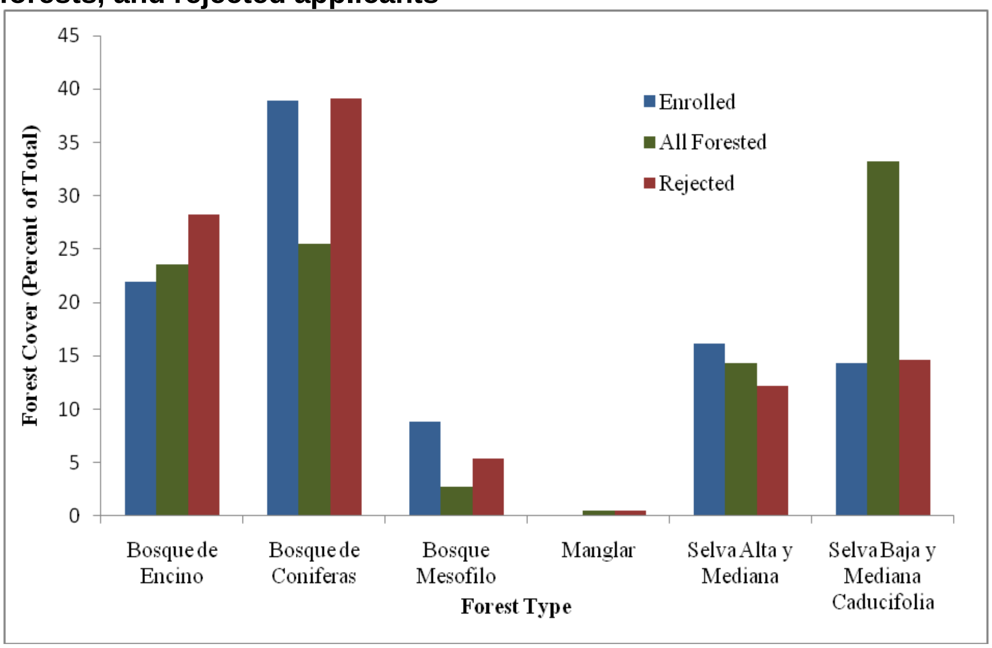
Targeting success on the basis of deforestation risk is less clear. The mean INE risk of deforestation for enrolled PSAH points is 2.49, which is significantly lower than the mean of 2.85 for all forested points. This value is, however, higher than the mean of 2.40 for rejected areas, suggesting that targeting on the basis of deforestation risk has been successful during the final selection of candidates. It is likely that some of the relatively low risk of deforestation for enrolled points may be due to poor recruitment in high-risk areas, possibly because payment rates are not currently high enough to attract the forest that has the highest risk of being converted to other uses. In addition, the INE classifications of risk of deforestation have only been used as a priority criterion for selection since 2006, so overall means for 2004–2010 obscure somewhat better targeting to high-risk areas in more recent years. It is important to note that this deforestation risk measure is somewhat noisy at the property level. Due to the increased difficulty of converting land to agriculture, grazing or forestry at higher slopes, land with higher slope and elevation may generally be at a lower risk of deforestation. Mean slope and elevation are higher for PSAH points than for both all forested points and points in rejected areas. It is possible that this selection of areas of higher slope and elevation may indicate a lack of good targeting to high-risk forests.

4.4 Targeting by forest type

Percentages by area of forest types enrolled in the PSAH program are generally comparable to the distribution of area for Mexico's forests as a whole, with bosque de encino (oak and pine forest) and bosque de coniferas (coniferous pine forest) composing the majority of both national forests and PSAH program areas (Figure 3). Relative to overall forests, the PSAH program has enrolled a greater percentage of bosque de coniferas and bosque mesofilo (cloud forest), and has under-enrolled manglar (mangroves) and selva baja y mediana caducifolia (low-altitude rainforest).

The initial two-tiered payment system for the PSAH program placed particular emphasis on enrolling parcels of cloud forest, due to the hydrologic importance of this forest type, and higher payments for cloud forest have persisted until the present (Muñoz-Piña 2008). The apparent targeting to cloud forest (with 8.75% of enrolled land in cloud forest vs. just 2.77% of all forested land) is an intentional and likely beneficial result of the PSAH program structure. It is possible that the over enrollment of coniferous pine forest may be explained by more extensive or effective recruiting in these areas; this possibility is supported by the similarly high percentage of coniferous forest in the rejected applicant pool.

Figure 3: Distribution of forest types for PSAH enrolled properties 2004–2010, all forests, and rejected applicants



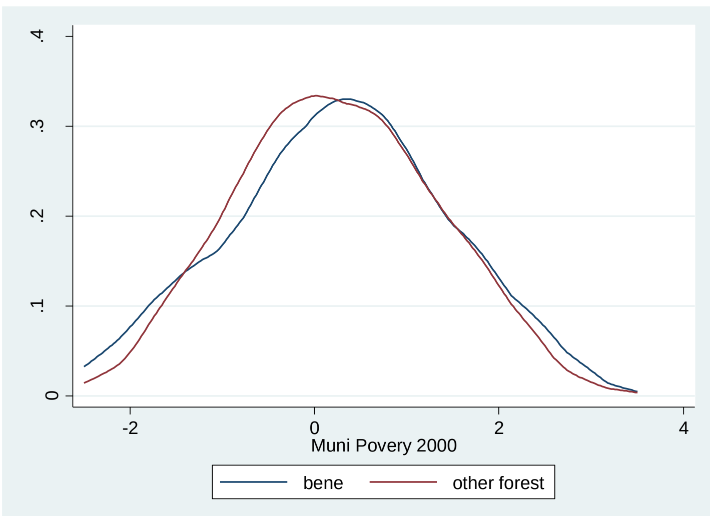
Forest type distributions were calculated using the INEGI Series III land use layer (circa 2002) and shape files of all PSAH applicants from 2004 to 2009. Forested areas from the landuse layer were identified as one of six forest types based on the following classifications: **Bosque de Coniferas**: bosque de ayarin, bosque de cedro, bosque de oyamel, bosque de pino, bosque de pino/encino, bosque de tascate. **Bosque de Encino:** bosque de encino**,** bosque de encino/pino. **Bosque Mesofilo:** bosque mesofilo. **Selvas altas y medianas:** selva alta perennifolia, selva alta subperennifolia, selva mediana perennifolia**,** selva mediana subperenifolia. **Selva baja y mediana caducifolia:** selva mediana subcaducifolia**,** selva baja caducifolia**,** selva baja espinosa caducifolia**,** selva baja espinosa subperenifolia**,** selva baja perenifolia**,** selva baja subcaducifolia. The area of each of these forest type classifications within all program area polygons was calculated and compared to the overall land area of each type for the entire country.

4.5 Targeting for poverty

As indicators of poverty we consider two measures. First, we use CONAPO's municipal marginality index, which ranges from -2 to 2, with higher values indicating greater poverty. Second, we calculate the likelihood that a property has a majority indigenous population, as this metric tends to be highly correlated with poverty in Mexico. Poverty levels for analyzed points were determined from the municipality-level index of marginalization for 2000, calculated and published by CONAPO. Analysis of points indicates successful targeting of funds to marginalized areas. The mean poverty index for PSAH points is 0.264, relative to 0.239 for all forested points and 0.251 for rejected points (a higher index indicates greater marginalization). Although the difference between PSAH points and all forested points is significant, the normalized difference of 0.017 suggests that the actual difference in this targeting is small. Figure 4 shows the distribution of municipality poverty index for enrolled properties compared to all other forested points. We see that the distribution of beneficiary properties is generally shifted to the right, compared to all other forested points, illustrating successful recruitment of properties which are more poor into the program.

Points within PSAH areas are also significantly more frequently located in municipalities with a majority indigenous population than all forested points or rejected points, indicating successful targeting to these areas. Finally, PSAH points are more frequently on communally held land (ejidos or comunidades) than all or rejected points, and on average households in common properties are less well-off than private landowners (Table 4.3).

Figure 4: Municipal poverty of beneficiaries (2004–2009) versus all other forested areas



Marginality index by municipality from CONAPO (2000). Numbers correspond to poverty grades as follows: very low (<-1.3), low (-1.3 to -.7), medium (-.7 to -.1), high (-.1 to 1), and very high (> 1). Data from points sample described above.

This section analyzes shifts in the characteristics of the properties enrolled and the populations participating in the program over time. To better elucidate how the changes in program rules affected the types of properties enrolled, environmental and social variables were analyzed for accepted and rejected areas for each year from 2004 to 2010 and characteristics of the eligible zones were compared across time.

4.6 Changes in selection among recipients

Mean values of a variety of indicators are summarized for all applicant properties inTable 4.4, which also includes the differences in mean values for accepted and rejected areas. The table shows significant changes in emphasis towards the selection of poorer properties and properties with higher risk of deforestation, both in the average trend and in the selection among applicants.

The average values of the marginality index for enrolled properties from 2004 to 2006 range from -0.329 to -0.121, and the likelihood of an enrolled property being located in a majority indigenous population during these years ranges from 0.125 to 0.185. The year 2007 marks a sudden shift in these social measures of targeting. Between 2006 and 2007, the mean marginality index for enrolled properties rises from -0.301 to 0.322; it then declines steadily to its 2010 value of 0.140. It is also important to note that the *difference* in marginality indices of accepted and rejected properties increases over time. This suggests that CONAFOR has tended, over time, to choose the poorer applicants from the pool. At the same time, the proportion of enrolled properties within majority indigenous municipalities rises from 0.139 to 0.427 before subsequently declining to 0.342. As with the marginality index, the difference in the probability of indigenousness between accepted and rejected properties increases over time, indicating greater selectivity of these types of properties within the applicant pool.

Concurrent with this apparent shift towards increased targeting to marginalized areas, targeting on the basis of deforestation risk also increases. We note that the risk of deforestation among enrolled properties generally increases over time, from an average of 2.241 in 2004 to 2.747 in 2009 and with the largest increase between 2006 and 2007. Slope and elevation, which are generally negatively correlated with risk of deforestation, also decrease substantially with the change in rules: between 2006 and 2007, the mean slope of PSAH areas decreases from 12.241 to 10.964, and the mean elevation decreases from 1737.731 to 1418.720. In addition, the differences in deforestation risk between accepted and rejected properties go from negative (indicating the selection of lower risk properties) in the 2004–2006 period to positive (selection of higher risk properties) in the post-2006 period.

Finally, during the same period, measures of targeting to areas of particular environmental and hydrological concern show little change. Surface water availability and the likelihood of being located in an overexploited aquifer or protected natural area remain relatively consistent from 2004 to 2010. This indicates that CONAFOR has been able to maintain these environmental goals while increasing the average risk of deforestation and marginality index.

Table 4. 4: Summary statistics by year for enrolled and rejected PSAH areas, with differences (enrolled–rejected)

Variable		2004	2005	2006	2007	2008	2009	2010
Slope	Enrolled	12.350	11.859	12.241	10.964	10.697	12.745	10.755
	Rejected	11.623	11.984	9.345	10.177	11.219	11.950	12.395
	Difference	0.727	-0.125	2.896	0.787	-0.522	0.795	-1.640
Elevation	Enrolled	2093.436	1895.637	1737.731	1418.720	1435.744	1625.065	1381.344
	Rejected	2035.405	1820.489	1729.242	1611.099	1393.201	1549.732	1565.308
	Difference	58.031	75.148	8.489	-192.379	42.543	75.333	-183.964
Surface water availability	Enrolled	6.610	6.637	6.548	6.607	7.012	6.855	6.942
	Rejected	6.491	6.650	6.270	6.835	6.934	6.708	6.849
	Difference	0.119	-0.013	0.278	-0.228	0.078	0.147	0.093
Overexploited aquifer	Enrolled	0.128	0.276	0.271	0.177	0.140	0.212	0.116
	Rejected	0.239	0.186	0.232	0.146	0.118	0.150	0.116
	Difference	-0.111	0.090	0.039	0.031	0.022	0.062	0.000
Distance to a locality w/ pop. over 5,000	Enrolled	23.947	26.734	30.760	28.471	25.203	29.391	31.156
	Rejected	24.811	22.996	25.912	30.039	27.221	28.369	32.268
	Difference	-0.864	3.738	4.848	-1.568	-2.018	1.022	-1.112
Risk of deforestation	Enrolled	2.241	2.321	2.246	2.994	2.914	2.469	2.747
	Rejected	2.453	2.505	2.605	2.672	2.763	2.587	2.505
	Difference	-0.212	-0.184	-0.359	0.322	0.151	-0.118	0.242
Priority mountain	Enrolled	0.634	0.385	0.442	0.284	0.340	0.429	0.267
	Rejected	0.531	0.487	0.371	0.249	0.179	0.170	0.145
	Difference	0.103	-0.102	0.071	0.035	0.161	0.259	0.122

Protected natural area	Enrolled	0.287	0.257	0.211	0.182	0.168	0.220	0.297
	Rejected	0.220	0.327	0.245	0.134	0.094	0.061	0.116
	Difference	0.067	-0.070	-0.034	0.048	0.074	0.159	0.181
Municipal Marginality Index 2000	Enrolled	-0.121	-0.329	-0.301	0.322	0.268	0.236	0.140
	Rejected	-0.201	-0.102	-0.213	0.018	0.054	-0.062	0.096
	Difference	0.080	-0.227	-0.088	0.304	0.214	0.298	0.044
Majority indigenous	Enrolled	0.185	0.125	0.139	0.427	0.338	0.332	0.342
	Rejected	0.115	0.168	0.158	0.244	0.246	0.302	0.228
	Difference	0.070	-0.043	-0.019	0.183	0.092	0.030	0.114
Communally held property	Enrolled	0.670	0.630	0.562	0.562	0.447	0.654	-
	Rejected	0.569	0.668	0.479	0.460	0.430	0.603	-
	Difference	0.101	-0.038	0.083	0.102	0.017	0.051	-

4.7 Changes in program rules and eligible zones

Changes in enrollment on the basis of social criteria and risk of deforestation are explained to some extent by changes in program rules and eligible zones. In 2006, the criteria identified by CONAFOR for prioritizing applicants to the PSAH program expanded notably for the first time since the program's inception. Among the criteria added were environmental considerations, including high surface water scarcity and location within a protected natural area, and social and economic criteria, including location in majority indigenous and marginalized areas. The year 2006 also saw the introduction of the INE risk of deforestation classification as an enrollment priority.[7]

To understand how the eligible zones impacted the pool of program applicants, we also construct relevant statistics for a sample of randomly selected points within eligible areas

[7]Note that above we see the most notable changes in targeting results occurred between 2006 and 2007, a year after these new criteria were introduced. It is possible that a lag in the recruitment of applicants to the program based on new priorities resulted in a delay in changes in targeting results. In addition, despite the introduction of new priority criteria in 2006, the relatively small size of the eligible zones may have limited the recruitment of well-suited properties until the next year. Between 2006 and 2007, the eligible zones for PSAH enrollment increased in size from 62,807 square kilometers to 210,542 square kilometers, and the number of applicants rose from 631 to 1,764 Table 2.

defined from 2004 to 2009 (Table 4.5). We see that mean values for the risk of deforestation generally increased over time from 2.025 in 2004–2005 to 2.541 in 2009, indicating CONAFOR's efforts to establish eligible zones that captured higher risk forest. As noted above, this did pay off in terms of leading to higher risk lands in later cohorts of the program. With respect to the marginality index, we also see that mean values within each year's eligible zones generally increased over time, with the largest jump from -0.057 in 2006 to 0.351 in 2007 and then a slight decrease in 2008 and 2009. The likelihood of an eligible point being within a majority indigenous municipality rose from 0.249 to .365 between 2004 and 2009. In general, the expansion of the eligible zones in 2007 appears to have allowed for better targeting to areas with high marginality and risk of deforestation on the basis of the new criteria introduced in 2006.

Overall, these results suggest that CONAFOR has generally been able to increase enrollment of the poor and of higher risk forest over time by changing the eligible zones and program rules. They have also successfully selected higher risk and more poor recipients from among the applicant pool. There may still be room to improve targeting on both dimensions, but the decline in the marginality index among later years (from .322 in 2007 to .140 in 2010) suggests they may have already exhausted the straightforward opportunities to attract properties which are both high risk and poor.[8]

Table 4. 5: Summary statistics by year, all forested points within the eligible zones, 2004–2009

Variable	2004–2005	2006	2007	2008	2009
Slope (grade)	12.143	12.136	12.050	12.004	12.289
Elevation (m)	1705.311	1548.019	1512.555	1490.135	1522.256
Surface water availability	6.754	6.627	6.801	6.825	6.810
Overexploited aquifer	0.164	0.207	0.156	0.142	0.143
Km to a locality w/ pop. > 5,000	30.370	32.691	35.230	34.493	34.525
Risk of deforestation	2.025	2.286	2.574	2.555	2.541
Priority mountain	0.499	0.284	0.193	0.182	0.185
Protected natural area	0.292	0.165	0.095	0.091	0.086
Municipal Poverty Index 2000	-0.046	-0.057	0.351	0.292	0.308
Majority indigenous	0.249	0.261	0.393	0.364	0.365
Communally held property	0.752	0.756	0.800	0.787	0.791

[8] An alternate potential mechanism for this change is a shift in the minimum land area for enrollment. Between 2008 and 2009, the minimum land area required for an individual to enroll in the program increased from 20 hectares to 100 hectares. Poorer landowners with smaller plots of land may have been unable to enroll in the program after this change in rules.

Summary

The PSAH program has the dual goal of decreasing deforestation in areas of water scarcity and alleviating rural poverty. The results of our analysis of enrollment in the program suggest that it has been effective at enrolling lands that have high ecological priority and that are representative of the overall marginality distribution of forested lands. We also find that targeting has improved substantially over time due to changes in the program rules and the eligible zones. In analyzing the characteristics of enrolled versus rejected properties for each year from 2004 to 2010, we found that enrolled properties had higher risk of deforestation and higher degrees of marginality and indigenous populations and that degree of difference increased over time. We attribute this improvement in targeting to refinements in the selection criteria for participants and in the eligible zones.

One potential area for improvement is in terms of selecting properties with even higher risk of deforestation. Even with substantial changes in the eligible zones, the average risk of deforestation among enrolled properties remains somewhat below the national average across all forested lands. Two possible ways to do this are to target further on the basis of multiple characteristics which determine avoided deforestation or to raise the payment amounts. These are discussed further in the final section of this report.

5. Impact results

The previous section showed patterns and correlations across all cohorts that ever applied to the PSAH, and focused on enrollment and changing program rules. This section will show two different types of results: first, we examine environmental effectiveness of the program across all cohorts using a combination of programmatic and remote sensing data. The second set of results will examine socioeconomic impacts and potential sources of spillover effects using survey data collected from a single cohort—the group of applicants from the 2008 cohort who we surveyed in 2011.

5.1 Environmental effectiveness

Using program data and GIS boundaries of program applicants from CONAFOR, we construct a spatial database of all program applicants from 2004 to 2009.[9] Figures 5 and 6 show the location of participants and controls as well as the outlines of the area forested in Mexico prior to 2003. To analyze program effects from 2004 to 2009, we use points as a unit of analysis; intersecting these points with the program polygons allows us to clearly code the program status of each point in each year.[10] The points are a random sample

[9] We analyze the 2004–2009 cohorts but we also collect and overlay the boundaries of the 2003 and 2010 PSAH recipients in order to correctly control for recipient status in all years.

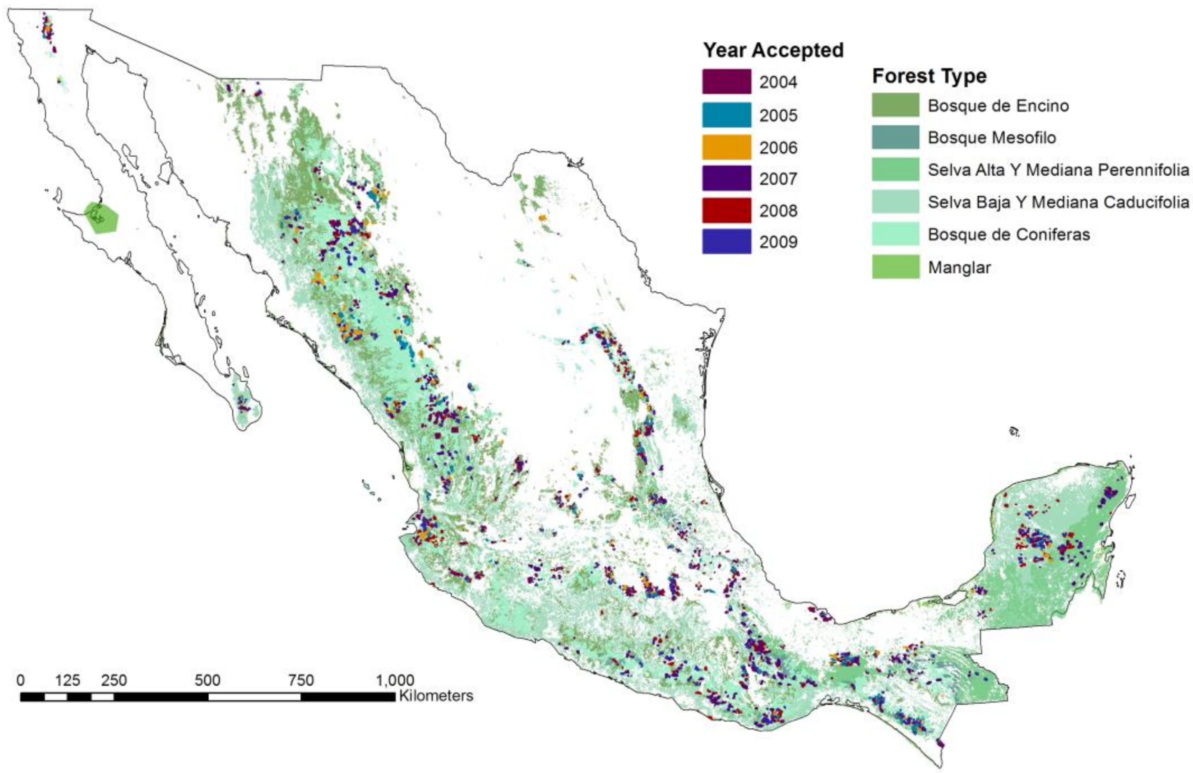
[10] This is necessary because of the complex spatial overlap of applications between years. For instance, a landowner may choose to apply with a portion of his land in one year and then if he is rejected, apply again with a different portion in the next year.

from within PSAH applicant boundaries from 2004 to 2009 which were classified as one of six forested categories in the INEGI Series III land use layer (circa 2002). To minimize spatial autocorrelation, we sample at a density of 1 point per square km (~38,000 points) and cluster standard errors by property.[11]

To assess the program's environmental effectiveness, we use the average dry season NDVI in each year from 2003 to 2011 as a measure of forest cover. NDVI measures the "greenness" of vegetation based on the reflectance signatures created by leafy vegetation versus other land cover (NASA 2012). Deforestation or significant forest degradation is indicated by a decrease in average annual NDVI. We construct mean NDVI measures for each year using MODIS composites from the Aqua and Terra satellites taken between February 15 and April 15. Although the data used in this paper was newly constructed by us, similar methodology has been previously established and field-tested by the Mexican National Forestry Commission (CONAFOR 2012; Meneses-Tovar 2009a, b). Economists have also relied on NDVI decreases to measure deforestation in previous research in both developed and developing countries (Foster and Rosenzweig 2003; Mansfield *et al*. 2005; Burgess *et al.* 2011).

