TWO-DIMENSIONAL EVALUATION: THE ENVIRONMENTAL AND SOCIOECONOMIC IMPACTS OF MEXICO'S PAYMENTS FOR HYDROLOGICAL SERVICES PROGRAM

December, 2012

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ABSTRACT

Payments for ecosystem services (PES) programs are likely to expand in developing countries under international agreements to reduce carbon emissions from deforestation and forest degradation, but empirical evidence on possible environment-poverty tradeoffs is extremely limited. We investigate two dimensions of impacts for a federal program in Mexico that compensates landowners for forest protection: avoided vegetation loss and changes in household wealth. To establish counterfactual deforestation rates and growth in household assets across time, we use matched controls from the program applicant pool. We find that the program reduced the downward trend in vegetative vigor by over 60%, and that on average there are slight household wealth increases for beneficiaries relative to matched controls. Our analysis of heterogeneity in program effects indicates that increasing avoided deforestation by targeting to higher quality land would likely have regressive wealth impacts but that additional targeting to common property landowners could achieve gains on both dimensions.

Acknowledgements: We thank the Mexican National Forestry Commission (CONAFOR) for their generous sharing of time, expertise and data (including but not limited to: Leonel Iglesias Gutiérrez, Sergio Graf Montero, Paola Bauche Petersen, Jesús Gutiérrez Cacique, Rodolfo Valdez García, Adriana Saldaña Espejel, Carmen Meneses Tovar, Efrain Abundio Ramírez, Iris Lilian Ruiz Montes, and Sofia Cortina Segovia). We thank our survey coordinator, Rodolfo Rubio Salas and our team of encuestadores for their perseverance and time in the field. We thank Volker Radeloff and Pedro Camilo Alcantara for their remote sensing expertise and the NDVI data on Mexico. We thank Carlos Ramirez Reyes, Leah Fine, Caroline Stedman, Melissa Sullivan, Alejandro Sucre, Adam Medoff, David Ortega Flores, and Mara Munoz Quetzalli for excellent research assistance. We are especially grateful to the International Initiative for Impact Evaluation (3ie) and the National Science Foundation #1061852 for financial support. We thank colleagues at the AERE summer meeting, the Harvard Environmental Economics Seminar, the Williams College Economics Seminar and in our departments for comments. Please send comments to: alixgarcia@wisc.edu and ksims@amherst.edu.

INTRODUCTION

Payments for ecosystem services (PES) initiatives are expected to expand quickly under international agreements to reduce carbon emissions from deforestation and forest degradation ("REDD" agreements, see IUCN 2009, UNFCCC 2009, Wunder and Wertz-Kanounnikoff 2009, Angelsen 2008). The UN-REDD Program (2011) estimates that future financial flows for REDD programs, which channel funding for forest conservation from developed to developing countries, may be up to US $30 billion a year. Direct payments to landowners for avoided deforestation is one of the most prominent of a suite of REDD policy options that recipient countries will employ. Mexico is one of a handful of countries (including Costa Rica, Ecuador and Brazil) that have already established national or state-level payments for avoided deforestation programs and countries including Indonesia, Bolivia, Vietnam, Colombia and Uganda are experimenting with similar programs (UN-REDD 2011, Wunder and Wertz-Kannounikoff 2009, Jindal et al. 2008).

However, despite their increasing popularity, there are significant concerns about using PES to achieve REDD goals, including whether PES can effectively generate avoided deforestation and whether these initiatives harm the poor by restricting access to forest resources or new agricultural land (Hawkins 2011, Corbera et al. 2011, Pattanayak, Wunder and Ferraro 2010, Bulte 2008, Pfaff et al. 2007, Zilberman et al. 2008). Unfortunately, current debate is limited by the small amount of rigorous empirical evidence about PES impacts in developing countries (see references in Alix-Garcia et al. 2012, Arriagada and Perrings 2011, Pattanayak, Wunder and Ferraro 2010, Uchida et al. 2009, Gauvin et al. 2010).

To shed light on the poverty-environment tradeoffs of avoided deforestation programs, we evaluate forest and wealth impacts for a federal ecosystem services program in Mexico which 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 450 million USD to enroll more than 2.6 million hectares of land (CONAFOR

2012) in payments for hydrological services (PSAH), making this program one of the largest PES in the world, along with the U.S. Conservation Reserve Program, China's Sloped Land Conversion Program, and Costa Rica's Payments for Ecosystem Services Program.[1] 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).

By studying Mexico's hydrological services program, we seek to contribute to the existing literature on incentive-based conservation in three ways. First, we provide new evidence on the environmental effectiveness of a national PES program. This information may be valuable for other developing countries contemplating a similar style of promoting avoided deforestation. To date, research on avoided deforestation at the national level and across multiple years has only been conducted for Costa Rica's program (Pfaff et al. 2011, Robalino and Pfaff 2011, Arriagada 2008, Sánchez-Azofeifa et al. 2007). Rigorous retrospective evidence about Mexico's program is limited, covering only the earliest program cohorts (Alix-Garcia et al. 2012, Muñoz-Piña et al. 2008) and the Monarca reserve (Honey-Roses et al. 2011).

Second, we simultaneously evaluate both environmental and development outcomes of PES. Such "two-dimensional" evaluation is difficult because of large differences in the scale and type of data needed to measure environmental versus socioeconomic impacts, but is necessary in situations where there is a possibility that environmental policy may have negative development impacts. Forest-based PES has been promoted as an anti-poverty tool because of the strong global association between forest cover and poverty (e.g. Lipper et al. 2009), but there is a clear theoretical potential for tradeoffs between cost-effective avoided deforestation and poverty reduction if characteristics which drive avoided deforestation are negatively correlated with

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[1] In comparison, the United States Conservation Reserve Program had approximately 15 million hectares of land (37 million acres) enrolled at its all-time high in 2007 (Ferris and Siikamaki 2009), with an annual budget of almost $2 billion USD.

poverty (Pfaff and Robalino 2012, Pagiola et al. 2005, Jack et al. 2008, Zilberman et al. 2008, Alix-Garcia et al. 2008b). To date, the wealth impacts of avoided deforestation programs have not been evaluated directly or compared to environmental impacts.[2]

Third, we consider how heterogeneity in impacts across spatial characteristics determines possible tradeoffs between environmental effectiveness and poverty alleviation. Previous research on PES suggests significant heterogeneity in environmental effectiveness across space (Pfaff and Robalino 2012, Alix-Garcia et al. 2012) but does not consider implications for social targeting. In the case of Mexico in particular, the government has explicitly promoted the program as having both environmental and poverty-alleviation goals (Shapiro 2010). Therefore, for this and other similar avoided deforestation programs, it is essential to examine the possibility of achieving positive outcomes along both dimensions and to understand how changes in targeting rules may affect tradeoffs.

To assess the avoided deforestation impacts of Mexico's program, we compare differences in forest cover, measured by mean dry season normalized difference vegetation index (NDVI), across time annually from 2003-2011. We estimate impacts based on panel data comparisons (including property-level fixed effects) between accepted and matched rejected applicants from the 2004-2009 cohorts. To assess socioeconomic impacts, we compare changes in household asset ownership from 2007 to 2011 between recipients and matched rejected applicants from the 2008 cohort. Household data comes from a national household survey designed and supervised by the authors. We thereby construct the counterfactual case for both the environmental and socioeconomic dimensions of our analysis based on the behavior of applicants rejected from the program. This allows us to control for the key unobservable issue of desire to enroll in the program, which may be correlated with land quality or other household

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[2] Previous work on China's Sloped Land Conversion Program, which pays for reforestation, finds impacts including increases in some types of assets and in off-farm labor participation (Uchida et al. 2009, 2007, Xu et al. 2006). Several previous studies evaluate the impacts of protected areas on both environmental and development dimensions (e.g. Ferraro et al. 2011, Sims 2010, Naughton-Treves et al. 2011).

characteristics which affect deforestation behavior or asset growth. We also control directly for observable characteristics which drove selection into the program and could influence outcomes, including parcel location, land quality, water availability, baseline forest type and tenure type.

We find that the PSAH program has significantly reduced forest loss compared to what would have been expected in the absence of the program. The point estimate of the program impact suggests that the program reduces the downward trend of NDVI in the counterfactual group by over 60%. This reduction could come from avoided deforestation or reduced degradation. We also find significant heterogeneity in environmental impacts, with larger impacts in communally held lands, on higher quality land, and in less poor municipalities. Together, these results indicate a moderate avoided deforestation impact, with room for stronger impacts through improvements in targeting of payments.

The socioeconomic analysis asks whether the program is reaching the poor, whether there are positive wealth impacts for the beneficiaries, and whether the poorest recipients benefit the most. We find first that the PSAH program did reach poor communities and households; in fact program recipients are poorer on average than those living on all forested lands. Second, we find, on average, no significant differences in asset acquisition for households in communal properties or for private property households. The data show mixed results on the progressivity of PSAH, with possibly regressive impacts across municipalities but progressive impacts by distance to cities and within communities. Overall, we interpret these results as important evidence that PES is not making households worse off, which has been a major concern of REDD+ negotiations. At the same time, it does not appear to be conferring large surplus rents to individual landowners. A possible explanation is that much of the payments are being used to increase forest management and patrol activities. Our survey data indicate that labor costs of forest management are higher for beneficiaries and are large compared to the payment amounts. The estimated value of the extra labor (both paid and unpaid) that beneficiary communities and private households report in the past 12 months relative to non-beneficiaries is .84-1.1 times that of the annual program payment. This additional forest management may confer longer term environmental benefits through prevention of fires, disease, or illegal use which cannot be detected in our analysis of short-term deforestation.

Considering the impact results from both dimensions simultaneously, our analysis indicates only limited potential for changes in targeting that could produce both more avoided deforestation and more poverty alleviation. 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.

The paper proceeds as follows. Section 1 describes a simple economic framework which illustrates how PES changes deforestation incentives and why we are likely to expect heterogeneity in impacts across geographic and social characteristics. Section 2 outlines the data and empirical strategy for assessing the avoided deforestation impacts of the program. Section 3 presents estimation results of program effectiveness with respect to avoided deforestation. Sections 4 and 5 describe the survey design, estimation strategy, and results on household wealth and Section 6 concludes.

1. ECONOMIC FRAMEWORK

1.1 Framework

In order to illustrate the problem faced by the program managers in designing a payments for avoided deforestation program, we discuss a simple von Thünen style model of land use (see e.g. Chomitz and Gray 1996, Samuelson et al. 1983, Pfaff 1999, Angelsen 2010, Robalino 2007, Pagiola and Zhang 2010, Pfaff et al. 2011).[3] Figure 1 shows a graphical representation. Assume that there is a set of landholders, varying in land quality (q), where quality is determined by factors such as distance to city, soil type, and altitude. This metric is decreasing across the x-axis so the highest rents are to the left (in keeping with the convention of standard von Thünen models where land quality is based on distance to city). 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.[4] By assumption, returns to agriculture on high quality land are greater than returns to forest, while returns to forest on low 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 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

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[3] See Zilberman et al. 2008 for a complete general equilibrium theoretical analysis of the potential distributional effects of PES. Other theory papers suggesting heterogeneous socioeconomic impacts include Pagiola et al. 2005, Jack et al. 2008, Wunder 2008 and Uchida et al. 2009.

[4] 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 (Alix-Garcia, de Janvry, and Sadoulet 2005, Alix-Garcia 2007, Bray and Klepeis 2005, Deininger and Minten 1999, 2002, Diaz-Gallegos et al. 2009.) We prefer the von Thunen 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 be 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.

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.[5]

1.2 PES payments and avoided deforestation

Now assume the regulator acts at time t=0 to combat this expected deforestation trend by offering to pay landowners who maintain forest cover. We 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 PES program from 2003 to 2010). However, to target the program, the regulator may establish "eligible zones" in which the payments are available and may exclude other areas. Looking at Figure 1, it is clear that in order to achieve full avoided deforestation[6], the regulator should choose a payment greater than or equal to the change in the agricultural rents (Δr_a). Assuming that there is no leakage or slippage, payments of Δr_a and eligibility from b^0 to b^1 would achieve "full" avoided deforestation at least budgetary expenditure[7]-- the rent curve for forest would shift up to r_f^{PESopt} and the boundary between agriculture and forest would remain at b^0.

In reality, of course, the regulator cannot perfectly predict the future. Let us consider two ways he may fail to achieve "full" avoided deforestation. First, he may set the payments too low. In this case, the forest rent curve shifts up to r_f^{PESlow} and the agriculture-forest boundary shifts to $b^{1'}$. Deforestation happens between b^0 and $b^{1'}$, and "avoided deforestation" is only between $b^{1'}$ and b^1. In general, the smaller the size of the payments, compared to the magnitude of the increase in agricultural rents, the less avoided deforestation will be achieved. Second, the

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[5] We confirm the expected patterns using data from Mexico's Monitoreo Forestal. Probit models indicate that deforestation between 2003-2009 is indeed strongly predicted by slope, distance to the nearest locality with population greater than 5000, and elevation with the expected signs.

[6] 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 we focus on the cost-effectiveness of the program.

[7] From an economic perspective, the true costs of the program are not measured by budgetary outlays, but by the opportunity costs of lost production or timber extraction from land that would have been cleared, the administrative and transactions costs of running and participating in the program, and any distortionary effects of raising the program revenue. The majority of the program budget therefore should be regarded as a transfer.

regulator may not be able to perfectly target payments to the eligible zones. Suppose, for instance, the payment is set correctly, but the eligible zone is chosen to be between b^0 and b^z. If the budget is fixed and payments are allocated on a first-come, first-served basis, many of the payments will go to landowners who would not have deforested even in the absence of payments (those between b^1 and b^z). Conversely, some of the landowners between b^0 and b^1 will not get payments and will deforest. If the budget is unlimited, then full avoided deforestation is achieved with the larger eligible zones, but many payments will be made to landowners who would not have deforested. In an impact analysis, the apparent average "effectiveness" of the payments will be low.

1.3 PES payments and socioeconomic gains

Let us now consider the socioeconomic implications of the program. In Figure 1, the surplus rent received by landowners equals (at most) the payments minus the opportunity cost of land use (transaction costs and maintenance costs would further 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 triangle (s). Note that the amount of surplus gained by individual landowners increases as land quality decreases because opportunity costs are lowest on this land. This suggests that we should see greater socioeconomic impacts of the program where land quality is lower.