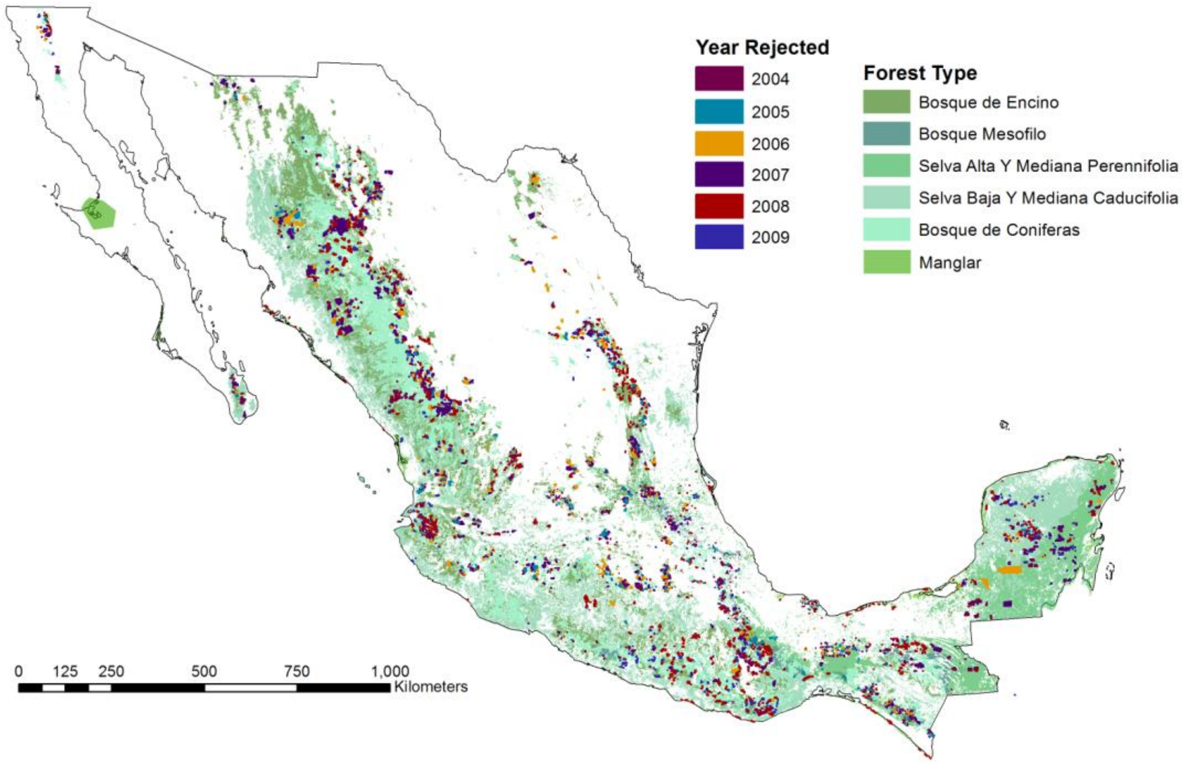
[11] We eliminate points which had 2003 NDVI values indicating they were not in forest in 2003. Specifically, we drop points where the 2003 NDVI is less than 0.3 in regions 1, 2, and 3 and less than 0.6 in region 4.

Figure 5: Recipients of PSAH, 2004–2009



Data on program recipients from CONAFOR. Forest types from the INEGI Series III land use layer (circa 2002). Bosque de Encino = oak and pine forest, Bosque Mesófilo = cloud forest, Selva Alta = Upland rainforest, Selva Baja = Lowland rainforest, Bosque de Coníferas = coniferous forest, Manglar = mangroves.

Figure 6: Rejected applicants to PSAH, 2004–2009



Data on program applicants from CONAFOR. Forest types from the INEGI Series III land use layer (circa 2002). Bosque de Encino = oak and pine forest, Bosque Mesófilo = cloud forest, Selva Alta = Upland rainforest, Selva Baja = Lowland rainforest, Bosque de Coníferas = coniferous forest, Manglar = mangroves.

The key advantages of the MODIS data are its temporal density (weekly products) and wall-to-wall coverage of Mexico. Frequent passes by the satellites mean that data is complete even for areas which experience significant cloud cover (such as the Yucatán peninsula). The downside is that MODIS is spatially coarse, with resolution at 250m pixels (~ 6 hectares). This does not mean we cannot detect smaller areas of forest loss; NDVI is a continuous measure, so clearing or degradation of smaller areas will still decrease the NDVI value. However, we are limited in that we do not know exactly where in each 250 x 250 m pixel this loss or degradation occurred. Given that the average size of the properties enrolled between 2004 and 2009 is 680 hectares (> 100 pixels), we believe the data's resolution is appropriate for this analysis. We also check robustness of the main results to several alternate definitions of forest cover.[12] Finally, we note that all forest cover measures are sensitive to seasonal vegetative cycles ("phenology") and annual rainfall variation. More rainfall at the right time increases the density of leaf cover, particularly in deciduous forests. To control for this variability, our regression models include a variety of rainfall event measures, described below.[13]

Evaluation of Mexico's PSAH program involves the standard identification problem: one does not know how recipients would have behaved had they not received payments. To construct a reasonable counterfactual case, we rely on comparisons across time between accepted and rejected applicants to the PSAH program. A key advantage of using controls drawn from the applicant pool is that all owners have demonstrated their otherwise unobservable desire to enroll in the program, revealing that their expected participation costs are sufficiently low to motivate application, and perhaps that they share a "conservation-oriented" inclination. However, even with program applicants as controls, characteristics which could be correlated with selection into the program and changes over time in deforestation could remain. To address this problem, we investigate the selection process, pre-match data on the basis of relevant characteristics, and then estimate panel regressions including property-level fixed effects to control for unobservable fixed characteristics of the parcels or landowners.

We estimate panel regressions with property fixed effects using NDVI as the dependent variable. The estimation includes state-year and vegetation effects as well, and controls for various measures of rainfall intensity. Standard errors are clustered at the property level to account for spatial and serial correlation. Given this specification, our identification comes from differences in within-property behavior between similar accepted and rejected applicants over time. This relies on the assumption that the trends in deforestation between these two groups would have been parallel in the absence of program participation—or in other words, that remaining variation in the timing of applications and acceptances in our regression model is not correlated with deforestation behavior. Since the program took a few years to become well-publicized and the details of the rules, prioritization schemes, and eligible zones were multidimensional and frequently changing, we think that reasonable sources of "quasi-random" variation in timing of acceptance remain. These include rejections due to being outside the eligible zones in a given year, small mistakes in paperwork or documentation, or having less priority for funding within those who are accepted. As a test of the parallel trend assumption, we assess the time trends of accepted and rejected properties prior to enrollment by running a regression of NDVI from 2003 to 2009 on rainfall variables, with property level, vegetation category, and

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[12]Alternate measures of forest health included the log of NDVI and NDVI normalized to have a mean of zero and standard deviation of one in each year and region. We also classify pixels into forest and non-forest categories based on expected NDVI values of forest and non-forest categories. Results available from authors.

[13] Rainfall data are from NOAA NCEP CPC Mexico daily gridded realtime precipitation (.25 x .25 degrees).

state-year fixed effects. The coefficients on interaction terms between year effects and eventual enrollment status among the unenrolled, that is, the pre-program trends for the two groups, are neither large nor statistically significant for any year. In addition, in order to assess whether the applicants rejected due to program budget constraints constitute a different type of counterfactual than those rejected for other reasons, we run a regression on the subsample of rejected properties using all the covariates in equation (1), but substituting for the beneficiary variable interactions between the year dummies and being rejected due to budget constraints. None of these 10 interaction terms is statistically different from zero at the 5% level, suggesting that rejected applicants have similar NDVI trends regardless of the reason for which they were rejected. Finally, the results are robust to using different subsets of the rejected applicants.

5.1.1 Average environmental impacts

Table 5.1 gives the estimates of program impact on mean NDVI, using the estimating equation (1) described above with property-level fixed effects. Column 1 shows average program impact while columns 2–7 test for heterogeneity in impacts. The coefficient in column 1 indicates that the average impact of receiving the program is an increase of 0.0041 in mean annual NDVI. On matched non-beneficiary properties, the average annual loss of NDVI, controlling for rainfall, vegetation type, and state, is -.0013 for one year. Over five years, this results in a loss of -.0065. Our estimates imply that the program reduces this loss to -.0025, which constitutes an “avoided NDVI loss” metric of 63% (.0041/.0065). Because NDVI loss (controlling for climate) can occur as a result of either deforestation or degradation, it is not possible to translate this number precisely into hectares of avoided deforestation. However, rough calculations indicate that it implies fairly low avoided deforestation as a fraction of land receiving payments due to the overall low expected deforestation rate on these lands.[14] Nonetheless, the result indicates that the program significantly reduces forest cover loss. It is consistent in magnitude with our pilot study on one early cohort of this program (Alix-Garcia *et al.* 2012), but more convincing given the inclusion of multiple cohorts. Finally, it suggests that payments are likely to be greater than opportunity costs on the enrolled lands, even if payments do not fully compensate for per hectare returns to conversion.

[14] The NDVI loss across five years on our matched controls (-.0065) is 16% higher than the NDVI loss for all of Mexico using our sample of all forested points (-.0056). From 2000 to 2010 the estimated annual rate of forest loss in Mexico was approximately 0.295% (FAO 2010). Scaling this to our sample gives an expected deforestation rate of approximately .34% annually or 1.71% across five years. This implies avoided deforestation on the order of less than 2 hectares out of each 100 hectares receiving payments.

Table 5. 1: Impacts of PSAH 2004–2009 on forest cover: property fixed effects

	Dependent variable: mean dry season NDVI						
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Beneficiary	0.0041***	0.0038***	0.0069***	0.0078***	0.0079***	0.0047***	-0.0014
	(0.0008)	(0.0010)	(0.0012)	(0.0021)	(0.0011)	(0.0008)	(0.0016)
Benef x center		0.0031*					
		(0.0017)					
Benef x southwest		-0.0016					
		(0.0018)					
Benef x southeast		-0.0008					
		(0.0036)					
Benef x km to large Locality			-0.0001***				
			(0.000033)				
Benef x ln(slope)				-.0017***			
				(0.0008)			
Benef x defor risk					0.0034***		
					(0.0007)		
Benef x mun poverty Index						-0.0030***	
						(0.0005)	
Benef x common property							0.0063***
							(0.0018)
N properties	3644	3644	3644	3644	3644	3644	3644
N total	201285	201285	201285	201285	201285	201285	201285

* p< .10 ** p < .05 *** p < .01

Property-level fixed effects model (equation 1). Robust standard errors clustered at the property level in parentheses. Dependent variable is mean dry season NDVI (ranges from 0 to 1). Regressions use data from program beneficiaries and matched rejected applicants; matching as described in footnote of Table 1. Large localities are those with more than 5,000 people.

5.1.2. Heterogeneity in environmental impacts across space

One pattern evident in the GIS data is that deforestation is highly spatially dispersed. Rather than a geographically concentrated frontier pattern, deforestation in Mexico tends to be scattered in small amounts over vast land areas. Data from CONAFOR's Forest Monitoring indicates that between 2003 and 2008, the average percent area of suspected deforestation per municipality was 0.51% (with the 25th percentile at 0.14% and the 75th percentile at 1.6%). While this clearing adds up to large areas deforested in total across Mexico, the dispersed spatial pattern means that it is very difficult for policymakers to target payments only to the “marginal hectares” that would be cleared in the absence of the program. Opportunities for managers to increase the cost-effectiveness of the program depend on whether there is systematic heterogeneity in avoided deforestation impacts that can be better exploited.

Motivated by the simple framework discussed in section 3, we test for heterogeneity in effectiveness across characteristics likely to determine deforestation risk, including region, distance to the nearest urban locality, and slope (Table 5.1, columns 2-5). We find that effects across the four regions are not significantly different from each other.[15] However, there is significant heterogeneity by distance to urban area and slope, both key determinants of land rents, with less avoided deforestation farther from cities and as slope increases. For instance, the magnitudes suggest that at 10 km from the nearest large locality (10th percentile of distance), the marginal effect of the program was .0059 (virtually eliminating the downward NDVI trend) while at 65 km (90th percentile) it was essentially zero. The coefficient on the interaction between beneficiary and slope indicates the program eliminates the NDVI loss trend at a slope of 0 (10th percentile) and has an impact of .002 (a 30% reduction in the downward trend) at a slope of 26 (90th percentile). We also find significant heterogeneity by an exogenous deforestation risk index which combines these characteristics.[16] The interaction of this term with beneficiary status indicates that the program is much more effective where our measure of deforestation risk is higher (Table 5.1, column 4).

In terms of social goals, we find less avoided deforestation at higher levels of baseline municipal poverty (Table 5.1, column 6), suggesting that there is no easy strategy to increase avoided deforestation and enroll more poor. The estimates indicate that at a municipal poverty index designated by CONAPO as "low" (-1.3 to -.7), avoided NDVI loss ranged from .0086 to .0068, while at a municipal poverty index of "high" (-.1 to 1) avoided NDVI loss ranged from .005 to .0017.[17]

The analysis up to this point shows no possibility of simultaneously increasing environmental effectiveness as well as enrollment of the poor. However, when we break recipients down into common property versus private and other types of beneficiaries, we

[15] The difference between region 1 (North) and region 2 (Center) is significant at the 5% level in some specifications, but is not robust to alternate specifications.

[16] The risk index is constructed using GIS layers indicating areas of "suspected deforestation" across Mexico for the years 2004–2009 and 2011 (Forest Monitoring). Using only the never-enrolled points, we regress suspected deforestation on elevation and slope categories, vegetation type categories, and the natural log of the distance to the nearest city. The coefficients from this regression are then used to predict the probability of deforestation for all the points in the sample. The risk index is the natural log of 100 times the predicted probability of deforestation, a transformation applied because the distribution of predicted probabilities is extremely left skewed.

[17] We also test for and find no significant heterogeneity in effectiveness by municipalities with majority indigenous status—a metric often associated with poverty in Mexico. We test for heterogeneity by availability of water and being in an overexploited aquifer. We find no significant differences in avoided deforestation by overexploited aquifer status but we do find significantly less avoided deforestation with higher water availability (coefficient = -0.0016, standard error 0.0004). Water availability is positively correlated with more poverty (corr=0.44) so additional targeting to low water availability areas in order to increased avoided deforestation or hydrological benefits again implies a likely tradeoff with poverty reduction goals.

find that the program is most effective in the common properties, with an approximate avoided NDVI loss of .0049 (Table 5.1, column 7). This suggests a possible win-win by targeting to common property beneficiaries, who are generally poorer than private property landowners: the average municipal poverty index for the common property points in our sample is .30, relative to -.115 in the private properties. Enrolled common property lands tend to be of lower quality than privately owned land along the dimension of slope (12.6 v 10.1), but are generally found at similar distance (around 33 km) to the nearest city, and have similar predicted deforestation risk.[18] From this we conclude that the differences in effectiveness are not driven by differences in land quality or distance costs. We speculate that they may be driven by available opportunities not captured by the geographic risk characteristics. Within common properties, households tend to be more dependent on agriculture (in our survey over 80% of common property households report participating in agriculture in 2007 compared to around 50% of private households), suggesting fewer off-farm labor opportunities.

5.1.3 Environmental spillovers

In the context of reducing deforestation or forest degradation, the goal of PES programs is to induce additional forest conservation ("additionality" or "avoided deforestation") by raising the returns to forested land (see for example Ferraro and Simpson 2002; Bond *et al*. 2009; Pagiola and Zhang 2010). Although this logic is theoretically sound, there is concern that PES programs may not generate additional environmental benefits. One concern is that programs are not effective at inducing additional forest conservation because they are paying landowners who would have kept land in forest even in the absence of payments (see for example Alix-Garcia *et al.* 2008b). A second possibility is "slippage" (also "leakage" or "negative spillovers'): even if forest conservation programs do induce additional conservation on enrolled lands, these benefits may be undermined by new deforestation in other locations (for previous work on negative environmental spillovers in the context of land conservation see: Berck and Bentley 1997; Wu 2000, 2005; Wu*et al.* 2001; Chomitz 2002; Lichtenberg 2004; Wear and Murray 2004; Murray *et al.* 2004, 2007; Fraser and Waschik 2005; Roberts and Bucholtz 2005, 2006; Gan and McCarl 2007; Robalino 2007; Plantinga and Richards 2008; Lichtenberg and Smith-Ramirez 2011).

In our pilot study for this project, we modeled and tested for slippage of deforestation to other areas using information only the 2004 enrollees. There are two possible types of slippage: substitution effects and output price effects. In the context of forest-conservation payments, a substitution slippage effect occurs when a landowner who removes one parcel of land from production (enrolling it in the program) shifts the planned production to another parcel within his landholdings. Credit constraints are discussed as one of a variety

[18] Both have risk of 2.4 according to the INE index; common properties have a slightly lower risk according to our index (-1.10 vs. -1.02, normalized difference of -.06).

of common market imperfections in developing countries that might lead to such substitution slippage. Our analysis used a simple household land allocation framework to illustrate that substitution slippage could occur as a result of households being credit-constrained. We tested for substitution slippage by comparing deforestation rates in the non-enrolled portions of enrolled properties to those of the matched control properties—a common sense approach but one that has not been possible in previous studies given data constraints. We found evidence for substitution slippage, with the sign and magnitude of the effects varying by the degree of marginality. In poor ejidos, we find increased deforestation, lending support to the credit constraints hypothesis and raising concerns that slippage could erase program impacts. In wealthier ejidos, substitution slippage is actually negative, complementing the program's avoided deforestation impacts. On average, we found that the substitution slippage effect reduces avoided deforestation within common properties from 1.22 to 1.17 percentage points, or about 4% of the program impact.

An output price slippage effect occurs if the removal of multiple parcels of land from production or the introduction of payments alters market prices and these changes in turn induce additional deforestation. Whether or not these changes will be spatially close to enrolled lands depends on the size of the relevant markets: we expect to see effects where there is sufficient overall enrollment to move prices and where markets are localized enough to concentrate those price effects. We test for output price slippage by comparing deforestation on un-enrolled land in high and low total enrollment areas. We use the connectivity of transportation infrastructure (surrounding road density) to proxy for the degree of market integration. We found evidence consistent with output price slippage from the program, although the potential endogeneity of market-level enrollment limits this conclusiveness of this test.

Because of the nature of the spatial data used in this preliminary analysis, we are not confident that these results are generalizable to the program as a whole. At this moment, we are attempting to use more detailed satellite imagery to assess the degree of slippage in all cohorts. There have been significant barriers to the interpretation of this imagery, including lack of images in the Landsat archives, images with missing data, and significant cloud cover over important regions of Mexico. We have detailed some of the challenges to the measurement of forest cover in the policy recommendations section, and we analyze the possible sources of this leakage using the socioeconomic data in section 5.3 below.

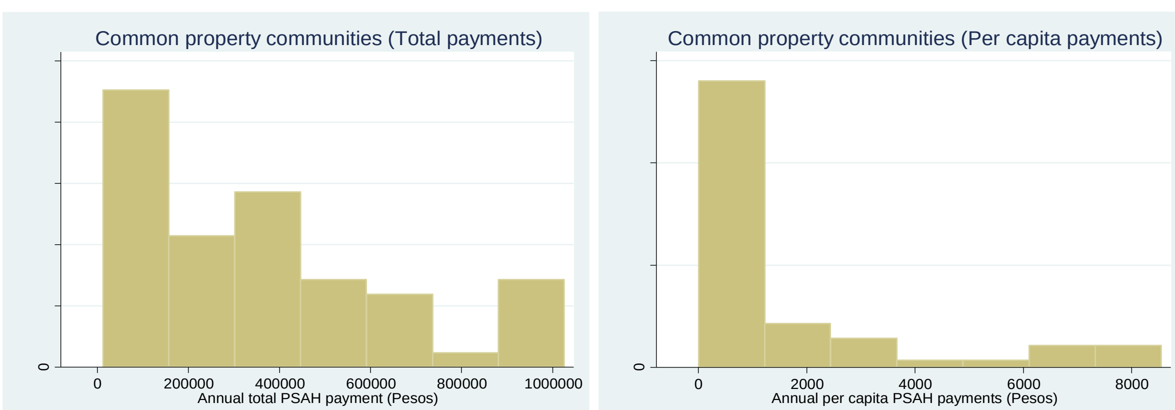
5.2 Socioeconomic impacts

The following subsections analyse impacts of the program on socioeconomic outcomes as well as on forest management activities and perceptions of the program. Details of the sampling and study design for the household and community surveys are given in the Appendix. Broadly speaking, our empirical strategy seeks to identify both average and heterogeneous treatment effects at the household level. We examine impacts on outcomes indicating both short- and long-term wealth effects: food consumption, purchase of durables, household improvements, and productive investments. We assess heterogeneity along internal community land-use rights and determinants of deforestation risk, in addition to examining potential heterogeneity across indigenous groups and women. All estimations compare differences over time in outcomes between beneficiaries and non-beneficiaries except those on food consumption, which use cross-sectional variation (recall questions were not asked about food consumption as this was unlikely to produce accurate answers). Prior to estimation, we pre-match beneficiaries with non-beneficiaries based upon pre-program participation in forest conservation activities.[19] Finally, we separately analyze households living in common property communities and private landowner households because common property households are a very different population, substantially poorer and less educated than private property households.