In addition, whether or not the program is progressive overall will depend on the correlation between wealth and land quality. In most cases, we expect that factors that increase land quality will be negatively correlated with wealth: distance to city and slope are clear examples as both are positively correlated with the degree of marginalization in our data and negatively related to land quality. Where wealth is negatively correlated with land quality, we expect that the program will be progressive within the set of households that receive payments. Unfortunately, note that for our optimal policy, the poorest landowners would be outside of the eligible zones and would not receive any benefits. In addition, as the regulator better targets the eligible zones to minimize budget expenditures, more payments go to the set of landowners in the middle of the land quality distribution, and the progressivity of the program is reduced. We will also likely see lower socioeconomic impacts on average because less of the payments would be surplus above opportunity costs. This implies a direct tradeoff between generating more avoided deforestation and generating more wealth.[8]

Possibilities for win-win outcomes exist only if factors that increase avoided deforestation are negatively correlated with baseline wealth. Two possibilities might be increased targeting on the basis of tenure type or by region. Tenure arrangements are a complex function of historical developments (Alix-Garcia 2008a) that were not driven by geography alone. In our data, common properties show both a higher rate of deforestation and lower wealth than private properties on average, suggesting potential for win-win outcomes. There may also be scope for additional targeting on the basis of region. To put this in the context of our graphical model, we might imagine a second region which looks similar but in which the zone of expected deforestation starts at a lower land quality, so PES in this region would on average be going to poorer households. Finally, since the correlation between threat of deforestation and poverty is not perfect, the regulator can also try to ensure that within the set of properties with high deforestation risk, payments are targeted to poorer households. This is in fact close to the system that has currently been established in Mexico. With this simple framework in mind, we turn to the data on Mexico's program.

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[8] 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 2000-2005. 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.

2. AVOIDED DEFORESTATION: BACKGROUND, DATA, EMPIRICAL STRATEGY

2.1 Program background

Mexico's program of Payments for Hydrological Services 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). Annual payment rates for the cohorts we study (2004-2009) are given in Table 1. They correspond to approximately $27 USD per hectare for general forest types and approximately $36 USD 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 (Shapiro and Castillo 2012). Our survey data indicates that on average, annual per capita payments for households in common properties were approximately $130 USD, which is greater than 1 month minimum wage. For private property households, the average per household payments were approximately $3050 USD per year, which is approximately 12% of household income given the estimated income brackets of the private property households.[9]

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[9] 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 and excluding the payments they give for technical support. These numbers are a lower bound as they include the total population in the community, including children as reported by community leaders. The final amount was converted to US dollars using the exchange rate reported for the 15th of July of 2011 (11.72 pesos/ USD). 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 there are 20 working days within a month, the monthly minimum wage is 1,161 pesos. Using the previous exchange rate, this is equivalent to 99 USD.

For private households, the mean payment per year is 35,777 pesos. With the same exchange rate as before, this is equivalent to 3,053 US Dollars. The survey we collected does not have information about households' income, so we used income results coming for the National Income and Expenditures survey (ENIGH 2010), collected by

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 a drawn-out 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 to peasants organized in communities (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, and are home to approximately 80% of Mexico's remaining forest (Bray et al. 2005). Within these same communities there also live many people who are not members of the ejido, usually descendants of the original members (ejidatarios) who were prevented from becoming members by the legal restriction on inheritance to only one child. The nonmembers do not have voting rights and are not formally given land, but in practice they often farm on ejido lands ceded by others or illegally taken from the commons and some may even be granted voting rights in the general community assembly.

2.2 Data on PES recipients

Using program data and GIS boundaries of program applicants from CONAFOR, we construct a spatial database of all applicants to the program from 2004-2009.[10] Figure 2 shows the location of the participants and controls as well as the outlines of the area forested in Mexico prior to 2003 by six categories of forest. To analyze program effects from 2004-2009, we use points as a unit of analysis; intersecting these points with the program polygons allows us to

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INEGI, and assumed that private households in our sample are located in the upper 3 deciles of the income distribution. According to this survey, the average quarterly income for the upper 3 deciles is 72,398 pesos, so average annual income ~ 289,593 pesos. Therefore the PSAH payments represent 12% of this total annual income.

[10] 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.

clearly code the program status of each point in each year.[11] The points are a random sample from within PSAH applicant boundaries from 2004-2009 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 only at a density of 1 point per square km (~38,000 points) and cluster all standard errors by property. In order to understand deforestation behavior in lands outside of program applicants during the same time period, we also randomly select 50,000 points which were classified as forested prior to the start of the program from across all of Mexico.[12]

2.3 Measure of forest cover

To assess the environmental effectiveness of the program, we use the average dry season normalized difference vegetation index (NDVI) in each year from 2003-2011 as a measure of forest cover. NDVI is a measure of 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 thus indicated by a decrease in average annual NDVI. We construct mean NDVI 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 2011, Meneses-Tovar 2009a,b). Economists have relied on NDVI decreases to measure deforestation in previous research in both developed and developing countries (Mansfield et al. 2005, Burgess et al. 2011, Foster and Rosenzweig 2003).

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[11] 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.

[12] 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).

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 Yucatan peninsula). The downside is that MODIS is spatially coarse, with resolution at 250m pixels (~ 6 ha). 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 2004-2009 is 680 ha (> 100 pixels), we believe the resolution of the data is appropriate for this analysis. As small areas of clearing do happen in Mexico, particularly in the south, we maintain the continuous measures of NDVI in our analysis rather than classifying each pixel as forested or non-forested. We do also check robustness of the main results to several alternate definitions of forest cover.[13] Finally, we note that all measures of forest cover are sensitive to seasonal vegetative cycles ("phenology") and annual variation in rainfall. More rainfall at the right time will increase the density of leaf cover, particularly in deciduous forests. To control for this variability, our regression models include measures of annual dry season (Feb-April) and growing season rainfall (May-Jan) as well as controls for extreme rainfall events described below.[14]

2.4 Selection of controls and regression models

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

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[13] 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.

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

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.[15] 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 investigate 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.

Selection into the PSAH program is described in more detail in Shapiro and Castillo (2012). Broadly, the requirements are that the submitted parcels have a set amount of forest cover to start (> 80% in 2003-2005; > 50 in 2006-2009) and be inside designated eligible zones. The characteristics determining eligibility or priority include: being in a watershed which supplies a locality with population greater than 5000, being within a watershed that is characterized as overexploited, being in a priority mountain or protected area and being within a poor or majority indigenous municipio. From 2006 onwards, priority was also given to properties with a high risk of deforestation (as measured by INE's version 1 layer). We solicited data on the reasons for rejection in each year and find that there are four main reasons for rejection in our panel dataset: 1) having all the qualifications but being rejected for lack of funding due to program budget constraints, 2) failing to meet the minimum forest cover requirement, 3) being located outside of the eligible zones, 4) having incomplete paperwork or failing to meet other technical requirements. More than 40% of our control points are in the first group, which is the best comparison group because these applicants met all of the requirements but submitted an application a few days or weeks later than other applicants. Approximately 30% of the applicants in our sample were rejected for the second two reasons, which constitute selection on

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[15] The main criticism of previous research on PES programs is that results may be driven by possible selection bias due to unobservable characteristics driving lower opportunity costs of enrolled parcels compared to non-applicant controls.

observables. To account for this selection, we match on or control for appropriate geographic characteristics as described below. The fourth reason for rejection is potentially more problematic: missing paperwork could reflect lower institutional capacity which is not directly observable, could change over time, and might be correlated with deforestation (approximately 20% of our sample). To minimize this problem, we limit our analysis to applicants which have sent in geo-referenced property boundaries and have already passed through a first round of screening, ensuring a reasonable level of institutional capacity. We also match on municipal poverty levels and tenure type, which may correlate with institutional capacity.

Prior to estimation, we match points within accepted parcels to rejected parcels on the basis of characteristics which determined selection into the PSAH program and could drive deforestation patterns. We use 1:1 covariate matching on the Mahalanobis metric, with replacement and with calipers excluding matches with distance > 5. The covariates we match on are slope, elevation, distance to the nearest locality with population greater than 5000, 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 municipio with majority indigenous population. Matching is conducted within region and tenure type (common vs. other) to ensure exact matches on these characteristics.

Our preferred specification ("property fixed effects") is 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 coefficient of interest (average program impact).[16]

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[16] Equal to 1 if the point was enrolled in the program in the previous year's cohort (including receiving "elaboration" support to develop a proposal.) The lag is 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 Feb-April.

Several variables are included to control for rainfall: ln *dry* is the natural log of annual dry 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 *sdrain*, 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), *hurricane*. We include state-year fixed effects (α_{st}) to control for possible economic shocks to states in each year and forest type fixed effects (α_v) to account for the different NDVI signatures of each vegetation category. Finally, we include property level fixed effects (α_p) to control for possible unobservable fixed characteristics. Standard errors are clustered at the property level to account for spatial and serial correlation.

3. AVOIDED DEFORESTATION: RESULTS

3.1 Summary statistics

Table 2 shows summary statistics for the unmatched and matched treated and comparison groups and the normalized difference in means (Imbens and Wooldridge 2009). For comparison, we also include summary statistics and normalized differences for a random sample of initially forested points outside of program applicants. From Table 2a, we see that beneficiary lands are somewhat closer to major localities than the non-beneficiaries (.167 standard deviations) and all other forest points (.147 standard deviations) but have higher slope and elevation than the non-beneficiaries and the random sample of forest points. The mean risk of deforestation among beneficiaries, according to Mexico's Instituto Nacional Ecología (INE),[17] is slightly higher among the accepted applicants vs. rejected applicants (.029 standard deviations) and somewhat lower (.204 standard deviations) than all randomly selected forest points. Compared to all forest in the country, the beneficiaries over-represent bosque mesofilo (cloud forest) and bosque coniferas (coniferous forest), and under-represent selva baja (low-lying rainforest). This

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[17] 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.

distribution of forest types reflects CONAFOR's stated focus on bosque mesofilo, which has been linked to hydrological services (Martínez et al. 2009, Bruijnzeel, 2004). In addition, the beneficiaries have a substantially higher probability of being in an overexploited aquifer than all forest points, (.161 vs. .122 and .074), as well as a lower degree of water availability (6.82 vs. 6.86 and 7.18), and a higher likelihood of being in a priority mountain area (.262 vs. .116 and .068). These differences also reflect CONAFOR's efforts to target the program to areas where hydrological services are most important. With respect to the social goals of the program, we see that the beneficiaries are in municipalities with higher poverty index values (.267 vs .265 and .239) although these differences are small (0.001 and 0.019) when normalized by standard deviations. The program also enrolled more land in municipios with majority indigenous populations (.380 vs. .253 and .248) and more land in common properties (88.0 % vs. 79.8 % and 60.4 %) and these differences are also substantial in standard deviation terms.

Taken together, these statistics suggest CONAFOR was moderately successful in targeting the program to areas with a substantial risk of deforestation, potential for hydrological services benefits, and more poverty. A major concern about PES programs has been that it will enroll only those areas with a very low risk of deforestation. These statistics indicate that this is not the case for Mexico's program. Within the available applicants, CONAFOR appears to have selected those which are closer to urban areas, have a higher risk of deforestation on INE's layer, more water scarcity, and have higher poverty. However, the beneficiaries do have higher slope and elevation and a somewhat lower risk of deforestation when compared to all other forested points-- this may indicate that the payments are currently too low to attract applicants with the highest risk of deforestation. Table 2b indicates the same summary statistics for the sample of matched beneficiary and non-beneficiary applicant points. Matching substantially improves the balance across distance to urban areas, baseline poverty and forest type, although we note that the matched non-beneficiaries have somewhat higher slope and elevation and lower likelihood of being in a majority indigenous municipality. Post-matching, none of the normalized differences are greater than .25 standard deviations, which is the rule of thumb suggested by Imbens and Wooldridge (2009).

3.2 Average impacts

Table 3 gives our main estimates of program impacts on mean NDVI, using the estimating equation described above with property-level fixed effects. Column 1 shows average program impact while columns 2-5 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 nearly 62% (.004/.0065). Because NDVI loss (controlling for climate) can occur as a result of either deforestation or degradation, it is difficult to translate this number directly into avoided deforestation or degradation. Nonetheless, the result indicates that the program reduces either deforestation, or degradation, or both.

One pattern which is evident looking at our GIS data is that deforestation is highly dispersed spatially. Rather than a frontier situation, where we might expect most clearing to be geographically concentrated, deforestation in Mexico is generally scattered in small amounts over vast land areas. Data from CONAFOR's Monitoreo Forestal 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%). In addition, most individual landowners are clearing only small amounts each year. While these small amounts add 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. Whether or not there are opportunities for managers to increase the cost-effectiveness of the program depends on whether there is systematic heterogeneity in avoided deforestation impacts that can be better exploited.

3.3 Heterogeneity in environmental impacts across space

Motivated by the simple economic framework discussed in section 1, we test for heterogeneity in effectiveness across region, distance to the nearest urban locality, slope, baseline municipal poverty and tenure type. We find (Table 3, column 2) that effects across the four regions are not significantly different from each other, although the coefficients indicate possibly higher avoided NDVI loss in the central region (.0038 +.0031 = .0069).[18] We do see significant heterogeneity by distance to urban area and slope, both key determinants of land quality. As expected by our von Thünen model, we see less avoided deforestation as we move away 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) the marginal effect 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 NDVI trend) at a slope of 26 (90th percentile).

In terms of social goals, we find less avoided deforestation at higher levels of baseline municipal poverty, unfortunately suggesting that there is no easy win-win strategy to increase avoided deforestation and make the program more progressive. 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

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[18] The different between region 1 and region 2 is significant at the 5% level in some specifications, but is not robust to alternate specifications.

NDVI loss ranged from .005 to .0017. However, when we break recipients down into common property beneficiaries (ejidos and communidades) versus private and other types of beneficiaries, we find that the program is most effective in the common properties, with an approximate avoided NDVI loss of .0049. This suggests possible win-win targeting if more payments were given to common property beneficiaries, who are in general more poor than private property landowners. In addition, we find no significant heterogeneity in avoided deforestation impacts by majority indigenous status, which indicates there is no loss of effectiveness by targeting to these municipios.[19]

3.4 Robustness checks

Several robustness checks are shown in Table 4. Columns 1-4 use subsets of the matched dataset while column 5 uses all rejected applicants. Column 1 changes the beneficiary variable to be defined in the same calendar year as the landowner received payments, rather than lagged by one year. We find smaller but still significant results (marginal effect on NDVI = 0.0028). Column 2 includes as controls only those points inside properties which met all the requirements but did not receive payments due to lack of funding ("aprobados sin recursos"). We see that the coefficient on beneficiary is again somewhat smaller (0.0027) but remains strongly significant. The smaller magnitude may be explained by the fact that many landowners in the approved without funds group do reapply in future years (more than half of the land in this category of the matched sample is resubmitted for application), so owners may delay planned deforestation in anticipation of applying again. Column 3 restricts the controls to only those within the eligible zones and column 4 restricts to the controls to lands which applied and were rejected only once

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[19] We also 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.

(i.e. did not reapply in future years). Both of these coefficients are very similar to the main specification in Table 3, column 1. Finally, the results are also robust to skipping the first step of matching and using all rejected applicants as controls (column 5).