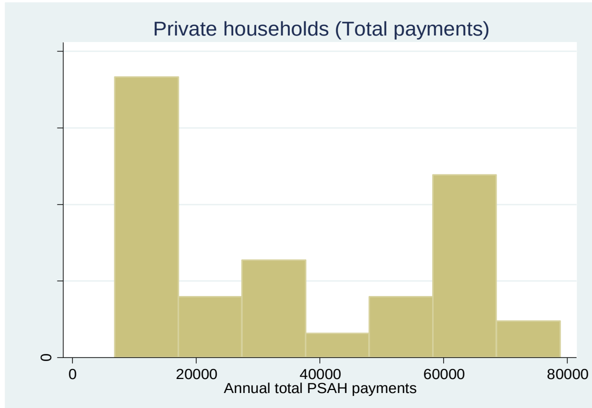
5.2.1 Distribution of payments

This section details the average payment size and distribution of payments within recipient properties of our 2008 survey sample. As was mentioned above, the annual per capita payment within common property communities is 1,539 Mexican pesos (approximately US$130). This is higher than the monthly minimum wage in Mexico, which is currently 1,161 pesos. For private households, the average annual payment they received from the program is 35,777 pesos, which we estimate to be approximately 12% of household income. Figure 7 shows the distribution of PSAH payments across beneficiaries. For common properties, these payments are somewhat skewed—larger numbers of ejidos, both on a per capita and total basis, receive a relatively small amount of payments, whereas a few ejidos receive large payments. For private properties, these payments are relatively more evenly distributed.

Figure 7: Distribution of PSAH payments across beneficiaries



[19] Forest conservation activities include: constructing or maintaining firebreaks to avoid fires spreading across different areas of the forest, constructing fences to avoid cattle entering into the forest, doing forest patrols, reforestation, soil conservation activities, pest control, among others.



As section 5.2.5 will explain in more detail, a large part of program funds, both for common property communities and private households, seem to be allocated to pay for labor devoted to forest management activities. Within communities participating in the program, there are some differences in how program funds are allocated at the community level. Some communities divide the payment among members (a "lump-sum transfer"), others provide wages for performing some specific forest management activities, and others invest in public goods ("non lump-sum transfers"). In some cases, we see a combination of these three strategies.[20] For those communities where payments are given directly to households as lump sum transfers, 92% of them go only to those with land-use rights and the average amount they report they received in the past 12 months is 12,881 pesos.[21]Table 5.2 reports the percentage of communities that provide lump-sum transfers by region and shows that most of the communities in the south east region follow this strategy.

Table 5.2: Distribution of program funds by region

Region	No. lump-sum transfers	Lump-sum transfers
Region 1 (North)	92.308	7.692
Region 2 (Center)	86.667	13.333
Region 3 (South West)	66.667	33.333
Region 4 (South East)	20.000	80.000
Total	**65.517**	**34.483**

Note: Numbers reported in each row are the percentage of communities within each region that provide lump-sum transfers and not.

When we compare the characteristics of communities providing lump-sum transfers with those that do not (Table 5.3), we can see that those providing transfers have, on average, smaller populations and less total land. Also, they have a higher percentage of indigenous

[20] The data confirms that when communities distribute funds directly to households, not all of them distribute the total amount. The average proportion distributed is 0.75.
[21] This number is the average of the payments received by households with land-use rights in our sample. It excludes all households with zero payments. The average overall households with land-use rights is 4,534 pesos.

population (61% vs. 42%) and a lower percentage of female ejidatarios (8% vs. 26%). Employment characteristics are similar: approximately 72% of the ejidatarios work in agricultural activities and only 6% work off-farm in both communities. There are some differences in the area of forest enrolled in the program. Communities with transfers enrolled, on average, 823 hectares, and those without transfers enrolled 1,141 hectares. In spite of this difference, per capita payments in communities providing lump-sum transfers are more than double those observed in communities without transfers (12,030 vs. 5,352 pesos). Moreover, since the ratio of ejidatarios to non-ejidatarios is lower in communities providing transfers, the per ejidatario program payments are also larger in these communities (46,242 vs. 23,408 pesos).

Table 5.3: Community characteristics by transfer type

Community characteristics	With lump-sum transfers	No lump-sum transfers	Difference
Total population	1281.150	3089.595	-1808.445
Total hectares of land in community	2640.550	9121.995	-6481.445*
Area of forest enrolled in program	823.328	1140.989	-317.661
Locality poverty 2005	0.496	0.790	-0.294
Indigenous in sample	0.610	0.418	0.192
Ejidatarios no education	0.166	0.235	-0.069
Ejidatarios that are women	0.085	0.265	-0.180***
Ejidatarios working off-farm	0.040	0.073	-0.034
Ejidatarios working agriculture	0.707	0.737	-0.030
Ratio ejidatarios/non-ejidatarios	2.822	4.098	-1.276
Total per capita PSAH payments	12030.198	5352.306	6677.892*
Total per ejidatario PSAH payments	46242.099	23408.070	22834.029*

The case studies provide more nuanced insight into the division and use of program funds. Decision-making concerning the distribution of payments to community members as lump sum vs. non-lump sum and how non-lump sum funds would be used varied between communal property case study sites. Interviewees from 4 of the 10 communal property sites stated that all decisions were made through the *asamblea*, the community council generally made up of all heads of all households with land rights. Interviewees in five of the other communal properties stated that decisions over distribution and use of the payments were made either directly by community leaders and/or through the asamblea. In two cases, the decision was made to calculate the lump sum payments proportionate to the amount of forestland enrolled per household.

Interviewees from 7 of the 10 communal property case study sites stated that at least part of the non-lump sum portion of program funds were used for public goods (that is, community projects, investments or activities). These included: repairs or upkeep of schools, churches or community centers, community celebrations, purchase of land for schools or other community buildings, civic or religious activities, purchase of a vehicle for community-related activities, or for infrastructure projects such as irrigation systems or road building.

Conflicts over the distribution and use of the payments were mentioned by 10 of the 49 case study interviewees. Interviewees from one of the communal properties stated that the decision to distribute the payments as a lump sum payment to households vs. thorough wages for labor-generated conflict within the community. An interviewee who had entered the program through an association of private property holders claimed that the differences in the amounts the payments received caused conflict amongst the members since, “we all have the same forest.” Two regional-level CONAFOR employees and three contractors mentioned having conflicts with participants who did not want to spend enough of the payment to complete the required forest management activities. One regional CONAFOR employee also noted cases in which problems of corruption amongst elected community leaders or in which leaders channel payments to community members of the same political party were also sources of conflict.

5.2.2 Strategy for estimating wealth effects

We estimate program effects on durable purchase (and loss), household improvements, and productive investment using a household fixed effects model which therefore controls for all baseline household characteristics. We test for heterogenous effects by interacting the covariates of interest with the variable indicating that a community or household benefitted from the program after 2008. Durables purchases and housing consumption are aggregated by price to reduce dimensionality.[22] The durables index includes the following assets: television, refrigerator, computer, car, stove, phone, and cell phone. The housing index includes wall and floor construction materials and number of rooms. The prices used for weighting are based on data from consumer agencies in Mexico and estimates of the values of housing characteristics. The 2007 weights or prices are used to construct the indices for 2011 in all cases. Results are robust to estimating impacts on individual consumption and housing characteristics and to using the natural log of the estimated payment per household rather than binary treatment.

For agricultural and education investments, we use the presence or absence of the investment as the outcome variable. For food consumption, we construct an index using prices reported by households and whether or not they purchased a particular food item in

[22] We also experimented with two other indices common to the development literature: the principal components analysis (PCA) on ordered data, which gives more weight to observations which provide more information about the variation in the data, and an inverse proportion index, which gives greater weight to assets which are relatively rare—like cars and computers—and less to more common assets, like televisions. The PCA results are consistent with price index results, while there is less correspondence between results using the inverse proportion index and the other three. In order to limit the number of tables we only present results from the price indices.

the past week. The food items of interest are tortillas, cheese, milk, beef, pork, beans, tomatoes, sugar, and bread. Since food estimations are cross-sectional, they also include a series of covariates to control for observable differences across beneficiaries and non-beneficiaries.

5.2.3 Average impacts on wealth

Table 5.4 shows estimates of program impact on consumption goods. Panels a and b show common property impacts and panel c shows results for private properties. We observe that none of the simple treatment effects is statistically significant, although all are positive for both common and private properties. The magnitudes are also quite small—ranging from 0.2 to 5 percentage point increases. Considering within-community heterogeneity, there are no significant differences in consumption impacts for ejidatarios versus non-ejidatarios although the estimated marginal effects for members are positive in each case.

Table 5. 4: Average impacts of PSAH on consumption: food, durables, housing

	Ln(Food index)	Ln(Durables index)	Ln(Housing index)
Common properties			
a. Simple treatment			
Beneficiary	0.046	0.030	0.002
	(0.059)	(0.039)	(0.006)
b. Treatment by tenure class			
Beneficiary	-0.034	0.016	0.005
	(0.086)	(0.043)	(0.007)
Beneficiary x ejidatario	0.121	0.022	-0.004
	(0.093)	(0.045)	(0.005)
Marginal effect (for ejidatarios)			
	0.086	0.038	0.0013
Base mean	.587	.686	2.30
N	806	1838	1830
Private properties			
c. Simple treatment			
Beneficiary	0.017	0.047	0.005
	(0.064)	(0.065)	(0.003)
Base mean	.855	1.54	2.72
N	115	234	234

* p < .10 ** p < .05 *** p < .01. Durables and household index estimates based on household fixed-effects model (equation 2). The food index column reports cross sectional regressions with 2011 data. As additional covariates, they include: ln (distance to nearest city), household size, municipal poverty in 2005, if the household has a member of the common property, and the mean elevation of the property. The food index is constructed using households' reported prices and considering the consumption of tortillas, milk, beef, pork, cheese, bread, tomato, and beans. Durables and housing index regressions are aggregates of assets (television, refrigerator, computer, stove, car, phone, cell phone) and housing improvements (floor, walls, number of rooms) valued at 2007 prices. These estimates include household fixed effects. Standard errors are clustered at the property level for common properties and are heteroskedastic robust for private properties.

Table 5.5 shows average effects on investments in agricultural/pastoral production and education. In the common properties, we observe a positive and marginally significant increase in the number of cattle (0.9 more per household) and a positive but not significant increase in the number of small animals (2.5 more). We do not see sizeable or significant changes in the likelihood of investing in livestock infrastructure, agricultural inputs or agricultural equipment. However, we do observe a fairly large increase (around 15% relative to baseline) in the probability of attending school for children between the ages of 15 and 17 years old. We also see positive but insignificant increases in school attendance for children between 12 and 14 years old and 18 and 22 years old. In general, we do not see significant variation between common property ejidatarios and non-ejidatarios, although the marginal increase in cattle is significant and sizeable for beneficiary households (1.2 more, relative to the base mean of 3.5). There are no significant impacts for private households, although the coefficient on schooling implies a 10% increase relative to baseline in the probability of attending school for students between 12 and 22 years.

Table 5. 5: Average impacts of PSAH on productive and educational investment

	Agricultural investment					Educational investment		
	# Cattle	**# Small animals**	**Livestock infrast.**	**Agricultural inputs**	**Agricultural equipment**	**Student 12-14 yrs**	**Student 15-17 yrs**	**Student 18-22 yrs**
Common properties								
a. Simple treatment								
Beneficiary	0.923*	2.507	0.033	-0.008	-0.006	0.043	0.122**	0.059
	(0.502)	(1.892)	(0.025)	(0.026)	(0.019)	(0.043)	(0.056)	(0.074)
b. Simple treatment by tenure class								
Beneficiary	0.445	3.522**	0.022	0.007	0.019	0.074	0.124*	-0.003
	(0.547)	(1.373)	(0.033)	(0.034)	(0.025)	(0.057)	(0.065)	(0.086)
Beneficiary	0.746	-1.583	0.017	-0.024	-0.038	-0.043	-0.026	0.097
x ejidatario	(0.529)	(2.804)	(0.036)	(0.033)	(0.026)	(0.044)	(0.055)	(0.065)
Marginal effect (for ejidatarios)								
	1.19**	1.94	0.040	-0.017	-0.017	0.031	0.097	0.094
Base mean	3.499	7.610	0.116	0.683	0.204	0.948	0.823	0.519
N	1848	1848	1842	1842	1841	547	614	832
Private properties								**Student 12-22 yrs**
c. Simple treatment								
Beneficiary	-1.830	9.684	0.084	0.053	0.019			0.090
	(4.673)	(12.582)	(0.065)	(0.061)	(0.056)			(0.076)
Base mean	21.017	21.466	0.203	0.381	0.161			0.872
N	236	236	236	236	236			205

* p< .10 ** p < .05 *** p < .01

Estimates include household fixed effects and standard errors clustered at the property level for common properties, and are heteroskedastic robust for private properties. Livestock infrastructure, agricultural inputs and equipment are all binary variables that take the value of 1 when the household invested in this category and zero otherwise. Regressions reported for these variables are linear probability models. The age of children corresponds to 2011.

Despite the scarcity of measured impacts, the people closely involved in implementing the program appear to believe that it generally has a positive effect on household incomes. Of the 33 case study interviewees who discussed their perception of program impacts on household income, the majority (29 total = 5/6 regional level CONAFOR personnel; 11/12 technical assistance contractors, 8/8 community leaders; and 5/7 private property holders) felt that the program had had a positive impact on household incomes. While no interviewees felt that the program has had a negative impact, 4 of the 33 did express that they felt that the funds were insufficient to have a significant effect. As one private property holder stated, "It is a subsidy, but really…one can't live on payments for ecosystem services."

These results suggest that PES is at least doing no harm to households on average, even for those without full land rights, and may have some marginally positive effects on consumption or investment. These results are an important empirical addition to the literature that questions whether PES initiatives might harm the poor by restricting access to forest resources or new agricultural land (for example Hawkins 2011; Pattanayak*et al.* 2010; Bulte *et al.* 2008; Pfaff *et al.* 2007; Zilberman *et al*. 2008). However, average impacts may obscure important heterogeneity; recall that our model suggests surplus rents conferred to landowners should be larger as the opportunity costs of forest conservation become smaller. There may also be heterogeneity by baseline poverty if deforestation risk is correlated with wealth. Alternately, the small impacts could indicate that there is simply little surplus to be gained by recipients, perhaps because the payment size is relatively small compared to the transaction and forest maintenance costs of participating. The following sections investigate these two possibilities.

5.2.4 Heterogeneity by deforestation risk and poverty

To explore heterogeneity by risk of deforestation, we create a metric of deforestation risk using the predictions from the environmental section, and divide our sample into "high" (above the median), and "low" (below median) deforestation risk.[23] To explore heterogeneity by baseline poverty, we divide the sum of the housing and durables indices in 2007 at the median, and include an indicator for "below median" as the proxy for poverty.

Results are shown in the appendix for the two types of interactions. For households in common properties, the estimates are somewhat consistent with the theory presented above. Where deforestation risk is high, we observe less program impact on food consumption, the purchase of durables, and housing improvements, although the interaction term is statistically different from zero only for durables consumption. The results imply that for low-risk properties, the durables index is about 12% higher relative to

[23] In order to create a parallel index for the socioeconomic analysis, the coefficients used to create the deforestation risk index used in Tables 3 and 4 are applied to the property-level covariates.

baseline, due to the program, while there is no positive impact for high risk properties. With respect to investment outcomes, we observe significant heterogeneity in education for the oldest age class of children. The results again imply no positive effect of the program in high-risk properties but an approximately 25% increase relative to baseline in low risk properties. Estimated heterogeneity by high deforestation risk is also negative and sizeable, but not statistically significant, for investment in students 15 to 17 years and the number of cattle. For private households, we find no significant heterogeneity in consumption effect by deforestation risk. The results on small animals, livestock infrastructure, and agriculture investment do have signs consistent with theory but are not statistically significant.

Recall that our model also suggests that if deforestation risk is negatively correlated with wealth, then one should observe greater wealth effects among relatively poorer recipients of the program. Consistent with this, we observe positive and significant interaction terms for the durables and housing indices in both the common properties (an impact of 18% relative to baseline in durables, 2% in housing) and the private properties (20% increase in durables, 1% in housing). However, with regards to investment, results are mixed. For common properties, we see significantly greater investment in higher education (students 18 to 22 years), but not in other age categories or other types of investment. For private properties, there may be more investment in cattle by those below median wealth, but we also see significantly less investment in agricultural inputs. Together, the results suggest that available surplus from the program is more likely to be used for consumption than investment by poorer households, which is sensible given that richer households already possess more of the basic durables and housing goods.

5.2.5 Participation costs

The surplus expected by landowners from an avoided deforestation program should be the difference between the payments and the opportunity costs of foregone deforestation, minus transaction and implementation costs. Survey participants were asked questions regarding the application process for the program, including the time spent to apply and payments to intermediaries and regarding the implementation costs in terms of forest conservation activities.

We find that application costs are relatively small as a fraction of the overall payments across five years, constituting approximately .006 and .016 of total payments to common and private property beneficiaries, respectively. The types of costs that case study community leaders and private property owners said they had incurred as part of the application process include transportation costs to visit the CONAFOR office in the state capital, photo copying and internet usage. 4 of the 14 of the technical assistance contractors interviewed also claimed that they incurred significant costs in assisting the community to prepare the application.

However, a surprising result from the survey data is that program implementation costs are considerable compared to payments. The most important household-level costs of the program are related to labor engaged in forest conservation activities. Community leaders in beneficiary common properties report on average a greater number of worker days per year spent in fire prevention (+66 days), pest control (+17 days), and forest patrols (+142 days) compared to non-beneficiary common properties. Valuing all labor—both paid and unpaid—at the minimum wage, we estimate that the median ratio of the cost of additional labor in beneficiary communities relative to the amount of the payments is 0.84.[24] Private households also report more days spent in fire prevention (+38 days), pest control (+4 days), and forest patrols (+76 days). In private households, the median ratio of additional labor costs to payments is 1.1. These high ratios suggest that the program may just cover the additional costs of forest protection, particularly against longer-term threats to forest health or from illegal logging.[25] It is important to note, however, that the longer term benefits of forest conservation may compensate communities in the future for these current labor investments, as suggested by previous case study research (McAfee and Shapiro 2010).

5.3. Potential leakage mechanisms

One of the research questions which we are continuing to probe are the potential avenues through which program payments might spill over into agricultural or labor markets in such a way as to undermine the original program goals. Our preliminary study of the 2004 cohort (Alix-Garcia *et al.* 2012) gave some evidence that "slippage" of deforestation might occur, particularly in common property communities. In this section we present some preliminary results on potential sources of program leakage. The evaluation framework is the same as above – we compare beneficiaries with reject applicants between 2007 and 2011.

[24] The mean annual payment for common property communities, excluding payments given for technical assistance, is 352,567 pesos. This is equivalent to US$ 30,082. These calculations subtract labor which could have been generated by other CONAFOR programs also operating at the community level. We note that the estimates of labor changes induced by the program in common properties are much smaller if we use data reported by the households themselves. For all households in common properties, we find that on average the program induces a change of 4.4 additional days of labor in forest conservation (relative to the changes in labor in non-beneficiary communities). For non-member households, the program induces six additional days of forest labor and for member households, the program induces 3.6 additional days of forest labor. Valued at the minimum wage, 4.4 days of labor is worth about 255 pesos, which amounts to only 16 percent of the estimated mean per capita payment (assuming the total payment is divided evenly among members). We think this difference may be explained by a skewed distribution of forest conservation activities among households—the system of rotating responsibilities for community activities means that some households will disproportionately contribute to forest conservation in any given year but might not have been surveyed in the household sample. Also, in many communities the payments were used to hire labor for the extra activities and some of the labor may have come from outside of the community.

[25] These ratios may also be overestimates if households value their labor at less than the minimum wage. For private households these labor costs tend to be paid labor extracted directly from payments, whereas for common properties they often represent voluntary service within the forest.

The case study interviews we conducted may offer insight into whether the program has induced expansion of agricultural production, although these types of impacts are often so complex and diffuse that they are not easily observed. Of the 18 interviewees who discussed the impact of the program on agricultural production, 10 felt that it had no impact, 6 felt that it had a negative impact, and only two felt that it had a positive impact. Several interviewees said that households were using program funds to purchase seeds and fertilizer. While we might assume that this would lead to an increase in agricultural production, two separate interviewees suggested that it might instead lead to an intensification of the use of existing agricultural land by increasing production per land area and/or allowing producers to decrease the time between crop rotations. A number also said that expansion was unlikely in ejidos because there are such strict limits on how much and which land each member can use for agriculture. A few interviewees, primarily private property owners, also mentioned using the program funds to increase the number of agricultural laborers they employed, another factor which could potentially lead to expansion of agricultural land use.