4. SOCIOECONOMIC IMPACTS: DATA AND EMPIRICAL STRATEGY

4.1 Survey design

To assess the socioeconomic impacts of Mexico's program, we conducted a community and household survey between June and August of 2011. The surveyed covered beneficiary and non-beneficiary applicants from the 2008 PSAH cohort. 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 3. Within each region, 3-4 Landsat footprints (areas 180 x 180 sq km) were randomly selected from within the set that contained sufficient good quality past images to monitor deforestation over time.[20] All 2008 cohort applicants within each footprint were matched to controls from the applicant pool who did not subsequently become beneficiaries in 2009 or 2010 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 5000, 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 in each region were eliminated from the possible sample. 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

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[20] Analysis of this sub-sample of Landsat data (30m x 30 m pixels) is currently in process.

two Landsat footprints for nearby ones and the addition of two footprints in order to increase sampling possibilities among the non-beneficiaries.

Enumerators 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 5 households with full land-use rights and voting power ("ejidatarios") and 5 without ("non-ejidatarios"). The final sample is composed of 118 private households (61 beneficiaries and 57 non-beneficiaries) and 1125 households in common property communities (596 beneficiaries and 529 non-beneficiaries) distributed over 111 communities. Table 5 indicates the breakdown of surveyed households in each region and Figure 3 shows the locations of the beneficiary and non-beneficiary properties (here shown as points rather than polygons for clarity). 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. The questionnaires contained sections on household demographics, assets, land use, production and participation in forest management activities. To establish baseline measurements, surveys included recall questions about assets, land use, etc. in 2007, which is the year prior to program implementation.

4.2 Estimation strategy

To identify program impacts at the household level, we compare differences over time in household asset ownership between beneficiaries and non-beneficiaries. We first estimate the presence or absence of each asset using a household fixed effects model:

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

Where A_{iet} indicates the presence of an asset for household *i* in property *e* at time *t* (2007 vs. 2011). The variable *beneficiary* is equal to zero for all properties in 2007 and to one in 2011 if the property was a beneficiary starting in 2008. 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.[21] The vector A_{iet} has many dimensions – recorded assets range in size from a cell phone to a car. We report average effects on individual assets, but in order to reduce the dimensionality we also calculate results which aggregate assets into an index.

Indices include three types common in the development literature, which use different weighting schemes (full details given in the appendix). The first index is created using principal components analysis (PCA) on ordered data, which constitutes an improvement over the traditional Filmer and Pritchett (2001) method based on binary data (Kolenikov and Angeles 2009). This approach gives more weight to observations which provide more information about the variation in the data. The second index, the inverse proportion index, applies weights to the assets which are the inverse of the proportion of households which hold a particular asset in 2007. This gives greater weight to assets which are relatively rare – like cars and computers– and less to more common assets, like televisions. Finally, we construct a price index based on data from consumer agencies in Mexico on the prices of consumer goods and estimates of the values of housing characteristics. In order to measure changes in wealth over time, the 2007 weights or prices are used to construct the indices for 2011 in all cases.

5. SOCIOECONOMIC IMPACTS: RESULTS

5.1 Summary statistics

Table 6 shows summary statistics of the covariates for beneficiary and non-beneficiary households. We analyze separately households living in common property communities and private landowner households. This is because, as can be seen from the summary statistics, common property households are substantially poorer than private property households. The last

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[21] 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.

column in Table 6 shows the normalized difference between non-beneficiaries and beneficiaries. For the households in common property communities, we see that the beneficiaries are slightly farther from localities greater than 5000 people, are at higher elevation, and have higher initial poverty within their locality. However, none of the normalized differences is greater than .25 standard deviations, suggesting reasonable balance in the sample between beneficiaries and non-beneficiaries. This rule of thumb is also met for the private landowners, although we note that the private beneficiaries are more than .1 standard deviations better off in 2007 according to each of our indices.

5.2 Average impacts

Figure 4 shows kernel density distributions of assets according to the PCA index for each of the three groups. The red solid lines show assets in 2007 while blue dotted lines show assets in 2011. Graphs on the left indicate beneficiary households while graphs on the right indicate non-beneficiary households. From this we extract several key insights. First, the overall distributions of beneficiaries and non-beneficiary households are fairly similar at baseline for each of the three sample groups, indicating reasonable balance across the distribution of wealth at baseline. Second, the graphs show that all households have gained assets over this time period, i.e. there is no evidence that participation in the program has made households worse off in an absolute sense. Third, the pattern of gains for beneficiaries and non-beneficiaries is not statistically[22] different; thus we do not expect to find dramatic wealth impacts of the program in our regression analysis. Figure 4 indicates that the ejidatario beneficiaries may have increased assets by more than non-beneficiaries, particularly in the middle and at the upper end of the distribution. The non-ejido beneficiaries have similar changes to the control group. For the private properties, we notice that the changes over time in assets are smaller but again see similar shifts between beneficiaries and non-beneficiaries over time.

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[22] Kolmogorov-Smirnov tests for equality of distributions fail to reject the null that the samples are drawn from the same distribution.

Table 7 shows estimates of program impact on ownership for each asset following equation (2) above. The first set of estimates is for households of ejido members with full voting status and land rights (ejidatarios) while the second set is for non-ejidatarios.[23] The third set combines these two groups and weights households by the share of each type of household in the community (weights are the ratio of the number of ejidatarios and the number of non-ejidatarios relative to the total community population). We interpret these results as the impact of the program on the entire community. The fourth set shows impacts for the private landowner households.

For households in common properties, we find that the program has had possible positive impacts but these are not statistically significant overall. Among ejidatarios, we find marginally significant increases in the probability of owning computers (0.034), cars (0.051) and number of rooms in the house (0.076). Given that the average baseline probabilities of ownership are .03 and .25 for computers and cars, and the average number of rooms is 2, these impacts constitute increases of approximately 100 percent, 20 percent, and 4 percent, respectively. For non-ejidatarios, there are no significant changes in asset ownership. These results are consistent with the likely distribution of more substantial payments to the ejidatarios versus the non-ejidatarios.[24]

We do not find significant positive or negative impacts for the private households, with the exception of cell phones, for which there is a marginally significant negative impact. It is possible that this may be explained by the greater presence of cell phones in the beneficiary group at baseline (49 percent of beneficiaries had cell phones in 2007, compared to 42 percent of non-beneficiaries) or by differential changes in access to coverage across this period. Estimations

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[23] Note that members of comunidades, in which all members have full rights, are grouped with ejidatarios.

[24] Analysis of our community survey data indicates that among communities that provided lump sum transfers, approximately 80% of the amount transferred went to households with full land rights.

substituting the amount of per capita payments for the binary treatment variable yield similar results for both households in ejidos and private property households.[25]

Table 8 gives results for each of the three household wealth indices which aggregate assets. For common property households, being a beneficiary has, on average, a positive but not statistically significant effect for each of the three indices. The weighted sample results show a 0.158 increase for the PCA index, a 0.058 increase for the inverse proportion index and a 0.092 increase in the price index. To get a sense for magnitudes, the price index is measured in 10,000's of pesos, so a coefficient of 0.092 indicates that the program resulted in an additional 900 pesos more of assets. Compared to the average baseline value among the beneficiaries of 11.3, this represents an approximately 0.8% change. For the private landowners, the estimated effect is larger, at 0.241, but the baseline value is also higher, at 20.4, so in percentage terms, this also implies a change of approximately 1.1% in assets. We note however that among private households, the results are negative for the PCA index and inverse proportion index. This inconsistency in signs leads us to conclude that there is no robust detectable effect on private households' assets.