Using the survey data, we considered a wide variety of outcomes to try to assess whether or not deforestation leakage might be generated by the program. These outcomes explore four important dimensions that might affect the environmental effectiveness of the program. First, we look at outcomes related to agricultural production decisions, such as the area of land used for agriculture, different types of agricultural investments, and types of crops cultivated. Second, we consider livestock production outcomes, such as number of animals and livestock infrastructure investments. Third, we explore outcomes related to forest extraction activities, such as the amount of firewood collected and the number of different forest products extracted, among others. Finally, we analyze labor market outcomes, such as the type of work and number of days devoted to different types of activities.

The analysis of program leakage is still in progress, but findings so far show zero average impacts on most agricultural production outcomes, with the exception of some changes in the types of crops that are being cultivated. There are also no impacts in labor market outcomes; therefore, we do not present these results here—they can be examined in some detail in our 2011 report to CONAFOR. Table 5.6 summarizes the significant results from a variety of dependent variables. These results refer to the analysis within common properties, and so are divided between members and non-members.

We can see that, over time, households that live in communities that benefit from the PSAH program reduce their production of staple crops, mainly maize and beans. There is no evidence of increases in production of other crops, such as cash crops, but we do observe positive impacts on households' participation in livestock activities, ownership of grazers, and quantity of large grazers, such as cattle. Most of the impacts on livestock activities are coming from members within the community, and changes in agricultural choices are observe across both types of households. We also observe increases in the amount of firewood collected, which is used not only for cooking but to produce charcoal that is sold in local markets.

Table 5. 6: Potential sources of leakage: average effects

	Produces staples	Quantity staples cultivated	Participates livestock activity	# Large grazers	Has large or small grazers	Quantity firewood collected
FULL SAMPLE						
Beneficiary	-0.106***	-0.119**	0.042*	0.041**	0.032	0.043**
	(0.038)	(0.048)	(0.023)	(0.020)	(0.021)	(0.019)
N	2,250	2,145	2,250	2,250	2,250	1,735
MEMBERS						
Beneficiary	-0.110**	-0.121**	0.046*	0.036	0.054**	0.047*
	(0.043)	(0.054)	(0.027)	(0.026)	(0.026)	(0.025)
N	1,464	1,401	1,464	1,464	1,464	1,162
NON-MEMBERS						
Beneficiary	-0.104**	-0.118*	0.033	0.040	-0.015	0.037
	(0.051)	(0.061)	(0.046)	(0.031)	(0.040)	(0.037)
N	778	736	778	778	778	570

* p< .10 ** p < .05 *** p < .01
Estimates include household fixed effects and standard errors clustered at the community level. Continuous grazers include variables have been transformed to logs using the inverse hyperbolic sine transformation. Members are households with land-use rights. Staples include maize and beans. Large cattle, horses, and bullocks.

We evaluate whether there are heterogeneous treatment effects depending on how PSAH funds are distributed to households within communities. More specifically, we consider whether community leaders provide lump-sum transfers to households or not. Given the endogeneity in the distributional choice, we exploit community-level information and use non-parametric techniques to predict, in a first stage, the distributional rule that communities in the control group would have adopted in case they had entered into the program.[26] In a second stage, we use the full sample to estimate heterogeneous treatment effects taking into account the predicted distributional rule. We consider a dummy variable that takes the value of 1 when lump-sum transfers are provided (or could have been provided for non-beneficiaries) and 0 otherwise. As we can see in Table 5.7, in communities with lump-sum transfers, and mostly for member households, there is an increase over time in investments related to livestock and forest activities, such as the

[26] For more details on this identification strategy, please check: Yañez-Pagans (2013).

numbers of large grazers or the number of different forest products extracted.[27] These activities could potentially be tied to program leakage, depending upon where the animals are pastured and the types of forest products that are extracted.

Table 5. 7: Potential sources of leakage: heterogeneous effects by distributional arrangement

	Participate livestock activity	# Large grazers	Has grazers	Participate forest activity	Timber extraction	Total forest products
FULL SAMPLE						
Beneficiary	0.020	0.033	0.003	-0.002	-0.008	-0.008
	(0.030)	(0.024)	(0.027)	(0.013)	(0.008)	(0.006)
Distrule*benef	0.046	0.032	0.058*	0.061**	0.027*	0.032**
	(0.035)	(0.036)	(0.031)	(0.029)	(0.015)	(0.015)
N	1,688	1,688	1,688	1,688	1,349	1,688
MEMBERS						
Beneficiary	0.041	0.012	0.031	0.009	-0.006	-0.000
	(0.035)	(0.032)	(0.032)	(0.013)	(0.011)	(0.008)
Distrule*benef	0.068*	0.064*	0.075**	0.062*	0.024	0.029*
	(0.038)	(0.038)	(0.035)	(0.033)	(0.018)	(0.016)
N	1,106	1,106	1,106	1,106	894	1,106
NON-MEMBERS						
Beneficiary	-0.034	0.056	-0.058	-0.025	-0.010	-0.020
	(0.067)	(0.039)	(0.060)	(0.032)	(0.010)	(0.014)
Distrule*benef	0.008	-0.032	0.015	0.059	0.033	0.035
	(0.071)	(0.074)	(0.052)	(0.048)	(0.025)	(0.022)
N	580	580	580	580	453	580

* p< .10 ** p < .05 *** p < .01
Estimates include household fixed effects and standard errors clustered at the community level. Continuous variables have been transformed to logs using the inverse hyperbolic sine transformation. Members are households with land-use rights. Staples include maize and beans. Large grazers include cattle, horses, and bullocks.

When we consider heterogeneity across space in ejido investment, households living far from urban centers show a significant increase in the propensity to invest in health as a result of the program, although these households also had a much higher propensity to do so in the baseline. Private households show no significant changes in investment, even when disaggregated by distance to urban area. Overall, it appears that the most severely credit constrained households (those in common properties, in remote areas, and with little investment in the baseline) do experience significant and positive investment impacts from the program.

[27] Some examples of forest products extracted are timber, firewood, flowers, plants, and fruits, among others.

Our initial hypothesis surrounding program production leakage revolved around the idea that the program loosened credit constraints, allowing for expansion of production. There is mixed evidence on this from the case study and survey data. Of the 20 case study interviewees that discussed program impacts on access to credit, 16 claimed that there was no impact, four that there was a positive impacts. For those that said that program participation provided some type of increased access to credit, three were from communal properties and one was a private property holder. In one communal property, a community leader said that the forest management the program had supported has improved the quality of the wood produced to such an extent that community members are now able to receive advances from lumber yards since they are sure they will get high quality product. In two communal properties that condition direct transfers to households on participation in communal workdays to complete program activities, many families have asked community leaders to advance funds before the work is complete. In these cases, interviewees said that the reason families asked for the loan were to cover unexpected medical expenses, to get family members out of prison, or to help cover the expenses of sending a child to the US. The private property owner said that participation in the program not only helped secure loans, but also another federal subsidy program from the Ministry of Agriculture, SAGARPA, though he did not specify how. Of those interviewees that said that they have not tried to use the program to access credit, the reasons they gave included: worry that they would not be able to pay back high interest bank loans; fear that CONAFOR would punish them if they use program funds a collateral; that the program is not well known enough to be acceptable as collateral; that there was no place they could go to access credit.

When we look at households' demand for credit using the survey data, we find that in private households, fewer beneficiary households requested a loan in the past 12 months (24% of beneficiaries versus 33% of non-beneficiaries). Of those who request loans, the vast majority (94%, receive them), and the main sources are private banks or the Caja Popular. One interpretation of this is that beneficiaries need fewer loans, since they have income from the program to supplement their liquidity. This would be a positive impact of the program since it is likely to lower households' overall borrowing costs. An alternative hypothesis is that beneficiaries have less access to credit and therefore do not request loans, but we find that 74% of the beneficiaries believed that a loan would have been easy to get if they had wanted one, compared to 58% of the non-beneficiaries. Seventy-five percent of beneficiaries who did not request loans also said that they didn't need one during the past 12 months, compared to 63% of non-beneficiaries. In common property households, 27% of households ask for a loan in the past 12 months, and this difference was not significant between beneficiaries and non-beneficiaries. Ninety-six percent of those common property households requesting loans receive one, though most of these come from family or friends. It appears that the program funds help replace formal credit for private households, but do not affecting borrowing behavior of common property households.

Finally, we also considered heterogeneous treatment effects taking into account whether a household is credit constrained or not. For this, and given that credit information was collected only for 2011 and might be affected by the program, we first estimate the probability of being credit constrained using baseline household and community-level characteristics and considering only the sample of non-beneficiary households. Most of the results, however, indicate that the program does not have differential effects based on whether the household is credit constrained or not. We are currently in the process of evaluating more carefully this and other information to better understand all potential sources of leakage.

Summary

This section of the report shows that the program has not significantly affected agriculture or livestock livelihoods and may have had some positive impacts on credit constraints. The majority of beneficiaries originally employed in agriculture, livestock, or forestry remain employed in those categories and the overall percentages of people employed in each sector are very similar across time. Production of food crops, in general, does not decrease on average or show different trends between beneficiaries and non-beneficiaries. There are some reductions in the amount of staple crops produced, but there is no evidence of negative program impacts on households' food consumption, which suggests that the program does not compromise food security. Both beneficiaries and non-beneficiaries show intensification of agriculture and rising value per hectare of production across time. We do not see significant differences between beneficiaries and non-beneficiaries in whether agricultural products are sold outside of the community although there is some evidence that common property beneficiary households are selling more within the community; it is possible that the cash payments have helped to activate local markets. Reported prevalence of land clearing for cultivation is also not significantly different across beneficiaries and non-beneficiaries.

Livestock production trends are generally not significantly different between beneficiary and non-beneficiary households, again results that are reassuring from a livelihoods perspective. We do, however, see an increase in the average number of livestock owned by beneficiary common property households, possibly indicating a positive impact on assets. The provision of lump-sum transfers in common property communities seems to incentivize more household investment in livestock activities, although this might also suggest the possibility of observing more leakage in these areas. Private property households overall showed decreases in livestock production and land used, but trends were very similar across beneficiaries and non-beneficiaries.

With respect to investment, we find tentative evidence that the program may have relaxed credit constraints for some households. We see less borrowing among private property beneficiaries and we see some increased production of cash crops among poor common property households. Common property households who were not investing in new crops or livestock infrastructure at baseline are more likely to invest in 2011 if they were beneficiaries. A related investment effect is the evidence that the program appears to have helped ejidatario households receiving lump-sum transfers and private property households to keep their kids in school longer, an investment likely to pay off in the future.

Although the lack of substantial increases in production or investment is somewhat disappointing from a poverty alleviation/income generation standpoint, it is reassuring that trends are generally similar between beneficiaries and non-beneficiaries. This suggests the program has largely preserved livelihood strategies that would have been adopted in the absence of the program. It is also reassuring in terms of possible concerns about substitution slippage or "leakage" (Alix-Garcia *et al*. 2012 which could have occurred if cash payments encouraged expansion of production that required new clearing on other parts of the same properties.

5.4 Direct participation costs of program for applicants

This section summarizes the costs of both application for and implementation of the program. It uses information from both the leader surveys and the household-level estimations of labor allocated to the program. The opportunity costs of the program, which might be from foregone agricultural or forestry production, have already been discussed and generally seem to be small. However, in general the application costs and participation costs seem to be large compared to the size of payments, particularly for smaller landholders.

5.4.1 Application costs

Survey participants were asked a variety of questions regarding the application process for the program, including who did the majority of the work, how much money was used to apply for the program, and the cost of application in terms of time. One shortcoming of our study is that we are unable to compare these costs to the costs of applying for other federal programs; hence, we cannot assess the PSAH application costs relative to similar programs within Mexico (or abroad). Since our survey is uniquely composed of program applicants, we can compare the effort put into application by both beneficiaries and non-beneficiaries.

Successful applicants from common properties tend to have spent significantly more time acquiring the relevant documents to apply for the program—they spent, on average, 109 days collecting this information, relative to non-beneficiaries, who spend 35 days on average. Private households spend significantly less time than ejidos collecting this information, which is not unexpected given the complications of decision-making in common properties. On average, they spend between 15 (beneficiaries) and 18 (non-beneficiaries) days collecting information required for the application, with no significant difference between successful and unsuccessful applicants. In both cases, the number of days required to complete the application is quite large—two work weeks for private beneficiaries, and considerably more for common property communities. At the same time, these application costs are relatively small as a percentage of the overall payments across five years. If we value this time at the minimum wage, these numbers constitute only 0.49% and 0.36% of total payments to private and common property beneficiaries, respectively.[28]

During the application phase, a considerable amount of money is also spent on payments to intermediaries and community members, travel and documentation. A sum of the mean amounts spent on each item indicates total payments for successful applicants on the order of 4,870 pesos for communities and 1997 pesos for private properties. However, these are again relatively small percentages of the total payments: 0.28% for common properties and 1.12% for private properties.

In addition, applicants make a significant number of trips to CONAFOR offices during the application process—common property applicants averaged 3.5 visits (with no significant difference between successful and unsuccessful applicants), private beneficiaries averaged three trips, and non-beneficiaries two (difference statistically insignificant). Finally, common properties incur the additional time cost of holding community assemblies to discuss application to the program. Applicants average nearly three such assemblies, with no significant difference between beneficiaries and non-beneficiaries.

5.4.2 Implementation costs

The calculation of the costs of program implementation is fraught with complications, particularly the cost of labor used in implementing the program (see below). Here we discuss approximations for the costs of technical assistance, materials, and labor used in implementation of the PSAH. A large percentage of beneficiaries receive technical assistance to implement the PSAH – 88 and 87% for common and private property beneficiaries, respectively. On average, leaders report these payments to be 186,949 pesos, or 51% of the average *yearly* common property payment, though of course if we take into account total program benefits it is considerably lower. For private households, survey participants report spending 33,772 pesos on these payments, which is almost equivalent to the average yearly PSAH payment for private properties, which is 35,600 pesos.

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[28] To do this calculation we consider the daily minimum wage reported by CONASAMI for the whole country for 2011, which is 58.1 pesos. Program payments exclude those given for technical assistance. The average payment for the five years for common property communities is 17,762,835 pesos and for private households it is 178,880 pesos.

Calculating the labor costs of program implementation is very difficult as labor may be valued differently depending on the alternative opportunities available to households. To make an estimate that can be compared to the payment amounts, we value labor using reported wage values within the community. In cases where all wages are unpaid, we use wage values for neighbouring communities to estimate reasonable rates. Both through the survey and through CONAFOR, we currently have information on the overlap of our surveyed properties with other CONAFOR programs. In some calculations, we are therefore able to assume that costs for activities associated with these programs (reforestation, for example) are not being paid out of PSAH funds.

Here we report only "induced" labor—that is, the extra forest labor resulting from the program (the difference between beneficiaries and non-beneficiaries). We report estimates with and without considering other CONAFOR programs, and using both leader and household reports (Table 5.8). Beginning with ejidos, we observe that the ratio of labor costs to benefits has a tremendous range, from a minimum of .01 to a maximum of 0.83. The estimates derived from days worked reported by ejido leaders are quite high: counting all labor, and excluding from the calculation activities covered by other CONAFOR programs, the median ratio of labor to payments is 0.75. Keep in mind, however, that these calculations also include unpaid labor (*faenas*) valued at the minimum wage. It also may very well not be the case that individuals place this exact value on their time. The median ratio of induced paid labor to program yearly payments, taking into account participation in other CONAFOR programs, is 0.02. The household ejido data suggests that between 13 and 20% of program payments can be considered compensation for labor (20 coming from the calculation which excludes activities paid for by other CONAFOR programs, and 13 without adjustment from additional CONAFOR programs[29]). When we factor out "additional" labor (using the differences over time reported by households), we observe that between 6 and 7% of payments can be considered as compensation for this activity.

Finally, the labor paid for by private participants exceeds the program payments. However, it is important to note that even non-beneficiaries spend a considerable amount of money each year on hiring labor to take care of the forest—for example, non-beneficiaries in 2011 average 45,879 pesos per year in paid forest maintenance labor. Beneficiaries averaged 156,454 pesos, implying that participating in the program increased labor expenditures by 110,575 pesos. Unlike ejidos, private households tend to hire in the majority of the labor used in the forest—over 90% of forest labor in private properties is paid.

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[29] The percentages with the adjustment from additional CONAFOR programs are higher since we are also taking into account the participation of non-beneficiaries in other CONAFOR programs.

Table 5. 8: Labor costs to PSAH payment ratios

Labor calculation	Median/yearly PSAH payment
Without using information about participation in other CONAFOR programs	
Total beneficiary—Non-beneficiary labor, 2011(Ejido leaders)	0.833
Paid beneficiary—Non-beneficiary labor, 2011(Ejido leaders)	0.015
Total beneficiary—Non-beneficiary labor, 2011(Ejido households)	0.196
(Total beneficiary—Non-beneficiary labor, 2011)—(Total Beneficiary—Non-beneficiary labor, 2007) (Ejido households)	0.077
Total beneficiary—Non-beneficiary labor, 2011(Private properties)	1.104
Paid beneficiary—Non-beneficiary labor, 2011(Private properties)	0.634
With information about participation in other CONAFOR programs	
Total beneficiary—Non-beneficiary labor, 2011(Ejido leaders)	0.751
Paid beneficiary—Non-beneficiary labor, 2011(Ejido leaders)	0.017
Total beneficiary—Non-beneficiary labor, 2011(Ejido households)	0.133
(Total beneficiary—Non-beneficiary labor, 2011)—(Total Beneficiary—Non-beneficiary labor, 2007) (Ejido households)	0.068
Total beneficiary—Non-beneficiary labor, 2011(Private properties)	1.040
Paid beneficiary—Non-beneficiary labor, 2011(Private properties)	0.486

Table 5.9 indicates a measure of economic or opportunity cost, since it considers all forest labor, whether paid or unpaid. We consider this the best reflection of the full labor cost of program implementation. However, we also engaged in one further calculation using the information from leaders that indicated to us in which activities PSAH funds were actually used. Table 5.8 calculates the total payments for activities which were indicated as financed with PSAH funds, relative to program payments. In this case, all of the calculations indicate that wage payments are not actually exceeding program transfers.

Table 5. 9: Actual payments for activities in beneficiary communities, relative to program payment

Labor calculation	Median/yearly PSAH payment
Total beneficiary (ejido leaders)	0.631
Paid beneficiary (ejido leaders)	0.007
Total beneficiary, 2011(ejido households)	0.136
(Total beneficiary, 2011)—(Total beneficiary, 2007) (ejido households)	0.054
Total beneficiary (Private properties)	0.475
Paid beneficiary (Private properties)	0.402

In summary, by most of the possible measures, the available surplus of the program beyond covering costs is quite small. This provides some explanation for the small average impact on assets observed above.

One explanation for the increase in the labor dedicated to forest management activities by both ejido and private property beneficiaries to a cost beyond that covered by the PSAH payments is that, at least in some sites, there was a need and a desire to improve management practices but not the capital to do so or a strong motivation to conserve forests. In addition, in areas with tree species suitable for lumber, additional labor for forest management may pay off directly in the long run, as work to protect the forest against fires, logging by outsiders, pests or disease is an investment in future harvests. As one community leader in Chihuahua explained when asked why his ejido had chosen to enter the PSAH program:

> It was precisely because of the high incidence of forest fires. You need to take care of your resource, no? To have funds given to you to take care of it, how wonderful. We had been [protecting it] ourselves but with money we obtained through timber harvest.

Based on the case study data, it appears that participants generally perceived the benefits of the program as outweighing the costs and were divided on whether the payment amount was sufficient to cover the costs of implementation. Of the 13 interviewees who discussed whether they felt the benefits outweigh the costs, all said that they did. Of the 16 interviewees who discussed whether the payments were enough to cover the costs, 9 said they were sufficient and 7 said not. The reasons given by those who felt that the payment was insufficient were that implementation of the forest management activities required significant added investments of labor and/or financing from the landowners and, in one communal property case, that there were so many ejidatarios that the amount received by each was very small.

Summary

Our survey data indicate considerable costs to applicants both from applying to the program and implementing forest management activities. Application costs are relatively small compared to the overall payments, but the full costs of additional labor used for implementation (if valued at the minimum wage) are large compared to overall payments. This indicates that the costs of participating in PES programs may deserve more attention. To date, most theoretical analysis of PES (including ours) has focused on the opportunity costs of possible forgone production, and opportunity cost has been used as a justification for setting payment amounts (Muñoz-Piña *et al.* 2008). However, the costs of forest management as well as the transaction costs of enrolling and communicating with CONAFOR deserve additional study since they may in fact be larger than opportunity costs. It would be important for CONAFOR to find out more about why participating communities are undertaking multiple forest management activities, since it is possible that there are also significant benefits from these activities which are gained by communities and households.

6. Policy recommendations

In the report that we gave directly to CONAFOR, we addressed several policy issues that were specific to their situation. We have omitted these here in favor of the more general prescriptions that arise from our analysis.

6.1 Environmental benefits, opportunity costs, and targeting

As discussed above, it would be difficult to further modify the program targeting strategy in order to simultaneously achieve jointly the goals of forest conservation and poverty alleviation. The one exception to this is potentially augmenting the amount of payments going to common property communities, given that they are both relatively poor and have a higher tendency toward deforestation than the private properties. We are cognizant of the fact that the program has already been combined with other PES programs managed by CONAFOR, and we applaud this interest in harmonizing criteria and potentially minimizing the administrative burden of these programs by conducting all of the resource allocation activities within one exercise.

Conceptually, one can think of the actual payment for environmental services as compensating the owner for, at a minimum, the opportunity cost of the land enrolled (the foregone profits from that land) plus the direct costs of participating, and at a maximum for the environmental benefits from that land which accrue to society as a whole. This statement has two implications for the setting of payment rates:

1. If landowners are not sufficiently compensated for what they would have otherwise earned using the enrolled land and time devoted to forest management, they will not participate.
2. From an economic perspective, it is not “efficient” to pay landowners if the environmental benefits of their participation are less than their opportunity cost.

For all practical purposes, however, it is extremely difficult to measure “environmental value.” Given this reality, the most cost-effective way of allocating payments in environmental programs is to calculate some measure of environmental benefits, and some measure of opportunity cost, then give each property a score based upon the ratio of benefits to cost. Properties with the highest benefit to cost ratio should receive payments first. This is similar to the methodology used by the US Conservation Reserve Program in the targeting of their program (http://www.ers.usda.gov/topics/natural-resources-environment/conservation-programs.aspx).

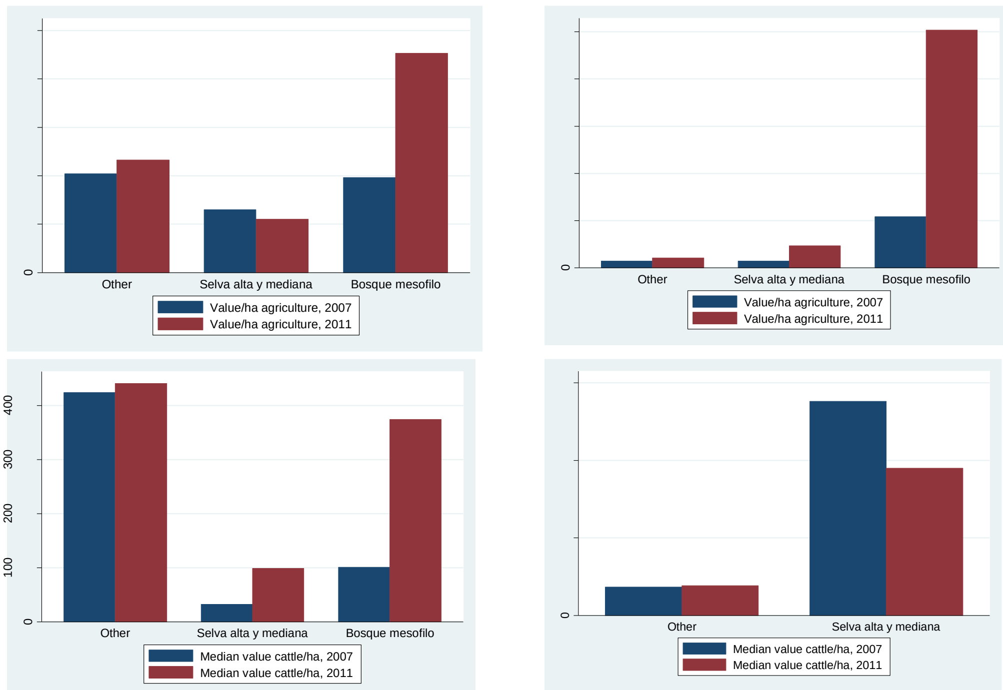
One of the complications here is that, theoretically, this ratio is undefined for forest with no anticipated use (in other words, an opportunity cost of zero). An alternative solution, which also avoids the problem of spending large amounts of money for environmental services that were never at risk of being lost in the first place, is proposed in Alix-Garcia *et al*. (2005). These authors suggest that weighting the environmental benefits by the risk of deforestation, thus creating a measure of "expected benefits," can help circumvent this problem. In essence, this assumes that the risk of deforestation is correlated with opportunity cost, so risk is used as a proxy. CONAFOR already uses INE's risk of deforestation layer to help target its payments, and in this sense partially satisfies this criterion. In addition, the existing layer used for establishing deforestation risk is now getting somewhat older, and it might be useful to update this tool using the existing Monitoreo de Deforestacion.

6.1.1 Revenues and the current payment scheme

The component of the 2010 targeting criteria that only corresponds partially to the guidelines presented here is the levels of the differentiated payments. The payment values themselves seem to be correlated with perceived environmental benefits rather than with opportunity costs. Our survey does not give us the information necessary to calculate opportunity costs of the land enrolled in PES. This calculation will require a lot of information and involves several complexities. Opportunity costs need to include all of the profits foregone from not using the land for other activities. The calculation of profit requires both revenues and input costs for expected land uses. Our data provides, for agriculture, pastoral activities, and forest extraction, an approximation of revenues (quantity of production multiplied by prices), but we have no way to approximate input costs, which would require significant field work in order to detail the labor inputs used in the production of the goods in question. In the following paragraphs, we examine the correlations between the current targeting scheme and these values, and then examine the variation in these values across regions. Because we do not find large program impacts on the benefits generated from agricultural or pastoral production, we include in this presentation statistics from beneficiaries and non-beneficiaries aggregated together. We do not include values from households that do not engage in these types of production.

Figure 8 shows median values by enrolled forest type for those who engage in agricultural and/or pastoral production. It is not clear, in our data, that the highest payments are being given where alternative values of the land are the highest. If this were the case, we would expect the level and growth of agricultural and pastoral yields to be highest in areas with cloud forest, then in areas with rainforest, and finally in other forest types. On the left panel of the graph we observe the values for ejidos, and on the right for private properties. Agricultural revenue growth was indeed highest in both private and communal properties that enrolled at least some cloud forest. However, in the ejidos, where the vast majority of residents engage in agriculture, the levels and growth of agricultural production in the lowest paid category of forest are higher than for those enrolling rain forest. The level of pastoral production is also quite respectable for these properties, although it does not appear to be growing as fast as it is in the rain and cloud forest properties. Among private properties, none of those enrolling cloud forest engage in cattle production, and the growth of cattle production in rain forest areas seems to be decreasing.

Figure 8: Median values of agricultural and cattle production by enrolled forest type



Ejidos **Private properties**

Median values only include those households participating in agricultural or pastoral activities. On average, more than 80% of common property households engage in agriculture, and 25% have cattle. For private properties, only 55% engage in agriculture, and 36% have cattle.

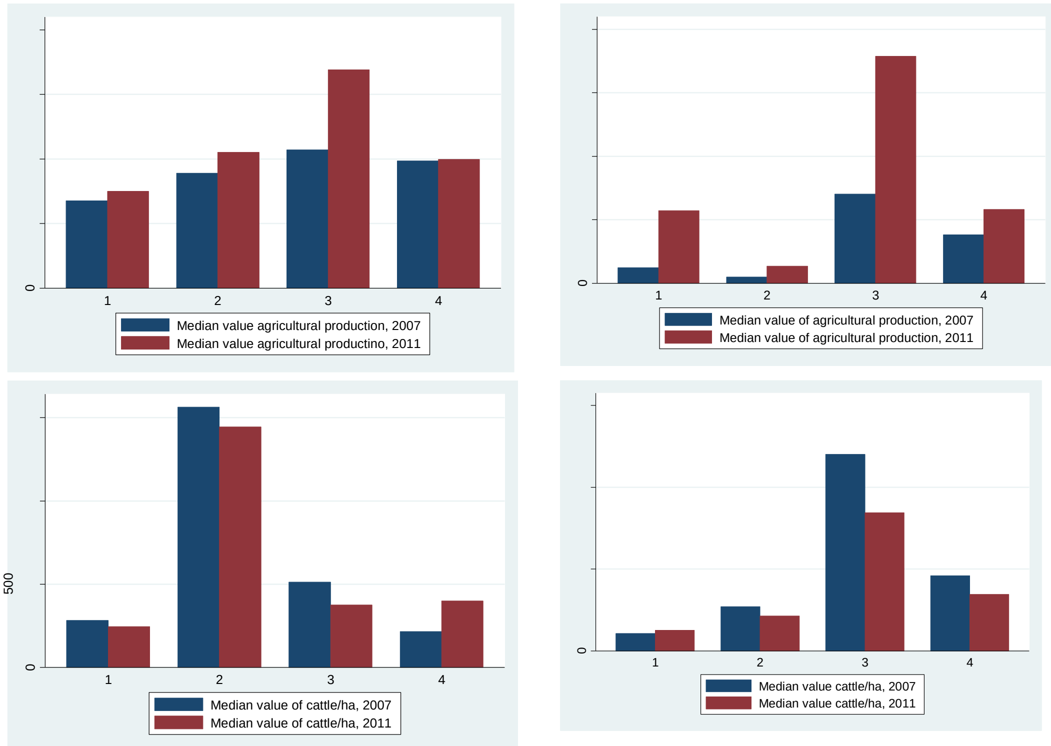
We would like to spend more time analyzing this information in order to provide a clearer assessment of the relative payment sizes. However, given the current statistics by forest type, it appears that while the higher payments to cloud forest are warranted from an opportunity costs perspective, it is not clear that such a generalization is possible for the relative difference between rainforest and coniferous/oak forests. The numbers overall suggest that payment rates might be set somewhat low—the median value of agricultural production per hectare (from Part II above) is US$1,891 for ejidos in 2011, and even higher for private properties engaged in agricultural activities. Two caveats to this statement are: (1) the number does not take into account costs of production, and (2) it is not clear that the land enrolled in the program is of the same quality as the land which individuals are currently farming. In fact, it is highly likely that the enrolled land has lower productivity possibilities.

A payment rate criterion that might correspond most closely to the framework above would be payments set at approximate values of alternative land uses, either agricultural or pastoral. The analysis in the previous section suggests that there is significant heterogeneity in revenues across regions, and this might possibly be an important way to stratify payments as well. We would recommend using information collected by researchers at the Universidad Autonoma de Chapingo, and the associated Centros Regionales. The data that we have thus far analyzed in our survey shed light only on the revenue side of agricultural and pastoral production, and it is necessary to understand costs in order to truly generate appropriate payment rates. Further analysis with more detailed data will be useful in helping to refine the levels of compensation for the program.

6.1.2 Regional variation in revenues

There seems to have been some sense, in our conversations with individuals from both the regional and the central CONAFOR office, that the variation in opportunity costs across the country has implications for the functioning of the PSAH. For this reason, we briefly examine the levels and growth of agricultural and pastoral revenues across regions. The median values per hectare for agriculture and cattle in 2007 and 2011 are shown in Figure 9. Here we observe that the highest levels of agricultural production in both years are in region 3, which includes Guerrero, Oaxaca, and Chiapas. This is also the region in which values have grown the most over time. For private properties, region 3 also has the highest level and growth of agricultural revenues per hectare. It is important to note that in most regions the levels of production for private households are an order of magnitude larger in private properties (note the scale of the y-axis). It is also important, however, to recall that more than 85% of the private property adults do not work in agriculture, but rather depend upon other sectors of the economy.

Figure 9: Agricultural and cattle values per hectare, common and private properties



Ejidos **Private properties**

The levels and trends in pastoral production differ in the ejidos, where the greatest amount of growth has taken place in region 4 (Veracruz, Tabasco, and the Yucatan Peninsula), while the highest level of production is encountered in region 2 (the central states south of Sinaloa, Zacatecas, Nuevo Leon, and Tamaulipas). In private properties cattle production, for those households that engage in it (around 35%) is significantly more valuable per hectare than agricultural production. As with agriculture, the most productive pastoral region for private households is region 3 (the South West). In all regions, the value of pastoral production has either fallen or remained the same over time for private households.

With a more detailed remote sensing analysis, it will be possible to correlate these values with a risk of deforestation in order to confirm the relationship between the two. One would expect that deforestation risk would be greater where there are higher values of alternative uses of the land. With this type of analysis in hand, it would be possible to calibrate the existing deforestation risk measurements in order to reflect this. A simple regression analysis reveals interesting correlations between the payment criterion (forest type), regional effects, and other covariates that we expect to determine deforestation. In particular, once other variables are controlled for, municipal measures of poverty to not affect the value of output. Values are lower in areas with higher slope and elevation, and, generally, higher where road densities are higher. Regions 2 and 3 tend to have higher values of cattle production, and region 3 of agricultural production. Once we control for regional variation, having enrolled forest with cloud forest is associated with significantly higher agricultural production for private properties, and much lower cattle production for ejidos. One should consider these impacts as changes in area of cloud forest enrolled, relative to other, non-coniferous, forest. Coniferous forests are associated with higher agricultural production, but lower cattle production.

Table 6. 1: Correlates of agricultural and cattle revenues

		Dependent variables			
		Ln(agricultural value/ha)		Ln(cattle value/ha)	
		Ejidos	Private properties	Ejidos	Private Properties
Deforestation risk variables	Median slope (deg)	-0.000**	0.000	-0.058**	-0.041
		(0.000)	(0.001)	(0.024)	(0.048)
	Median elevation (m)	-0.023*	-0.037	-0.000	0.001
		(0.012)	(0.067)	(0.000)	(0.001)
	Road density in 10 k buffer (km rds/ km2)	1.877	7.670	8.312***	-7.107
		(1.901)	(5.012)	(3.097)	(4.835)
Targeting variables	Proportion enrolled area coniferous	0.534**	0.674	-1.296**	-0.243
		(0.243)	(0.569)	(0.537)	(0.428)
	Proportion enrolled area bosque mesofilo	1.132	2.922***	-7.638**	
		(0.763)	(0.606)	(3.341)	
	Municipality poverty	-0.118	0.065	-0.222	0.314
		(0.079)	(0.334)	(0.215)	(0.399)
Regional variables	Region 2	0.304	-1.040	1.727***	1.764*
		(0.191)	(1.067)	(0.459)	(0.906)
	Region 3	0.447*	1.714	1.974***	3.202**
		(0.237)	(1.299)	(0.638)	(1.364)
	Region 4	-0.529	0.762	-1.681**	2.604
		(0.407)	(1.742)	(0.786)	(1.887)
	Constant	7.992***	6.307***	7.098***	6.244***
		(0.320)	(1.753)	(0.765)	(1.757)
	N	824	51	258	44
	R-squared	0.0579	0.4468	0.3948	0.3571

6.2 Weighting schemes in the selection process

This last section represents some reflections on the weighting scheme currently used by CONAFOR in the selection process. A first point is that these criterion change with great frequency. We have observed above that, on average, these changes have generated improvements in the targeting of the program. Over time, we see more payments going to places with higher deforestation risk and poverty. As a general observation, however, it is worth noting that it is difficult to establish separate impacts of rule changes when the rules change with such frequency; in particular, when rules change every year, it is difficult to say whether differences in impact are due to some external shock occurring at the same moment (such as changes in agricultural prices, wages, or timber prices), a peculiarity of the cohort, or to the rules themselves.

More specifically, there seems to have been a trend of adding more criteria over time in order to improve the targeting process. In principle this could result in positive changes, but it also leads to difficulties in implementation. It is therefore important that additional criterion be associated with specific program goals, and that the addition of new criterion does not undermine the potential impact of the program. Table 6.2 serves to underscore this point. The table was developed on the basis of the hydrological services criterion associated with article 14 of the 2010 rules of operation. It is probable that these rules have changed somewhat, but the general implications of this exercise remain the same. The table shows the maximum and minimum points for each criterion. It also attempts to associate each criterion with one of four goals: poverty, environmental quality, opportunity cost, and implementation capacity. The first two are the stated purpose of the program, and constitute measures of the "benefits," social and environmental, of enrolling particular properties. The third is associated with generating avoided deforestation impact—that is, giving a higher weight to properties with higher opportunity cost/risk of deforestation—and the fourth with giving payments to properties where contracts are more likely to be honored.

At the bottom of the table we have summed up the maximum and minimum points associated with each of the broader criterion. Working under the assumption that properties are ranked according to the simple sum of points, we begin with the observation that the maximum total points for a hydrological services property according to this schedule of points is 89, and the minimum 19. A second observation is that this system gives the highest weight (55%, to be exact) to environmental quality and the lowest points to opportunity cost. This is likely to result in the selection of properties with high environmental quality that are not at risk of deforestation.

At the very bottom of the table, under the panel heading "system with equal weights on each component," we have shown a system which allows for the same calculation of points, but gives equal weight to the categories of environmental quality, poverty, implementation capacity, and opportunity cost. To implement the equal weights, the number of points is divided by the maximum number of points possible so that each category is normalized to be between 0 and 1. Each then receives .25 or ¼ of the total weight. Note that the equal weighting system is arbitrary. It might be the case, for example, that policymakers would want to give a higher weight to poverty, or to opportunity cost. In any case, if program managers would like to broadly maintain equal prioritization under the broader categories, while allowing for the introduction of new criterion over time, they might consider using a system such as this one, which calculates a score within each of the categories, and then maintains a constant weighting system through time. This does not eliminate the possibility of introducing new criterion, for example, certified forest, but it does limit the likelihood that the introduction of these new criteria undermines the other goals of the program.

Table 6. 2: Weighting of targeting scheme

Criterion	Max	Min	Program goal
Social criterion			
Ejidos never having received support from ProArbol	7	0	Poverty
Applications from within 100 x 100 municipalities	5	0	Poverty
Applications from SEDESOL priority attention zones	3	0	Poverty
Municipality with majority indigenous population	3	0	Poverty
Female applicant	2	0	Poverty
Stimulant to good forest management	3	1	Implementation capacity
Criterion for both modalities (biodiversity and water services)			
ANAP	5	1	Environmental quality
Other PSA polygons in watershed	5	1	Environmental quality
Ejido o comunidad with Red Vigia	3	1	Implementation capacity
Area of influence for local development mechanism	4	1	Environmental quality
Ordenamiento Ecologico Territorial	4	1	Implementation capacity
Deforestation pressure index	6	2	Opportunity cost
Natural Disaster Zone	6	2	Environmental quality
Georeferenced polygon	4	1	Implementation capacity
Hydrological services criterion			
% with forest cover	5	1	Environmental quality
Overexploited aquifer	6	3	Environmental quality
Superficial water availability	7	1	Environmental quality
Soil degradation	3	1	Environmental quality
Strategic restoration zone	3	1	Environmental quality
Biomass density	5	1	Environmental quality
Actual weighting system			**Implied weight**
Environmental quality points	49	13	0.55
Poverty points	20	0	0.22

Implementation capacity points	14	4	0.16
Opportunity cost points	6	2	0.07
Score	89	19	
System with equal weights on each component			
Environmental quality points/49	1	0.26	0.25
Poverty points/20	1	0	0.25
Implementation capacity points/14	1	0.29	0.25
Opportunity cost points/6	1	0.33	0.25
Equally weighted score	1	0.22	

6.3 Some lessons from Landsat

One of the most difficult parts of this evaluation was the measurement of forest cover, forest loss, and degradation. The process was fraught with complications which are likely to be common in all tropical countries, particularly those which, like Mexico, have complex topography. The outcome measure used in this report – NDVI – is not the precise measure that we intended to use initially for this project. We are still in the process of generating more precise measures so as to create reliable leakage estimates. Monitoring of forest cover is *essential* for any land-use management program, and our impression is that policymakers and academics have underestimated its complexity in the very locations in which it is most pressing. Here we briefly summarize the steps that we have taken, so that others might learn from the experience. The various processes are described briefly in Table 6.3, with further details subsequently.

Table 6. 3: Summary of the remote sensing datasets that we generated and the analyses that we conducted. Where the table refers to "13 footprints," this refers to the area of 13 Landsat satellite scenes, each about 183 x 183 km in size, which cover the majority of all properties enrolled in the program

Dataset	Description	Status
Vegetation change tracker (VCT) deforestation maps	Annual deforestation maps from 1993 to 2011 for all 13 footprints. Other ancillary datasets such as annual cloud-free Landsat composites were created to run VCT, and are a by-product of this final dataset.	Complete for all footprints for all years for which wet season images were available. However, due to data gaps, clouds, inconsistent phenology, open forests, and the limitations of the VCT algorithm, output deforestation maps were not sufficiently accurate to provide meaningful information about deforestation location and timing.
Annual Landsat forest/non-forest classifications	Forest/non-forest classifications of annual cloud-free Landsat composites from 1993 to 2011 for all 13 footprints. These composites differ from the VCT annual cloud-free Landsat composites in that they were created using the cloud masks generated by the more reliable Fmask algorithm and composited using an in-house algorithm that we developed for this project.	Complete for all footprints for all years that have wet season images. However, due to data gaps, clouds, inconsistent phenology, open forests, output deforestation maps were not sufficiently accurate to provide meaningful information about deforestation location and timing.
Trajectory analysis of Landsat classifications	Annual deforestation maps from the mid-1990s to the late 2000s for all 13 footprints. The analysis consists of an in-house algorithm that we developed for this project to confirm deforestation events by examining suspected events in the context of a user-defined number of years preceding and following the event.	Complete for five footprints. However, due to data gaps, clouds, inconsistent phenology, open forests, output deforestation maps were not sufficiently accurate to provide meaningful information about deforestation location and timing.
Google Earth deforestation analysis	Hand-digitized deforestation polygons resulting from a visual assessment of a sample of all available Google Earth high resolution imagery from the early 2000s to the present day for all 13 footprints. Imagery is not uniformly available for all areas and time periods within the 13 footprints, so the digitized deforestation polygons are not randomly sampled and only	Digitizing all deforestation polygons within the sampled imagery is complete, as is the quality assurance and the calculation of deforestation rates. Due to extended time periods between image capture dates (e.g. > 2 years) some deforestation is missed. This dataset cannot be used to assess the PES program, because most properties are not covered by high-resolution data, but it provided

	track deforestation in a small portion (~15%) of each footprint.	validation data for our other satellite analyses.
Enrolled/ unenrolled properties and ejidos examined in Landsat imagery	Visual investigation of potential deforestation events in all enrolled/unenrolled properties and ejidos from 2000–2012 in cloud-free annual Landsat composite images. Deforestation or missing imagery is noted in the dataset.	Complete for 2000–2012 for all footprints.
MODIS phenology analysis	Annual analysis from 2004-2010 of MODIS phenology images for all of Mexico. This dataset tracks the start, peak, and end of the vegetation growing season.	Complete for the entire country from 2004–2010. Due to data gaps and phenological inconsistencies, the summaries result in data that do not match expected vegetation conditions on the ground.