We interpret these results as evidence that PES is not making households worse off but is also not conferring large surplus rents to individual landowners which are showing up in asset growth. As previously stated, the payments are significant compared to income, representing more than one month minimum wage for ejido households and approximately 12% of annual income for private households, and the small avoided deforestation results suggest that opportunity costs should be small on average. The lack of difference in asset growth may therefore indicate that the size of the payments is relatively small compared to the transaction costs and forest maintenance costs of participating.

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[25] Available upon request. In addition, a robustness check where we use only households in communities where the per capita total payment is greater than 1000 pesos (results available from authors) indicates statistically significant average impacts on car purchases and wall upgrades for households in communal properties and no significant or marginally significant impacts on private households.

The survey data indicate that program implementation costs are indeed considerable compared to payments. The most important household level costs of the program are related to labor engaged in forest management activities. Community leaders in beneficiary ejidos report on average a greater number of worker days per year spent in fire prevention (+65 days), pest control (+17 days), and forest patrols (+142 days) compared to non-beneficiary ejidos. 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.[26] Private households also report more days spent in fire prevention (+41 days), pest control (+4 days), and forest patrols (+76 days). For private households, the median ratio of the cost of additional labor to payments is 1.1. These high ratios suggest that the program may be just covering the additional costs of protecting forest, particularly against longer-term threats to forest health or from illegal logging.[27]

5.3 Heterogeneity in impacts

In order to assess the impact of potential adjustments to targeting, this section examines heterogeneity in impacts across the same dimensions as shown in the avoided deforestation analysis. Table 9 shows tests for variation in impacts of the program using the price and PCA

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[26] The mean annual payment for common property communities, excluding payments given for technical assistance, is 352,567 pesos. This is equivalent to 30,082 US Dollars. 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 management (relative to the changes in labor in non-beneficiary communities). For non-ejidatario households, the program induces 6 additional days of forest labor and for ejidatario 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 ejidatarios). We think this difference may be explained by a skewed distribution of forest management activities among households—the system of rotating responsibilities for community activities means that some households will disproportionately contribute to forest management 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.

[27] These ratios may also be overestimates if households value their labor at less than the minimum wage.

indices. None of the regional interactions are significant (at the 5% level) for the weighted sample of ejido households or for private landowners. For the ejido households, there are overall positive impacts in the north. The sum of the coefficients of north and each region indicate overall positive impacts in the center and southeast regions and negative impacts in the southwest. According to the price index, private landowners gain in three out of four regions—the north, the center and the southwest, but lose in the southeast. However, impacts on private households in all regions are not significantly different from zero.

In the second panel of Table 9, an interaction term between beneficiary and a dummy variable indicating that the property is farther than 40 km (75th percentile) to the nearest locality with population greater than 5000 shows the expected pattern for all four groups. In all estimates, the estimated gains in wealth are increasing with distance from large localities, which is consistent with the notion that the economic surplus gained by landowners is greater when the opportunity cost of enrolling in the program is lower. It is not statistically significant in all cases, although the impacts for ejidatarios and the weighted estimates for those far from cities are positive and significant at the 10% level in all cases. Given that the average growth in the PCA index for non-beneficiaries was .83, the point estimate of .30 for the impact beyond 40 kilometers suggests an increase in growth of 36%.

The third set of results indicates heterogeneity in the program impact by 2005 municipality poverty level. For the households living in communities, we find that the program leads to more asset acquisition by those in lower poverty municipalities. Impacts are positive and significant in municipalities falling in the very low, low, and medium marginality categories (marginality index cutoffs at -1.2, -.65, -.08). They remain positive but with very small and insignificant coefficients at higher levels of marginality. Effects for private households are uniformly small and insignificant.

Finally, in Table 10, we investigate within ejido outcomes by including ejido-level fixed effects in order to analyze the extent to which relative wealth within the ejido determines program impacts. The ejido-level fixed effect controls for the average level of impact within the ejido, and the interaction with the baseline household wealth index identifies differential impact across this dimension. In contrast to the municipal poverty interactions, the within-community estimates suggest a possibly progressive effect of the program. Beneficiary households with greater initial wealth are significantly less likely to acquire assets including TVs, refrigerators, stoves, and floor improvements. However households wealthier at baseline are more likely to acquire larger assets including computers and cars. Although this evidence alleviates concerns that Mexico's program has harmed the poorest households, it also does not suggest that the program can act as a major poverty alleviation tool. Affiliated case-study research in Oaxaca and Yucatan found that many participants felt that the payments were not sufficient to reinvest in income-generating projects or lifestyle changes (Baker and Rice 2012). At the same time, of the beneficiaries who answered the question in our survey "Do you agree with your community's participation in the program?", 99% answered yes.

Comparison of Tables 8, 9, 10 and 3 yields several insights into the tradeoffs inherent in adjusting the targeting scheme. First, although there is some indication that impacts differ across region, these are not conclusive enough to motivate changes in targeting by region. Table 9's estimates suggest that avoided deforestation could be potentially higher in center of the country. Table 3, however, indicates shifting targeting towards the center would yield no additional asset increases, and to the extent that it reduces payments to the southeast, might actually yield lower average welfare impacts. A second potential targeting shift would be to send more payments to areas closer to large localities. As predicted by our simple model, this could increase environmental effectiveness (column 3, Table 3) but would reduce poverty alleviation (panel 2, Table 9). The obviously regressive strategy of targeting wealthier municipalities could increase environmental effectiveness (column 5, Table 3), and yield greater asset increases in beneficiary communities (panel 3, Table 9), but these benefits would accrue to the relatively wealthy. Finally, the estimates do show one potential win-win for poverty and the environment –

payments appear to have more avoided deforestation impact in common property communities without having negative impacts on asset acquisition (Table 8) or regressive impacts within ejidos (Table 10). To the extent that these properties house the poor, this shift could result in greater avoided deforestation as well as more payments received by the poor.

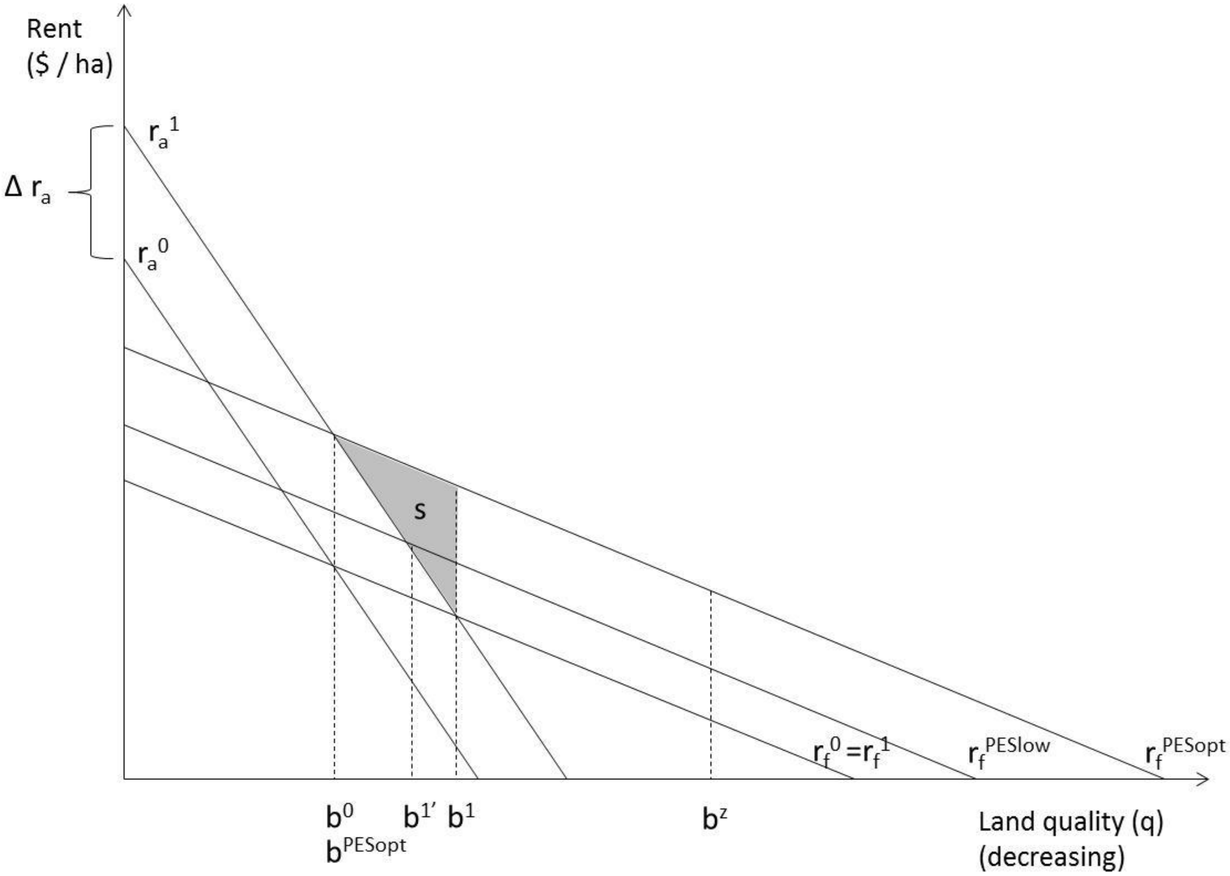
6. CONCLUSION

In general, our analysis indicates that Mexico's Payments for Hydrological Services program has succeeded in reducing expected deforestation rates while protecting livelihoods. This justifies optimism about the potential of payments for ecosystem services to maintain existing forest cover while establishing compensation for services provided in the case of missing markets. However, our findings suggest caution in terms of expectations that PES will generate significant poverty alleviation, as we do not find evidence for significant gains on average in wealth by beneficiaries when compared to controls. In addition, the results highlight that it may be unrealistic to expect significant future gains in avoided deforestation without either raising payments or using more regressive targeting. In Mexico, avoided deforestation might be increased by additional targeting on the basis of land quality (areas closer to cities, lower slope areas) but such changes would likely be regressive. There is some scope to improve on both dimensions by targeting more payments to common properties.

The poverty-environment tradeoffs that arise from the PSAH in Mexico are a function of the complex interaction between history, land quality, and poverty. Specifically, the poor in Mexico presently possess a significant amount of forest, but they are not necessarily those who put the forest at greatest risk. For policymakers concerned about the impact of incentive based conservation on the poor, careful analysis of the ownership distribution of the resource in question, and of the relationship between over-extraction and poverty should provide significant guidance regarding potential impacts of such programs on the poor.

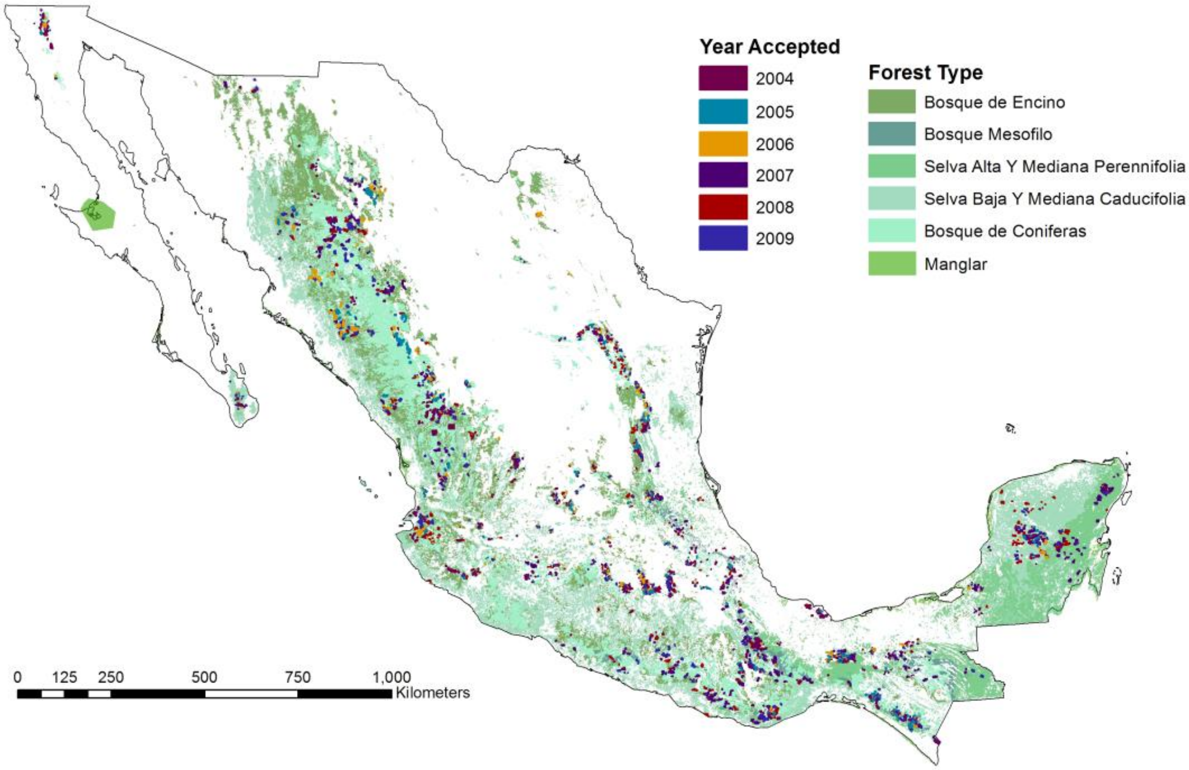
Our analysis highlights several interesting avenues for future research. These include questions about how the duration of the contract matters, if the program generates longer term wealth impacts through changes in investment, whether there are significant non-linearities in the heterogeneity of impacts and whether there is slippage or leakage of avoided deforestation. Previous work (Alix-Garcia et al. 2012) suggests significant slippage effects for an early cohort of PSAH, possibly due to the relaxation of credit constraints in more poor communities. Such effects would amplify the tradeoff between targeting based on avoided deforestation versus poverty. In addition, our analysis of changes in forest management activities suggests that the costs of participating in PES programs may be underestimated by policymakers. Most theoretical analysis of PES (including ours) focuses 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 the regulator deserve additional study.