Our goal was to measure deforestation rates during the period 1990–2010 in 13 regions across Mexico by analyzing Landsat TM and ETM+ imagery for each of the study year's growing seasons (roughly July through September). After downloading the imagery from the United States Geological Survey's GLOVIS web portal (glovis.usgs.gov), we minimized the effects of variable atmospheric conditions on the imagery by processing it with the National Aeronautical and Space Agency's (NASA) Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) software (http://ledaps.nascom.nasa.gov/tools/secure/PREPROCESS).

We first attempted to measure deforestation of the atmospherically corrected imagery with the VCT algorithm (Huang *et al.* 2008), a program that automatically detects deforestation through consecutive growing seasons by searching for changes in surface reflectance values in the annual cloud-free Landsat image composites it creates. VCT generates a local image window (e.g. 5 km by 5 km) that moves through each cloud free Landsat image composite and analyses each resulting histogram for Landsat's band 3 (0.63–0.69 micrometers), the band in which forest pixels are most easily delineated from non-forest pixels (Huang *et al.* 2008). If a local image window has a sufficient proportion of forest pixels, these pixels will form a "forest peak" in the lower range of the reflectance values in the histogram and indicate the location of probable forest pixels (Huang *et al.* 2008). Because this forest peak is identified individually for each image through an analysis of its local image window histograms, this forest identification method is not sensitive to spectral variations between images due to vegetation phenology, atmospheric conditions, and illumination geometry (Huang *et al.* 2008). VCT compares the probable forest pixels against an existing land cover map produced by the Mexican National Institute of Statistics and Geography to ensure that it hasn't over-identified the quantity of forest in each local image window (Huang *et al*. 2008). Also, in order to exclude non-forest pixels located in the forest peak by virtue of their low reflectance values in band 3 (for example, water, dark soil, burn scars), VCT identifies and masks out all pixels having an NDVI value of less than 0.2 (Huang *et al.* 2008).

Once VCT determines the location of forest/non-forest for each annual cloud-free composite image, it compares these images to prior and following years' forest distributions to determine the locations of annual forest disturbance. For instance, if a 1998 cloud-free Landsat image composite determines a particular pixel to be a forest pixel and a 1999 composite image determines that same pixel to be non-forest, VCT marks the pixel as "disturbed forest" in 1999. VCT generates annual forest disturbance images for each year of the analysis showing forests disturbed during the year in question, forests previously disturbed during the analysis, and forests not disturbed during the analysis (Figure 1). We tested VCT on Landsat footprint W2 Path 046 Row 029 in Oregon, US, with satisfactory results (Figure 2). However, VCT produced unsatisfactory results in the Mexico study areas. We found that VCT's automated forest detection algorithm consistently undercounted forest in the study area and thus could not produce accurate maps of annual forest change. This may be because VCT's band 3 forest peak detection method is not as suitable to Mexican forests compared to the temperate northern forests upon which the method has been more extensively tested. Additionally, VCT was unable to satisfactorily manage data inconsistencies related to the 2003 scan-line corrector failure on Landsat 7. Tests of VCT which included Landsat 7 data with the scan line error showed erroneous disturbance pixels which were simply the result of misinterpreted scan line errors (Figure 3). Because VCT's automated forest detection algorithm did not produce satisfactory results in Mexico, we transitioned to a manual forest classification and deforestation detection method. Similar to the VCT method, our classification of satellite images to detect deforestation detection analysis relied on the examination of changing spectral characteristics of annual growing season cloud-free Landsat image composites. Rather than relying upon an automated training data and classification method similar to VCT's, we manually generated 1,000 point forest and non-forest training datasets to be classified using a Support Vector Machine algorithm. The training data were randomly selected from forest and non-forest points that were spectrally stable from 1990 to 2010, minimizing the chance that the training data would lead to erroneous classifications. We generated cloud-free annual growing season composites by using the Function of Mask (Fmask) algorithm (Zhu and Woodcock 2012) and developed a proprietary image compositing algorithm that selected the best available non-cloud pixel from each growing season to contribute to that season's composite image. Classification was automated using a Support Vector Machine (SVM) algorithm to generate annual forest/non-forest maps for each year and each footprint.

Accuracy assessments of the forest/non-forest classifications indicated accuracies in the 65% to 85% range, which is unfortunately not accurate enough to conduct a meaningful assessment of annual deforestation. In an attempt to control for these relatively low accuracies, we developed a "trajectory analysis" algorithm to filter out the noise related to the occasional erroneous pixel classification. Unfortunately, the algorithm's results showed that the classifications were insufficiently stable from year to year in order to be analyzed with such an algorithm. For instance, the estimated land change rate for one Landsat footprint over a one-year period might be 1%, while a comparison of those years' forest–non-forest classifications indicated that upwards of 10% of the image's pixels experienced change. With so much apparent change due to the low accuracy of the classifications, the trajectory analysis algorithm was unable to separate the noise of erroneous deforestation from the signal of actual deforestation on the ground.

In conclusion, neither the VCT nor the SVM method of deforestation detection proved capable of measuring deforestation in Mexico. The primary reason for the failure of these two methods is due to the quality and quantity of available Landsat imagery. In theory, one Landsat image per footprint should be available every 16 days at minimum (when multiple Landsat satellites were operating concurrently, images should be available at an even shorter interval). However, in practice the Landsat archive for Mexico is incomplete (due to a number of factors such as the loss of an earth-based data receiving station) and in some cases footprints lacked even a single image per year. Because of the incomplete data record, we tried to determine deforestation with a less-than-optimal dataset which included images which were phenologically inconsistent with our analysis (for example, images taken before the onset of a temporally variable rainy season), were excessively cloudy, or contained data errors due to the Landsat 7 scanline corrector malfunction. Additionally, the Mexican landscape itself posed particular challenges due to topographically induced shading, open forests which transmitted a disproportionally large fraction of the underlying soil's spectral signal to the Landsat sensors, phenological variability, and the prevalence of sub-900 square meter (the area of a Landsat pixel) deforestation patches.

In order to provide at least some information on deforestation, we digitized deforestation visually on Landsat images for all enrolled and rejected properties and also for the entire ejidos that had parts of their properties enrolled in the program. This dataset is complete and useful for analyses, but does not allow assessing leakage since it is not feasible to manually digitize the landscape at large.
Similarly, we digitized deforestation on Google Earth high-resolution satellite imagery. These data are valuable to assess the accuracy of our satellite classification and VCT results, and can be used to estimate approximate deforestation rates, but they are not suitable to analyze PES program effectiveness since most enrolled and rejected properties are not covered by high-resolution data in Google Earth.

In summary, our remote sensing analyses were unfortunately not as successful as we had hoped. We accomplished all the tasks that we had proposed, and went far beyond that, but the results were not accurate enough to provide reliable estimates of deforestation. The main reasons for this were limitations of existing algorithms, limitation in the availability of Landsat satellite data, the challenging terrain and open nature of many of Mexico’s forests, and also the fact that deforestation rates appear to have declined considerably in Mexico since 2000 making it more difficult to detect deforestation accurately.

Appendix

Appendix A: Sample design

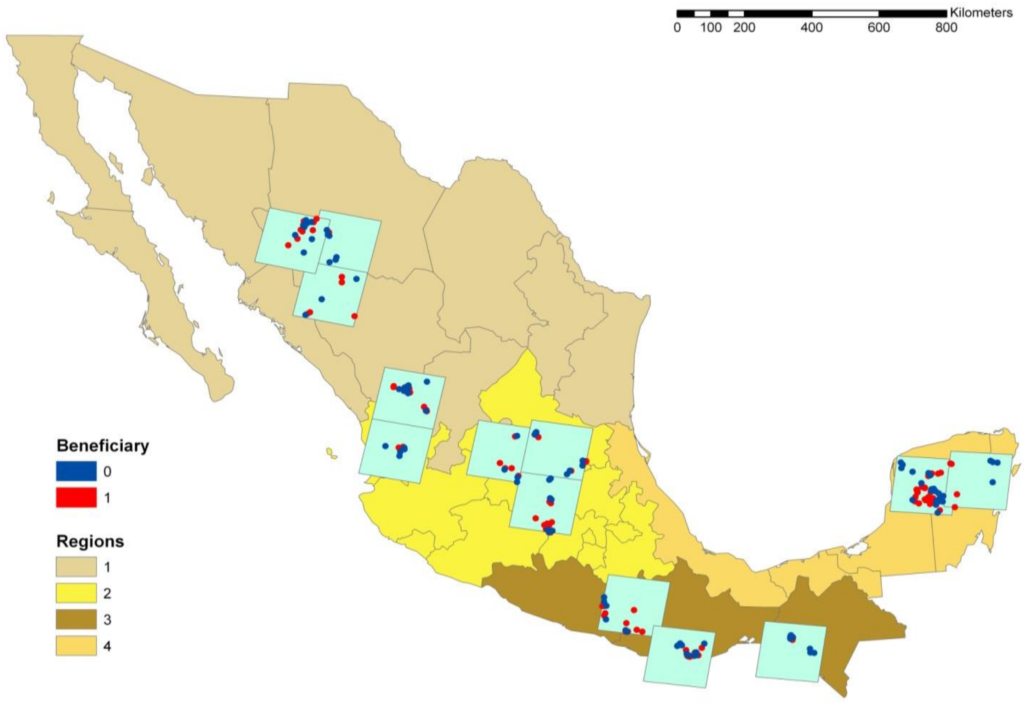
In order to assess the socioeconomic impacts of the PSAH program, we conducted a national-level field survey of a sample of beneficiary and matched non-beneficiary applicants from the 2008 program cohort. Surveys in communal properties were implemented with both heads of households and community leaders and with private property household heads. Case studies were also conducted in 18 of the survey sites with in-depth interviews conducted with CONAFOR employees, intermediary agents, and participants.

Survey sample and timing

We fielded the survey between June and August of 2011. A stratified random sampling strategy was applied by region. The four regions (north, central, southwest, and southeast) were determined by dominant ecosystem type and socioeconomic groupings and are shown in Figure A1. Across all regions, a total of 13 Landsat footprints (areas 180x180 sq km) were randomly selected from within the set that contained past images of sufficient quality to monitor deforestation over time.[30] We then identified all 2008 cohort applicants within each footprint and matched them to controls from the applicant pool that did not subsequently become beneficiaries in 2009, 2010, or 2011 using nearest-neighbor covariate matching. Matching was conducted applying the Mahalanobis metric within region and tenure type (common property vs. private property) and on the basis of the following covariates: distance to the nearest locality with population greater than 5,000, elevation, slope, the area of the property submitted to be enrolled, the density of roads within a 50 km buffer, the average locality poverty level in 2005, and the percentage of submitted forest in coniferous forest, oak forest, cloud forest, upland tropical forest, and lowland tropical forest. Matches with high distance measures between covariates were eliminated from the possible sample (that is, because there was no good match available). Within region and tenure type, priority then was given to possible survey properties which had multiple good matches among the controls and vice versa. Some last minute adjustments in the sample were made due to security concerns—this resulted in the swapping of two Landsat footprints for nearby ones and the addition of two footprints in order to increase sampling possibilities among the non-beneficiaries.

[30] Analysis of the more detailed Landsat data (30m x 30 m pixels) is currently in process.

Figure A 1: Survey sample and survey regions



Centroid points of properties surveyed (summer 2011). Total number of properties surveyed = 233.

Surveyors further stratified the sample within common property communities by land-use rights. Based on lists provided by program officers or community leaders, surveyors randomly selected five households with full land-use rights and voting power (ejidatarios) and five without (non-ejidatarios). The final sample is composed of 118 private households (61 beneficiaries and 57 non-beneficiaries) and 1,125 households (596 beneficiaries) and (529 non-beneficiaries) distributed over 116 common property communities. Table A1 indicates the breakdown of surveyed households in each region and Figure A1 shows the locations of the beneficiary and non-beneficiary properties (here shown as points rather than polygons).

Table A 1: Sample size of survey and distribution by region

Regions	Households in common property			Private landowners		
	Non-beneficiaries	Beneficiaries	Total	Non-beneficiaries	Beneficiaries	Total
1. North	140	138	278	14	15	29
2. Center	137	161	298	15	15	30
3. Southwest	133	150	283	15	16	31
4. Southeast	119	147	266	13	15	28
Total	**529**	**596**	**1,125**	**57**	**61**	**118**

Regions as shown in Figure.

The reasons for rejection in our surveyed sample are similar to the overall rejected pool. 35% were approved but rejected due to lack of funding, 50% were rejected due to having less than the required percentage of forest cover on the submitted property, 6% were outside of the eligible zones and the remaining 9% had incomplete documentation or did not meet other technical criteria. As shown in Table A2 the survey sample is fairly representative of the regional and ecological distribution of 2008 enrollees in the PSAH.

Table A 2: Distribution of surveyed and enrolled properties by region and ecosystem type, 2008

	Oak	Pine	Mixed mesophytic	Tall/medium rainforest	Dry tropical forest		
Region	**Surveyed properties**					**% by region**	**Ha by region**
1	62.35	52.00	0.00	0.00	11.09	38.71	483.75
2	24.02	15.69	0.00	0.00	3.74	12.75	159.30
3	13.63	32.31	100.00	27.61	8.31	22.41	280.07
4	0.00	0.00	0.00	72.39	76.87	26.14	326.69
Ha by forest type	230.09	581.64	7.90	88.82	1249.82		143.47
Region	**Enrolled properties (2008)**						
1	52.87	44.46	1.49	0.01	17.38	31.15	572.14
2	27.92	22.62	9.21	2.27	12.72	17.81	327.12
3	18.85	31.41	85.03	27.00	17.10	28.07	515.6
4	0.37	1.51	4.26	70.72	52.79	22.97	421.87
Ha by forest type	473.88	575.28	119.59	299.6	368.38		1836.73

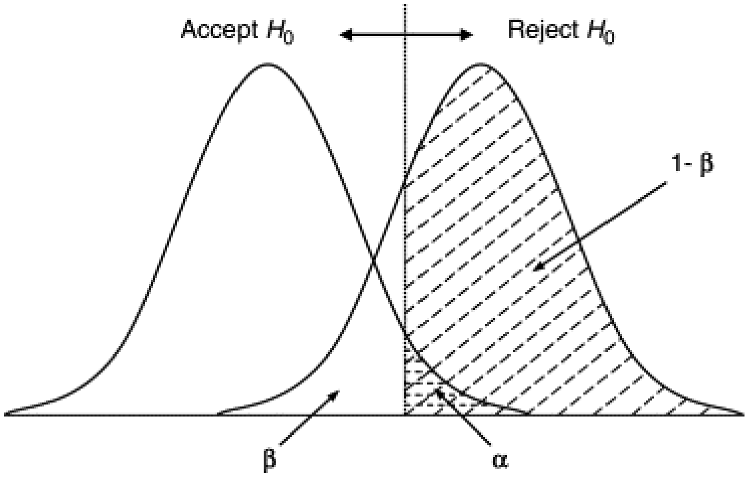
Appendix B: Survey instruments

Six survey instruments were created: for non-beneficiaries, one survey was generated for private property households, for common property leaders, and for common property households. The same three types were written for beneficiary communities, although these contained an additional set of questions regarding the program. In general, the household surveys included the following broad topics: Housing and locality characteristics, household characteristics (including demographics and employment), land access and holdings, production and income, shocks and credit, household expenses and investments, participation in PSAH and forest management, prices of recent purchases, and, for common properties, community participation. At the community level, survey sections included: community infrastructure and location, participation in community activities, production, government transfers and shocks, perceptions of PSAH benefits, and transactions costs for enrolling in PSAH. We have submitted with this report the household and community surveys for beneficiary communities.

Appendix C: Power calculations

Statistical power is the probability that we reject the null hypothesis when it is false. Power calculations can be performed a priori to compute adequate sample sizes and post hoc to help interpret non-significant results. The basic idea of power can be summarized in Figure C1. The sampling distributions represent the possible values of sample means based on samples of size nif the null hypothesis is true (distribution on the left) or if the alternate hypothesis is true (distribution on the right). The dashed line represents the decision criterion: we reject the null hypothesis if we observe a sample mean greater than the criterion. Power is represented by the shaded area, which is nothing more than the probability that a sample mean will be greater than the criterion if we are sampling from the alternate population. If β is the probability of type II error (probability of rejecting the null hypothesis when it is true), then power can be just represented as $1-\beta$.

Figure C 1: Statistical power



Study design and software

Power calculations are conducted taking into account the hierarchical design of the study. More specifically, we follow methods used in "cluster randomized trials," where household or individual-level outcomes are evaluated but treatment is assigned at the cluster level. In the case of PSAH, and particularly for common property communities, payments are given at the community level but the outcomes we evaluate are at the individual or household level.

Besides sample size, effect size, and significance level of the test affecting power, in multilevel research designs there are two additional elements that affect power: the sample size at each level (cluster) and the correlation within each level or cluster. Different configurations of sample size at each level could lead to different statistical power even though they all involve the same sample size.

In addition, and given that we randomly selected beneficiary and non-beneficiary communities from four different regions, we follow methods used in cluster randomized trials with blocking, where the blocking variable is the region. Blocks or sites are fixed in our case, instead of being random, as they were not randomly selected from a larger universe.

To perform power calculations we use Stata[31] and the Optimal Design software, which was developed by the University of Michigan. For more details on the Optimal Design software and the power calculations for cluster randomized trials with blocking, refer to Spybrook *et al*. (2011). The advantage of the Optimal Design software compared to the Stata calculations is that it allows to explicitly introduce the blocking component of the

[31] The Stata commands used are "sampsi" and "sampclus."

design in the power and sample size calculations. As opposed, Stata only considers the clustering of the data.

Study design and power calculations

As is explained in detail by Spybrook *et al*. (2011), to test treatment effects we look at an F statistic that compares the treatment variance versus the error variance. This statistic can be written as a function of a non-centrality parameter, which can be expressed as the ratio of the squared treatment effect to the variance of the estimate of the treatment effect. When there is no variation between treatments the non-centrality parameter is equal to zero. However, if the null hypothesis is false, the non-centrality parameter can be either positive or negative and then F follows a non-central distribution. The non-centrality parameter is strongly related to power. Power increases when this parameter increases.

Depending on the design of the study, the centrality parameter can be a simple and increasing function of the effect size and the sample size (for example, single-level trial where individuals are randomized into treatment) or could be a more complex function of the number of clusters, the number of observations per cluster, the intra-cluster correlation and the number of sites or blocks. For example, the number of sites/blocks has the greatest impact on power and it is especially important to have many sites if there is a lot of between-site variance. Increasing the number of clusters also increases power, particularly if there is a lot of variability between clusters. Finally, increasing the number of observations per cluster also increases power, and it is most beneficial if there is a lot of variability within clusters, which is measured by the intra-cluster correlation.

A priori power analysis

Since a stratified random sampling strategy was applied by region and we determined four different regions based on dominant ecosystem type and socioeconomic groupings, the number of sites or blocks is set equal to four in the analysis (that is, K=4). In addition, as it is conventionally done, we establish the statistical significance or probability of type I error (α) equal to 0.05.

Given that this was the first time that data was being collected from this population and that there was no reliable baseline information at the community or ejido level on the outcomes we evaluate (for example, household assets and investment choices), a priori power and sample calculations required making a number of assumptions and conducting multiple simulations. We adopted a conservative approach and assumed small effect sizes, equivalent to 0.2 standard deviations, as recommended by Cohen (1988)[32]. Moreover, since there was no prior information about the intra-cluster correlation, we

[32] Cohen (1988) proposes that an effect of 0.2 standard deviation is “small”, 0.5 is “medium” and 0.8 is “large.”

compare results across a low correlation scenario (ρ=0.05), a medium correlation scenario (ρ=0.20), and a high correlation scenario (ρ=0.50).[33]

In this section we present two separate calculations that allow us to determine the ideal sample and cluster size needed in order to achieve a specific level of power (that is, 1-β=0.8). First, we fix the number of observations per cluster and calculate the number of clusters needed to be sampled within each region. Second, we fixed the number of clusters and calculate the number of households needed to be surveyed within each cluster. It is important to understand that although the numbers obtained in an a priori power calculation are very important, they can only be seen as reference values. The final sample size needs to take into account also the budget available and some specific characteristics of the context and how the program operates. For example, the number of communities that can be sampled within a given region is limited by the number of communities that applied to the PSAH program in the year of interest. Also, the number of households that can be surveyed within a given community is limited by their total population.

Assuming that 10 households are surveyed within each cluster or community, the number of clusters needed within each region varies according to the intra-cluster correlation. As it can be seen in Figure C2a, for a small effect size (0.2) and very low level of correlation (ρ=0.05), the number of clusters per site needed to achieve a 0.8 power is around 28. For a large intra-cluster correlation (ρ=0.50) the number of clusters needed per site is approximately 100. Assuming an intermediate intra-cluster correlation (ρ=0.20) the number of clusters needed is 50. When we look at medium effect sizes (0.5), as reported in Figure C2b, we can see that having 17 clusters per site is sufficient to achieve a power of 0.8 in cases with large intra-cluster correlation.

[33] The intra-cluster correlation (ICC) can be very important for power calculations. When ICC is close to zero, this means there is little redundant information in the cluster and power will be close to a design that used simple random assignment and used the total sample. When ICC is close to one then most variation is coming from between clusters and power is close to a simple random assignment with total sample equal to the number of clusters.

Figure C 2a: Power and number of clusters per site (small effect size)

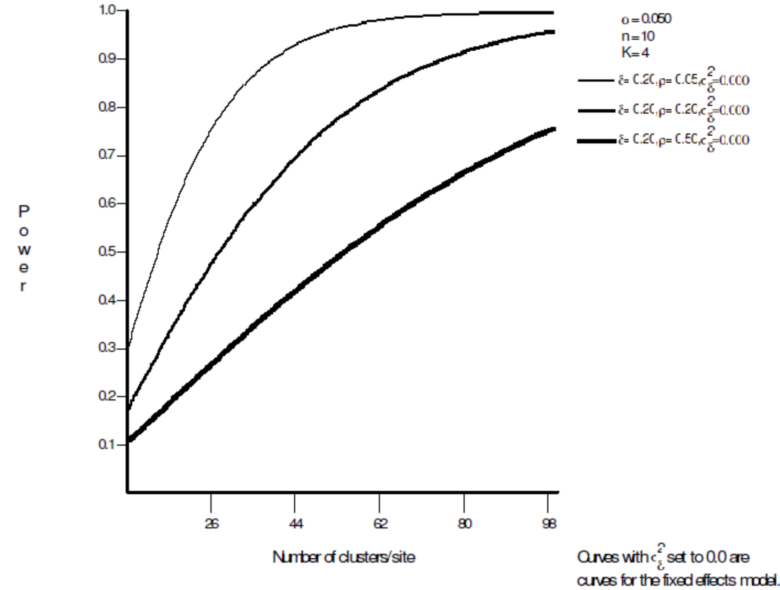
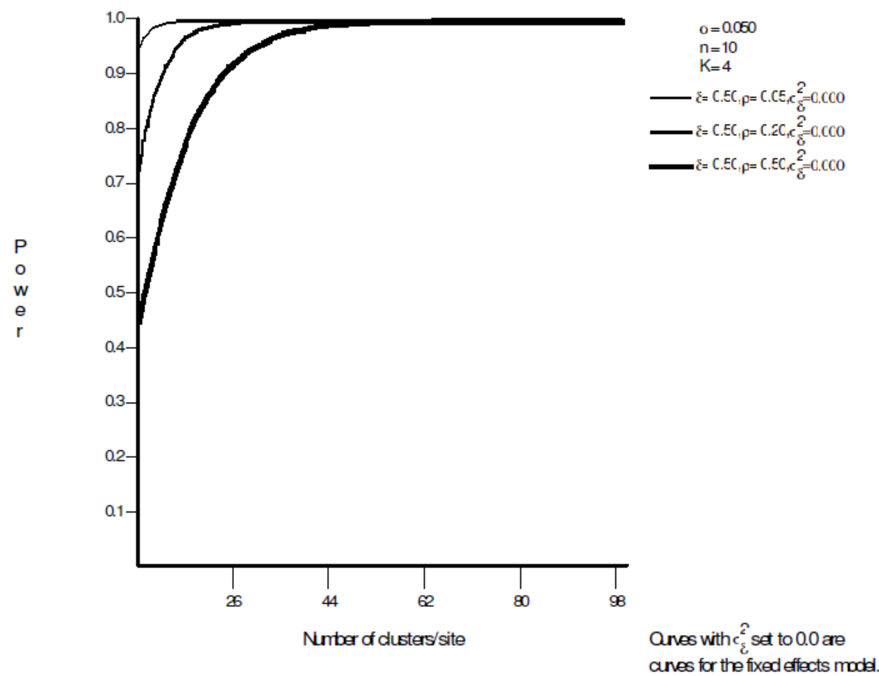


Figure C 2b: Power and number of clusters per site (medium effect size)



In Figures C3a and C3b we fixed the number of clusters per site to 28 and calculate the number of observations we need to survey per cluster for small and medium effect sizes respectively. Results also vary depending on the intra-cluster correlation. For a small effect size (0.2) and low levels of correlation, approximately 10 observations are needed to achieve a power of 0.8. As opposed, for medium or high levels of correlation, together with a small effect size, it will be impossible to achieve high levels of power regardless of how many households we surveyed within each community. In these cases, power never goes above 0.6 and 0.3 respectively. For a medium effect size, power is always above 0.8 regardless of how many households we survey within each cluster.

Figure C 3a: Power and number of observations per cluster (small effect size)

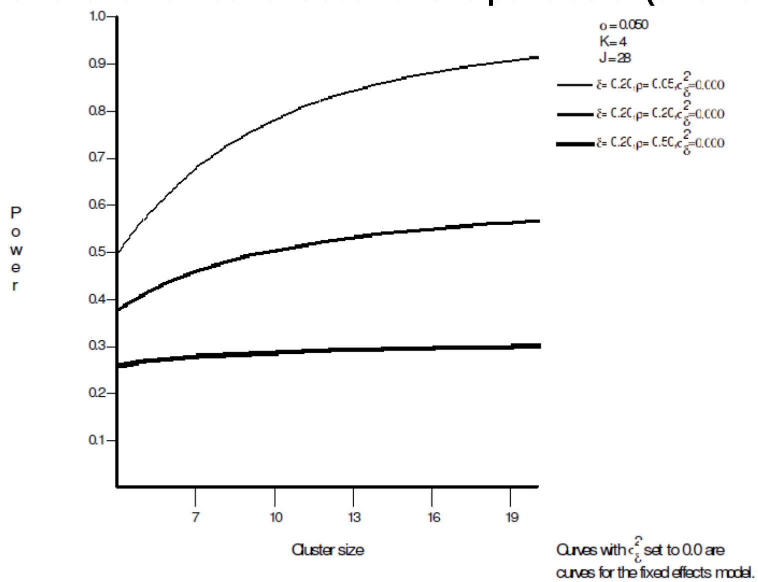
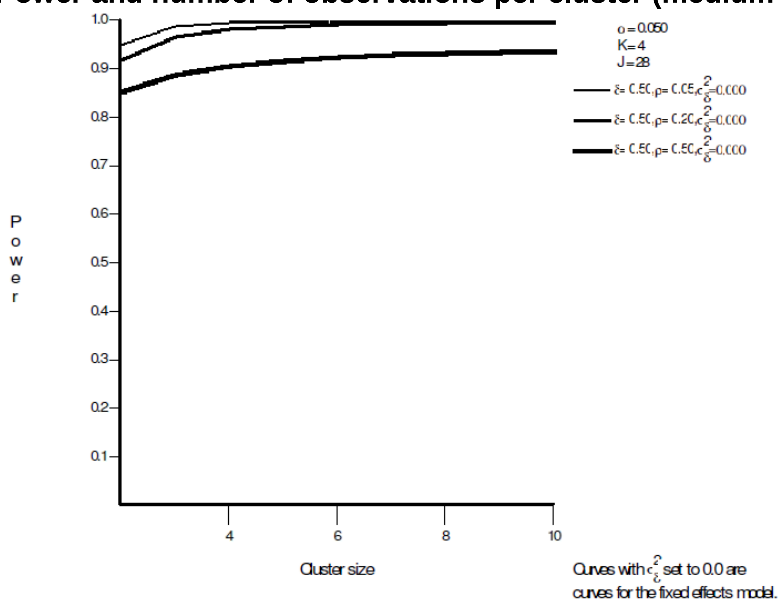


Figure C 3b: Power and number of observations per cluster (medium effect size)



To double check the previous numbers, we perform calculations in Stata. The following numbers are not completely equivalent as Stata does not take into account the blocking in the design. If we divide evenly the number of clusters reported by Stata by region, we can see in Table C1 that for low levels of intra-cluster correlation and assuming that 10 households are surveyed within each community, the number of communities that need to be sampled per region is 37. When the intra-cluster correlation increases to 0.5, the number of clusters is 140. When we fix the number of clusters to 111, we see that the number of households needed to be surveyed by community is 17 for low levels of intra-cluster correlation. For medium and high levels of correlation, calculations are omitted as the number of cluster assumed is too small. The numbers in parentheses in the table are the minimum numbers of clusters needed.

Table C 1. Sample size and clusters needed (Stata results—small effect size)

Intra-cluster correlation	**Effect size**	**Sample size required**	**Number of clusters**	**Number of observations per cluster**
Number of observations per cluster fixed and small effect size				
0.05	0.2	992	100	10
0.20	0.2	1916	192	10
0.50	0.2	3762	377	10
Number of clusters fixed and small effect size				
0.05	0.2	958	111	9
0.20	0.2	-	111 (137)*	-
0.50	0.2	-	111 (343)*	-
Number of observations per cluster fixed and medium effect size				
0.05	0.5	184	19	10
0.20	0.5	354	36	10
0.50	0.5	694	70	10
Number of clusters fixed and medium effect size				
0.05	0.5	134	111 (67)*	2
0.20	0.5	152	111 (76)*	2
0.50	0.5	190	111 (95)*	2

*Minimum number of clusters required is in parenthesis.

Post hoc power analysis

Given that a priori statistical power analyses are based on multiple assumptions about effect sizes and intra-cluster correlations, they cannot rule out the possibility of having low statistical power post hoc. For example, if the effect size is smaller than the one hypothesized for the a priori power analysis, then the sample might end up being too small to detect it. In this section we focus on looking at the minimum detectable effect size and compare it with the observed program effects for multiple outcomes. In addition, we compute the intra-cluster correlation (ICC) taking into account baseline data reported by households. The following parameters are considered:

K = number of blocks/sites = 4

J = number of clusters per site = 28 ~ 28*4=111

n = number of households per cluster = 10

Effect size variability = 0 (since regions are fixed and not part of a larger universe)

In Figure C4 we can see that given a power level of 0.8, we will only be able to detect small program effects when intra-cluster correlation is low. More specifically, effect sizes of 0.2 or less will only be detected with correlation levels less than 0.05. When we look at the actual data, we can see that the average ICC for a set of outcomes related to wealth and household investment decisions is 0.2. This means that, on average, the minimum effect size we will be able to detect is approximately 0.27.When we look at the estimated effect sizes we see that all of them are below 0.2, which confirms that statistical power post hoc might be low.

Figure C 4: Minimum detectable effect size and intra-class correlation

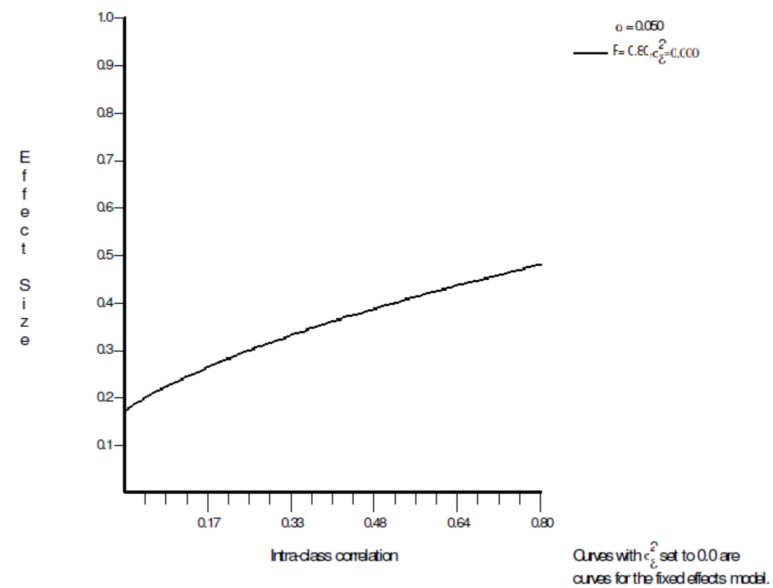
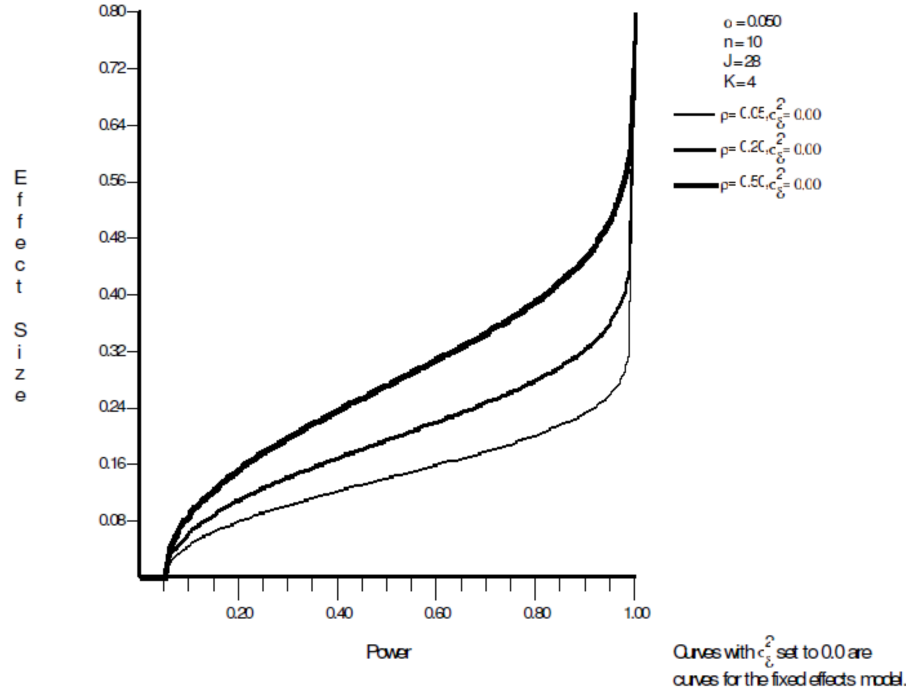


Figure C5 shows the relationship between the level of power and the minimum detectable effect size for different ICC. As we can see, given the average ICC (0.2) and the average effect size observed in the data (0.05), post hoc power is equal to 0.08. We can use this graph as well to 81 analyse the minimum detectable effect size needed in order to achieve a specific level of power and with a determined intra-cluster correlation. Table 3 summarizes these results for each of the outcomes used in the impact evaluation analysis. Overall, we see that the actual power given the estimated effects sizes is very small and ranges between 0.05 to 0.35. The minimum effect sizes needed to achieve the conventional 0.8 power value are also much larger than those observed in the data.

Figure C 5: Minimum detectable effect size and power



Since several authors point out that confidence intervals can better inform about the possibility of an inadequate sample size than post-hoc power calculations (Levine and Ensom 2001), we also evaluate confidence intervals. Table C2 presents the confidence intervals[34] constructed using the estimated impacts. These intervals allow us to analyse what is the largest effect size that is consistent with the data[35]. We can see that in all of the cases, except for the number of small animals and livestock infrastructure, the minimum detectable effect sizes for a fixed level of power (0.8) are larger than the maximum effect sized supported by the data.

[34] Confidence intervals are calculated as: Estimated coefficient +/- (1.96 * Standard Deviation).

[35] For variables that were estimated in logs we first transform these values to levels.

Table C 2. Intra-cluster correlation and confidence intervals for estimated effects

Variables	Mean baseline	Std dev baseline	ICC	Estimated effect ($\widehat{\beta}$)	Effect size ($\widehat{\beta}$/std dev)	$\widehat{\beta}$CI lower bound	$\widehat{\beta}$CI upper bound	Effect size upper bound
Food index (control group)	0.59	0.53	0.222	0.029	0.05	-0.041	0.095	0.18
Consumption index 2007	0.69	0.73	0.179	0.021	0.03	-0.027	0.065	0.08
House index 2007	2.30	0.43	0.223	0.005	0.01	-0.023	0.032	0.07
# Cattle 2007	3.50	13.02	0.092	0.923	0.07	-0.060	1.906	0.15
# Small animals 2007	7.61	23.39	0.035	2.507	0.11	-1.201	6.215	0.26
Livestock infrastructure 2007	0.12	0.32	0.086	0.033	0.10	-0.016	0.082	0.26
Agricultural inputs 2007	0.68	0.46	0.166	-0.006	0.01	-0.059	0.043	0.09
Agricultural equipment 2007	0.20	0.40	0.462	-0.008	0.02	-0.043	0.031	0.08

Table C 3. Power and minimum detectable effect size

Variables	ICC	Estimated effect size ($\widehat{\beta}$/std dev)	Actual power given effect size	Minimum detectable effect size for 0.8 power
Food index (control group)	0.222	0.05	0.08	0.28
Consumption index 2007	0.179	0.03	0.07	0.21
House index 2007	0.223	0.01	0.05	0.28
# Cattle 2007	0.092	0.07	0.14	0.22
# Small animals 2007	0.035	0.11	0.35	0.18
Livestock infrastructure 2007	0.086	0.10	0.23	0.22
Agricultural inputs 2007	0.166	0.01	0.06	0.25
Agricultural equipment 2007	0.462	0.02	0.05	0.36

Appendix D: Descriptive statistics

Table D 1: Summary statistics: points within applicant boundaries and other forested points
a. Unmatched

Variable	Beneficiaries		Non-beneficiaries		Norm diff 1	Other forest points		Norm diff 2
	Mean	sd	Mean	sd		mean	sd	
Slope (deg)	12.35	9.94	11.32	9.64	0.075	10.27	9.522	0.151
Elevation (m)	1537	980.8	1436	921.0	0.075	1161	886.7	0.285
Dist to loc > 5,000 (km)	32.94	22.06	38.76	26.00	-0.167	38.11	27.36	-0.147
Municipal poverty 2000	0.267	1.121	0.265	1.127	0.001	0.239	1.019	0.019
Common property	0.880	0.325	0.798	0.401	0.159	0.604	0.489	0.470
Overexploited aquifer	0.161	0.367	0.122	0.328	0.078	0.0742	0.262	0.192
Water availability	6.823	1.698	6.859	1.526	-0.016	7.180	1.311	-0.167
Priority mountain	0.262	0.440	0.116	0.321	0.268	0.0680	0.252	0.383
Majority indigenous	0.380	0.485	0.253	0.435	0.195	0.248	0.432	0.203
Mangroves	0.0067	0.081	0.0203	0.141	-0.084	0.0090	0.0946	-0.019
Oak/pine forest	0.213	0.409	0.267	0.443	-0.091	0.225	0.418	-0.021
Cloud forest	0.0900	0.286	0.0422	0.201	0.137	0.0314	0.1745	0.175
Upland rainforest	0.143	0.350	0.150	0.357	-0.014	0.154	0.361	-0.023
Lowland rainforest	0.144	0.351	0.180	0.384	-0.070	0.311	0.463	-0.289
Coniferous forest	0.405	0.491	0.341	0.474	0.094	0.269	0.443	0.205
Risk of defor	2.455	1.331	2.401	1.301	0.029	2.847	1.390	-0.204
Mean ndvi	0.625	0.153	0.573	0.162	0.234	0.556	0.162	0.310
Δ mean ndvi	-0.0030	0.0629	-0.0031	0.0651	0.001	-0.0032	0.0719	0.002
N	17,881		18,456			44,104		

b. Matched

Variable	Beneficiaries		Non-beneficiaries		Normalized difference
	Mean	sd	mean	sd	
Slope (deg)	12.14	9.84	13.03	9.45	-0.066
Elevation (m)	1538	988.2	1637	905.5	-0.074
Dist to loc > 5,000 (km)	32.99	21.97	32.97	21.92	0.001
Municipal poverty 2000	0.259	1.11	0.223	1.09	0.023
Common property	0.884	0.320	0.860	0.347	0.052
Overexploited aquifer	0.160	0.367	0.172	0.378	-0.023
Water availability	6.805	1.69	6.714	1.62	0.039
Priority mountain	0.244	0.430	0.204	0.403	0.068
Majority indigenous	0.377	0.485	0.301	0.459	0.114

Mangroves	0.0064	0.080	0.0061	0.078	0.003
Oak/Pine forest	0.213	0.409	0.261	0.439	-0.080
Cloud forest	0.0834	0.277	0.0696	0.255	0.037
Upland rainforest	0.141	0.348	0.1090	0.312	0.069
Lowland rainforest	0.146	0.353	0.1259	0.332	0.041
Coniferous forest	0.411	0.492	0.4285	0.495	-0.026
Risk of defor	2.47	1.33	2.41	1.28	0.033
N	17,137		5,228		

Matches are found using 1:1 covariate matching with replacement and calipers of 5 on the Mahalanobis metric. Matching is conducted within region and tenure type on the basis of slope, elevation, poverty index, distance to nearest locality with population greater than 5,000, forest type, overlapping with an overexploited aquifer, the degree of water availability, being inside of one of the priority mountains, and being in a municipality with majority indigenous population. The municipal poverty measure is the marginality index constructed by CONAPO in 2000 (see note in Table 4). Normalized difference is the difference in average covariate values, normalized by the standard deviation (Imbens and Wooldridge 2009). Norm diff 1 is between the beneficiaries and non-beneficiaries; Norm diff 2 is between the beneficiaries and other forested points. Risk of deforestation is available for 16,883, 16,691, and 37,394 unmatched observations and 16,142 and 4,732 matched observations.

Table D 2. Sample size of survey and distribution by property type and region

Regions	**Households in common properties**			**Private landowners**		
	Beneficiaries	Non-Beneficiaries	Total	Beneficiaries	Non-Beneficiaries	Total
1. North	138	140	278	15	14	29
2. Center	161	137	298	15	15	30
3. Southwest	150	133	283	16	15	31
4. Southeast	147	119	266	15	13	28
Total households	**596**	**529**	**1,125**	**61**	**57**	**118**
Total properties	**58**	**53**	**111**	**61**	**57**	**118**

Regions as shown in Figure 3.

Table D 3: Summary statistics: beneficiary and non-beneficiary households
a. Households living in common property communities

Variables	Non-beneficiaries		Beneficiaries		Normalized difference
	Mean	Sd	Mean	sd	
Durables index 2007	1.648	2.193	1.856	2.415	0.064
Durables index 2011	2.301	2.446	2.635	2.609	0.093
Housing index 2007	10.091	4.238	9.934	4.623	-0.025
Housing index 2011	10.292	4.222	10.171	4.605	-0.019
Food index 2011	0.611	0.515	0.642	0.512	0.043
# Cattle 2007	4.410	15.134	2.956	9.594	-0.081
# Cattle 2011	3.909	11.366	3.255	9.178	-0.045
# Small animals 2007	6.310	22.352	8.257	22.245	0.062
# Small animals 2011	5.847	16.096	9.896	39.732	0.094
Livestock infrastructure 2007	0.112	0.315	0.124	0.330	0.028
Livestock infrastructure 2011	0.124	0.329	0.164	0.371	0.082
Agricultural inputs 2007	0.625	0.485	0.693	0.462	0.102
Agricultural inputs 2011	0.633	0.482	0.688	0.464	0.082
Agricultural equipment 2007	0.206	0.405	0.176	0.381	-0.054
Agricultural equipment 2011	0.219	0.414	0.185	0.388	-0.060
Children in school 2007	0.725	0.447	0.706	0.456	-0.029
Children in school 2011	0.513	0.500	0.516	0.500	0.005
Elevation (m)	1466.848	976.351	1598.794	1104.335	0.090
Slope (deg)	9.815	7.383	9.272	7.188	-0.053
Dist. to loc > 5000 (km)	30.045	19.637	32.181	16.818	0.083
Municipal poverty 2005	0.752	1.091	0.724	0.881	-0.020
Area of property enrolled (ha)	1235.955	1007.653	1023.696	878.622	-0.159
Member household	0.658	0.475	0.647	0.478	-0.017
Household size	4.532	2.296	4.850	2.367	0.096
Days FCA 2007	7.512	24.931	17.395	42.473	0.201
Days FCA 2011	13.701	42.681	23.406	47.060	0.153
Participation FCA 2007	0.412	0.493	0.577	0.494	0.237
Participation FCA 2011	0.556	0.497	0.765	0.424	0.320
Number of observations	529		596		

FCA = Forest conservation activities. The food index is constructed using households' reported prices and considering the consumption of tortillas, milk, beef, pork, cheese, bread, tomato, and beans. Durables and housing index regressions are aggregates of assets (television, refrigerator, computer, stove, car, phone, cell phone) and housing improvements (floor, walls, number of rooms) valued at 2007 prices. Children enrolled in school consider those that are between 12 and 22 years old in 2011. The rule of thumb suggested by Imbens and Wooldridge (2009) for the normalized difference is 0.25. The municipal poverty measure is the 2005 marginality index constructed by CONAPO, which considers multiple dimensions: education, access to basic services, employment, and population.

b. Private landowners

Variables	Non-beneficiaries		Beneficiaries		Normalized difference
	Mean	Sd	Mean	Sd	
Durables index 2007	4.311	2.652	4.776	2.542	0.127
Durables index 2011	4.831	2.601	5.429	2.245	0.174
Housing index 2007	15.054	5.157	16.702	12.148	0.125
Housing index 2011	15.075	5.142	16.790	12.118	0.130
Food index 2011	0.855	0.410	0.897	0.262	0.087
# Cattle 2007	22.895	53.454	19.262	42.513	-0.053
# Cattle 2011	21.053	54.647	15.590	30.382	-0.087
# Small animals 2007	11.368	55.694	30.902	192.301	0.098
# Small animals 2011	9.193	39.815	38.410	256.239	0.113
Livestock infrastructure 2007	0.211	0.411	0.197	0.401	-0.024
Livestock infrastructure 2011	0.175	0.384	0.246	0.434	0.122
Agricultural inputs 2007	0.439	0.501	0.328	0.473	-0.161
Agricultural inputs 2011	0.386	0.491	0.328	0.473	-0.085
Agricultural equipment 2007	0.158	0.368	0.164	0.373	0.012
Agricultural equipment 2011	0.123	0.331	0.148	0.358	0.051
Children in school 2007	0.822	0.387	0.912	0.285	0.187
Children in school 2011	0.630	0.488	0.825	0.384	0.313
Elevation (m)	1290.460	865.543	1268.101	949.670	-0.017
Slope (deg)	9.825	7.256	8.961	6.611	-0.088
Dist. to loc > 5000 (km)	29.928	18.418	26.681	16.522	-0.131
Municipal poverty 2005	0.660	1.083	0.908	1.008	0.168
Area of property enrolled (ha)	118.037	103.070	105.311	73.712	-0.100
Household size	3.860	2.150	4.333	1.963	0.163
Days FCA 2011	70.579	138.760	258.164	367.541	0.477
Participation FCA 2011	0.509	0.504	0.885	0.321	0.630
Number of observations	57		61		

FCA = Forest conservation activities. The food index is constructed using households' reported prices and considering the consumption of tortillas, milk, beef, pork, cheese, bread, tomato, and beans. Durables and housing index regressions are aggregates of assets (television, refrigerator, computer, stove, car, phone, cell phone) and housing improvements (floor, walls, number of rooms) valued at 2007 prices. Children enrolled in school consider those that are between 12 and 22 years old in 2011. The rule of thumb suggested by Imbens and Wooldridge (2009) for the normalized difference is 0.25. The municipal poverty measure is the 2005 marginality index constructed by CONAPO, which considers multiple dimensions: education, access to basic services, employment, and population. For private landowners there is no data about FCA in 2007.

Appendix E: Analytical tables

Most of the tables discussed are included in the text. However, we do include here two tables discussed in section 5 that were not presented. These are tests of heterogeneity in impact by deforestation risk and baseline poverty. We also conducted similar heterogeneity explorations for indigenous groups, which were insignificantly different from zero and are not shown here.

Table E 1: Heterogeneous effects on consumption by deforestation risk and baseline poverty

	Ln(Food index)	**Ln(Durables index)**	**Ln(Housing index)**
Common properties			
High risk of deforestation			
Beneficiary	0.082	0.111*	0.009
	(0.097)	(0.063)	(0.008)
Benef x high risk	-0.072	-0.133**	-0.010
	(0.122)	(0.064)	(0.008)
High poverty			
Beneficiary	0.044	-0.051	-0.009
	(0.051)	(0.043)	(0.005)
Benef x poor	0.019	0.167***	0.023***
	(0.091)	(0.064)	(0.006)
N	833	1838	1830
Private properties			
High risk of deforestation			
Beneficiary	-0.025	0.037	0.000
	(0.097)	(0.082)	(0.004)
Benef x high risk	0.084	0.018	0.008*
	(0.122)	(0.090)	(0.004)
High poverty			
Beneficiary	0.008	-0.048	-0.001
	(0.057)	(0.077)	(0.004)
Benef x poor	0.014	0.193**	0.011**
	(0.118)	(0.088)	(0.004)
N	115	234	234

* p< .10 ** p < .05 *** p < .01

The food index is constructed using households' reported prices and considering the consumption of tortillas, milk, beef, pork, cheese, bread, tomato, and beans. Durables and housing index regressions are aggregates of assets (television, refrigerator, computer, stove, car, phone, cellphone) and housing improvements (floor, walls, number of rooms) valued at 2007 prices.

Table E 2: Heterogeneous treatment effects on investment by deforestation risk and poverty

	Agricultural investment					Educational investment		
	# Cattle	**# Small animals**	**Livestock infrast.**	**Agricultural inputs**	**Agricultural equipment**	**Student 12-14 yrs**	**Student 15–17 yrs**	**Student 18–22 yrs**
Common properties								
High risk of deforestation								
Beneficiary	1.059	1.080	0.034	0.016	-0.021	0.002	0.156**	0.150*
	(0.692)	(1.169)	(0.034)	(0.035)	(0.026)	(0.062)	(0.067)	(0.085)
Beneficiary x	-0.223	2.345	-0.001	-0.039	0.025	0.070	-0.059	-0.157**
high risk	(0.611)	(2.846)	(0.033)	(0.036)	(0.028)	(0.057)	(0.056)	(0.066)
High poverty								
Beneficiary	1.049*	4.898	0.029	-0.027	-0.027	0.079*	0.135**	0.001
	(0.601)	(3.244)	(0.029)	(0.028)	(0.025)	(0.042)	(0.060)	(0.077)
Benef x	-0.259	-4.906	0.009	0.039	0.044	-0.068	-0.028	0.140***
poor	(0.537)	(3.207)	(0.027)	(0.035)	(0.027)	(0.041)	(0.055)	(0.053)
N	1848	1848	1842	1842	1841	547	614	832
Private properties								**Student 12–22 yrs**
High risk of deforestation								
Beneficiary	-2.586	23.175	0.178*	0.088	-0.001			0.094
	(7.767)	(20.179)	(0.095)	(0.089)	(0.050)			(0.087)
Beneficiary x	1.398	-24.939	-0.173*	-0.066	0.036			-0.008
high risk	(8.917)	(18.250)	(0.099)	(0.096)	(0.083)			(0.076)
High poverty								
Beneficiary	-5.642	16.304	0.067	0.182**	-0.029			0.141*
	(7.199)	(18.974)	(0.071)	(0.072)	(0.073)			(0.075)
Benef x	7.751	-13.462	0.034	-0.262***	0.098			-0.096
poor	(10.810)	(8.878)	(0.122)	(0.103)	(0.110)			(0.073)
N	236	236	236	236	236			205

* p< .10 ** p < .05 *** p < .01

Appendix F: Study Design and Methods

The study design of this work is described in some detail in the text above. We use a quasi-experimental design exploiting the presence of rejected applicants who serve as the control group for our study. The study design is somewhat different for the measurement of environmental effectiveness, which uses all cohorts from 2004 to 2009, than for the socioeconomic portion of the analysis. We will discuss both of these methods briefly here, as well as describe the methodology used to develop the case studies.

Case study methodology

We also carried out case studies in a subsample of 18 of the survey sites, conducting semi-structured interviews with 48 state-level CONAFOR employees, intermediary agents (for example, NGOs, private contractors, forestry consultants), and participants who had been most involved in PSAH implementation in each site. The purpose of these case studies was to understand in a more nuanced way the perceptions and motives of people who had been intimately involved in the implementation of the program at multiple levels with the objective of enriching our understanding of trends we might observe in the quantitative survey or remote sensing data.

Table F 1: Distribution of case study sample by region, tenure type, and role

State	Region	Tenure Type		Interviewee Type		
		Private Properties	*Communal Properties*	*CONAFOR employees*	*Intermediaries*	*Participants*
Chihuahua	1 (North)	0	2	1	2	2
Durango	1 (North)	2	0	1	1	2
Michoacán	2 (Central)	0	3	3	3	4
Oaxaca	3 (SW)	3	3	4	4	9
Yucatán	4 (SE)	3	2	4	4	4
TOTAL		**8**	**10**	**13**	**14**	**21**

Selection of case study sites was not randomized both because of the small sample size and because we had no intentions of conducting statistical analyses on the primarily qualitative data collected. However, in order to obtain relatively equal representation by region, property type and role in the implementation of the project, we did stratify according to these characteristics. Because the overarching question we were asking was, “When do these programs achieve their objectives and under what conditions?” we also stratified the sites according to the CONAFOR state-level employees’ and our own surveyors’ perceptions of functional vs. non-functional project sites, selecting paired sites that were close geographically, but in which the PES program was perceived to have had less socioeconomic and/or environmental impacts.

Interviews were semi-structured. Interview guides were developed with input from CONAFOR personnel at the national level to ensure that the data gathered would be relevant to policy design. The case studies were conducted after the survey had been completed in each site and ranged from August to December 2011. Contact was made with potential interviewees through the same state-level CONAFOR employees who had assisted with survey logistics. Interviews were conducted by five members of our research team: one of the PIs, our research coordinator from Mexico, a PhD student from the University of Wisconsin, Madison, and two master's students from Duke University, all of whom were fluent in Spanish and had significant experience working in rural Latin America.

For each site, every attempt was made to interview the project participant as well as the CONAFOR employee and intermediary (for example, NGO employee, private consultant, forester, etc.) who had been most involved with implementing and monitoring the project in the site. Interviews ranged from .5 to 3.5 hours and for participants were normally conducted at the project site. For intermediaries and CONAFOR employees, interviews were conducted in their place of business.

The principal themes touched upon during the semi-structured interview included:

1. *Interaction with the program* (that is, the process of entering and implementing the program, understanding of program objectives, costs and benefits of participation, and perceptions of program impacts and effectiveness)
2. *Impact on the local economy* (that is, impact on access to or restrictions on credit, generation of employment)
3. *Interaction with local institutions* (that is, direct impact of the program on strength and functionality of local institutions, direct impact of program on rules and sanctions associated with forest access and use)
4. *Impact on land use decisions* (that is, perceptions of changes in land use since program inception, perceptions of the principal threats to forest health, direct impacts of program on forest health, and direct impacts of program on valuation of forest benefits)

Interviews were recorded and transcribed into the original Spanish. Interview transcripts were then imported into the qualitative data analysis software NVivo 9. Full analysis of the case studies is still ongoing but preliminary insights have been included in the sections below as appropriate.

Estimation—environmental and socioeconomic impacts

To construct a reasonable counterfactual case, we rely on comparisons across time between accepted and rejected applicants to the PSAH program. A key advantage of using controls drawn from the applicant pool is that all owners have demonstrated their otherwise unobservable desire to enroll in the program, revealing that their expected participation costs are sufficiently low to motivate application, and perhaps that they share a "conservation-oriented" inclination. However, even with program applicants as controls, characteristics which could be correlated with selection into the program and changes over time in deforestation could remain. To address this problem, we investigate the selection process, pre-match data on the basis of relevant characteristics, and then estimate panel regressions including property-level fixed effects to control for unobservable fixed characteristics of the parcels or landowners.

Above we investigated the selection of properties into the program in detail. Broadly, the program requirements were that the submitted parcels have a set percentage of forest cover to start (> 80% in 2003–2005; > 50 in 2006–2009) and be inside designated eligible zones which encompass existing areas of forest cover within high priority watersheds and protected natural areas. In most years, there were considerably more applicants meeting the requirements than available funds (more than 40% of our control points met all of the criteria but were rejected due to budget constraints). In 2004 and 2005, priority was given within these applicants to those with higher initial forest cover. From 2006 onward, priority was given on the basis of a points system rewarding higher initial forest cover, higher risk of deforestation,[36] greater water scarcity and other social characteristics. Given that the points system shifted somewhat from year to year due to changes in government priorities, we match data directly on the basis of characteristics important to this selection process and which might affect deforestation. Specifically, we match points on the following characteristics: slope, elevation, distance to the nearest locality with population greater than 5,000, baseline forest type, baseline municipal poverty, overlapping with an overexploited aquifer, the degree of water scarcity, being inside one of the priority mountains, and being in a municipality with majority indigenous population. Matching also includes exact matching within region and tenure type (common vs. other[37]). We use 1:1 covariate matching on the Mahalanobis metric, with replacement and calipers excluding matches with distance > 5.

We then estimate panel regressions with property fixed effects as follows:

(1) $$MNDVI_{ipvst} = \beta beneficiary_{it} + \delta_1 \ln dry_{it} + \delta_2 \ln grow_{it} + \delta_3 sdrain_{it} + \delta_4 hurricane_{it} + \alpha_{st} + \alpha_v + \alpha_p + \varepsilon_{ipt}$$

where *MNDVI* is the mean dry season NDVI value for point *i* in property *p*, forest type *v*, state *s,* and year *t*. The variable *beneficiary* is an indicator equal to 1 if the point was enrolled in the program in the previous year's cohort; *β* is the average program impact.[38] Several variables are included to control for rainfall: ln *dry* is the natural log of annual dry

[36] As measured by INE's 5 point scale. "Index of Economic Pressure to Deforest / Risk of Deforestation". version 1. Methodology at http://www.ine.gob.mx/irdef-eng.
[37] Other types of beneficiaries include private landowners that apply to the program in groups or associations.
[38] We introduce the lag to take into account the timing of the applications versus the timing of the NDVI measurements. Applications are submitted in the spring and notifications are made in late summer, while NDVI is measured between February and April. During the period of analysis, properties both enter and exit beneficiary status. Enrollment in the program in the previous year's cohort also includes properties that received financial support to elaborate a proposal for forest conservation.

season rainfall for each point and year and ln *grow* is the natural log of rainfall in the other months prior to the dry season. To control for extreme weather events, particularly hurricanes, we also include the standard deviation of rainfall across the year, and a dummy variable for being in the top 10th percentile of rainfall during the hurricane season (October/November). State-year fixed effects (α_{st}) control for possible economic shocks to states in each year and forest type effects (α_v) account for the different NDVI signatures of each vegetation category. Finally, property level fixed effects (α_p) control for possible unobservable fixed characteristics. Standard errors are clustered at the property level to account for spatial and serial correlation.

Given this specification, our identification comes from differences in within-property behavior between similar accepted and rejected applicants over time. This relies on the assumption that the trends in deforestation between these two groups would have been parallel in the absence of program participation—or in other words that remaining variation in the timing of applications and acceptances in our regression model is not correlated with deforestation behavior. Since the program took a few years to become well-publicized and the details of the rules, prioritization schemes and eligible zones were multidimensional and frequently changing, we think that reasonable sources of "quasi-random" variation in timing of acceptance remain. These include rejections due to being outside the eligible zones in a given year, small mistakes in paperwork or documentation, or having less priority for funding within those who are accepted. As a test of the parallel trend assumption, we assess the time trends of accepted and rejected properties prior to enrollment by running a regression of NDVI from 2003 to 2009 on rainfall variables, with property level, vegetation category, and state-year fixed effects. The coefficients on interaction terms between year effects and eventual enrollment status among the unenrolled, that is, the pre-program trends for the two groups, are neither large nor statistically significant for any year. In addition, in order to assess whether the applicants rejected due to program budget constraints constitute a different type of counterfactual than those rejected for other reasons, we run a regression on the subsample of rejected properties using all the covariates in equation (1), but substituting for the beneficiary variable interactions between the year dummies and being rejected due to budget constraints. None of these 10 interaction terms is statistically different from zero at the 5% level, suggesting that rejected applicants have similar NDVI trends regardless of the reason for which they were rejected.

Finally, to check robustness, we also run the following specifications: defining the beneficiary variable to be in the same calendar year as the landowner received payments; using as controls only those points inside properties which met all the requirements but did not receive payments due to lack of funding; restricting the controls to only those within the eligible zones; and restricting the controls to properties which applied and were rejected only once (that is, did not reapply in future years). The results are robust to these specifications (available on request). They are also robust to skipping the first step of matching and using all rejected applicants as controls. For comparison, we also run a simple estimation using just the beneficiary variable and no covariates. This yields a coefficient of 0.016 (se .004). Relative to the unadjusted NDVI trend of -0.022 for 5 years, this constitutes an impact of 72%, very similar to the average impact above. Finally, in order to assess whether or not the effect is driven by deforestation after payments stop, we re-estimate the same equation recoding recipients as treated for all years after they are first enrolled. This results in a point estimate on recipient status of .0047 (se .00087), thus suggesting that the program impact is not driven by delayed deforestation.

Socioeconomic impacts

The analysis of assets also relies on the comparison between beneficiaries and rejected non-beneficiaries over time, where the pre-program outcomes were assessed using recall data. The survey itself was constructed around a matched sample, but within that sample, prior to estimation, we pre-match beneficiaries with non-beneficiaries based upon pre-program participation in forest conservation activities.[39] Our results are robust to eliminating this step, but it is included because the level of forest engagement is a key determinant of opportunity costs of participating in the program (and was not available for the pre-survey matching process). Finally, we separately analyze households living in common property communities and private landowner households because common property households are a very different population, substantially poorer and less educated than private property households.

We estimate program effects on durable purchase (and loss), household improvements, and productive investment using a household fixed effects model:

(2) $$A_{iet} = \beta_1 beneficiary_{et} + \beta_2 beneficiary_{et} * X_i + \gamma_i + t + u_{iet}$$

Where A_{iet} represents outcomes for household *i* in community *e* at time *t* and $beneficiary_{et}$ measures program enrollment (equal to zero for all properties in 2007 and one for recipients in 2011). The estimation includes both household (γ_i) and time (t) effects. We test for heterogeneous effects by interacting treatment with covariates represented by X_i. Standard errors are robust and clustered at the community level. For private households, the errors are simply heteroskedastic robust, and the *e* subscript is superfluous.[40]

We have conducted various analyses to attempt to assess the extent to which recall bias might be differential across treatment groups, but find no evidence of this. The presence of simple recall bias that does not vary across groups is not particularly troubling to us, since this simply biases the estimates towards zero.

[39] Forest conservation activities include: constructing or maintaining firebreaks to avoid fires spreading across different areas of the forest, constructing fences to avoid cattle entering into the forest, doing forest patrols, reforestation, soil conservation activities, pest control, among others.
[40] For simplicity, we use a linear probability model, but we check robustness using first differences in assets and an ordered probit model and results are similar.

John Henry effects

Henry effects might be generated if it were the case that the control grouped changed their deforestation behavior as a result of having applied to the program. The most likely expression of this type of effect would be a delay in deforestation activity. In our environmental analysis, we control for pre-award trends using flexible time trends and test for differences in pre-program behavior between beneficiary and non-beneficiaries. We do not observe these differences. In any case, in this situation the measurement bias could go either way: if rejected beneficiaries deforest in retaliation for having been rejected, then our estimates on forest loss will be biased upward. If they refrain from reforesting in anticipation of applying again, then the estimates will be biased downward. In our deforestation data we test for differential behavior between those who are rejected once and those who reapply, and find none. Among our survey participants, we surveyed only those who had not reapplied for the program by 2011.

Hawthorne effects

Hawthorne effects are generated if the act of being studied changes subjects' behavior. While we do not deny potential bias in survey responses, particularly to questions regarding their perception of the program, since surveys were completed in communities which had already been participating in the program for three years, it is impossible that the study could have affected their actual behavior.

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Policies for reducing emissions from deforestation and forest degradation (REDD) have been a crucial part of international climate change negotiations. To achieve their REDD goals, many countries have national or state-level programmes that offer direct payments to landowners to avoid deforestation.

This evaluation examines the environmental and socioeconomic impacts of Mexico's federal payments for a hydrological services programme. As part of the programme, payments were offered to landowners to maintain forest cover under five-year contracts.

Using satellite data, a comparison of forest cover across time between beneficiaries and rejected applicants suggests that the programme reduced forest loss compared to what would have been expected in the absence of the programme. Larger impacts were seen in communally held lands, on land of lower slope and closer to cities and in less poor municipalities. The wealth increases for beneficiaries were not significantly larger than those for non-beneficiaries.

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