Fig 1: Economic framework: von Thünen model of PES



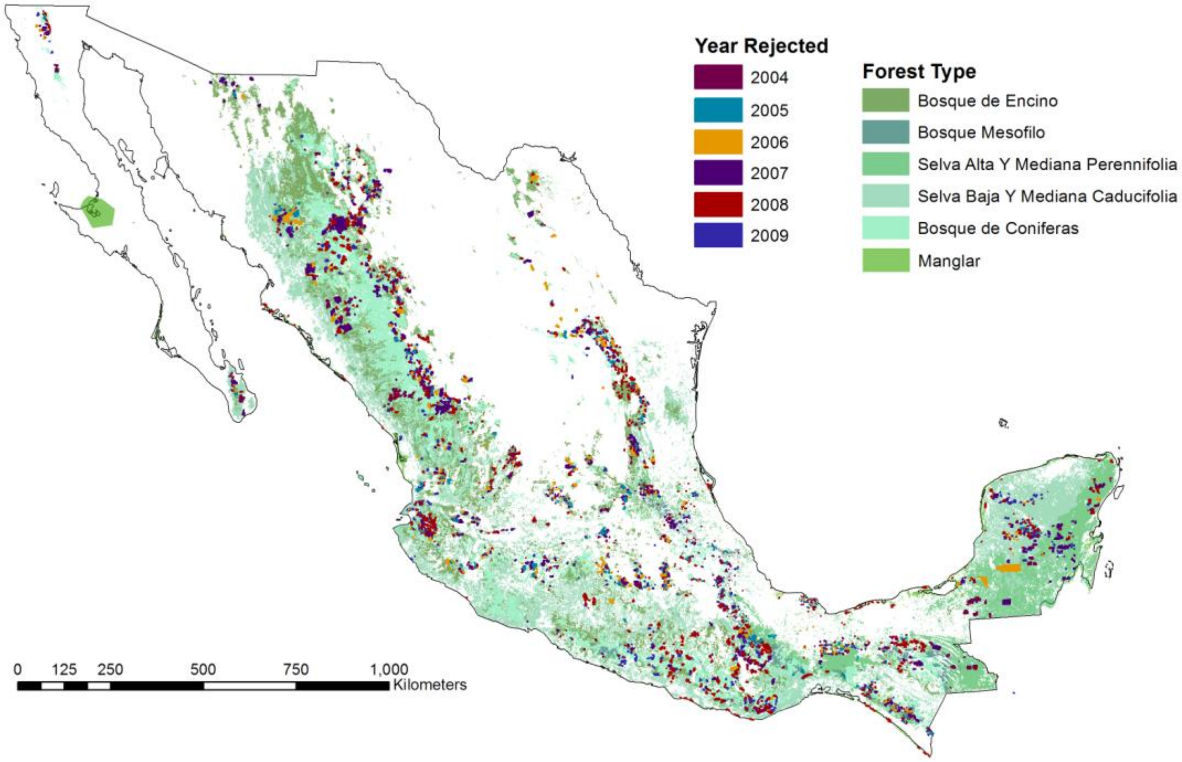
Graphical von Thünen model. X-axis indicates quality of land parcels (decreasing). Y-axis indicates rents from agricultural or forest land use. See text in Section 1 for full explanation.

Fig 2a: Recipients of PSAH 2004-2009



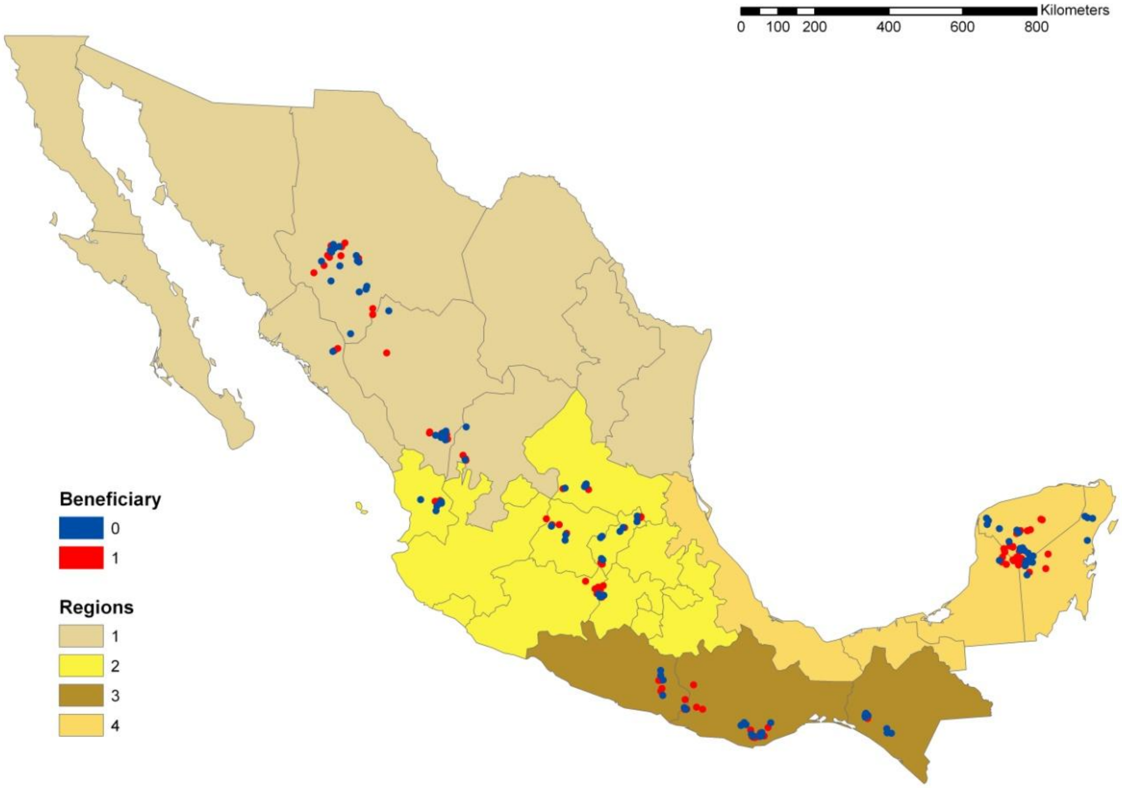
Data on program recipients from CONAFOR. Forest types from the INEGI Series III land use layer (circa 2002). Bosque de Encino = oak and pine forest, Bosque Mesofilo = cloud forest, Selva Alta = higher altitude rainforest, Selva Baja = low-altitude rainforest, Manglar = mangroves.

Fig 2b: 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 Mesofilo = cloud forest, Selva Alta = higher altitude rainforest, Selva Baja = low-altitude rainforest, Manglar = mangroves.

Figure 3: Survey sample and survey regions

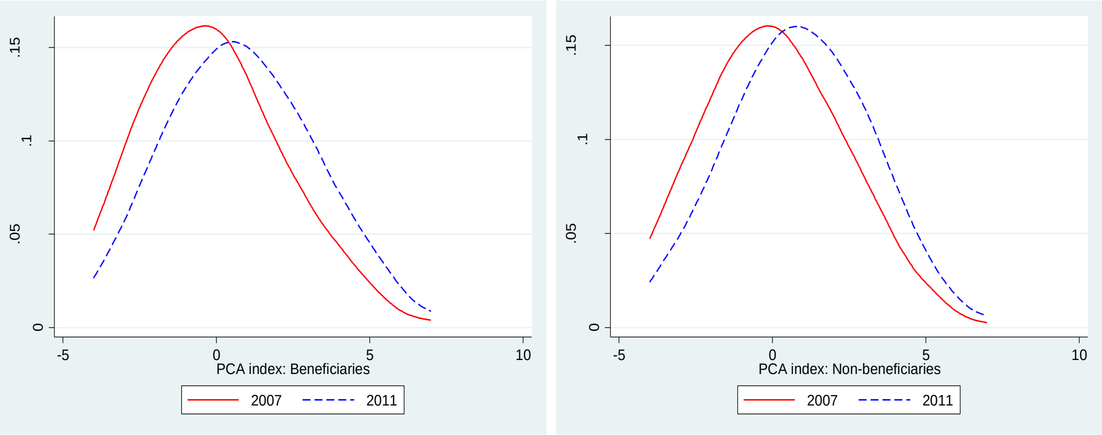


Centroid points of properties surveyed (summer 2011). Total number of properties surveyed = 233.

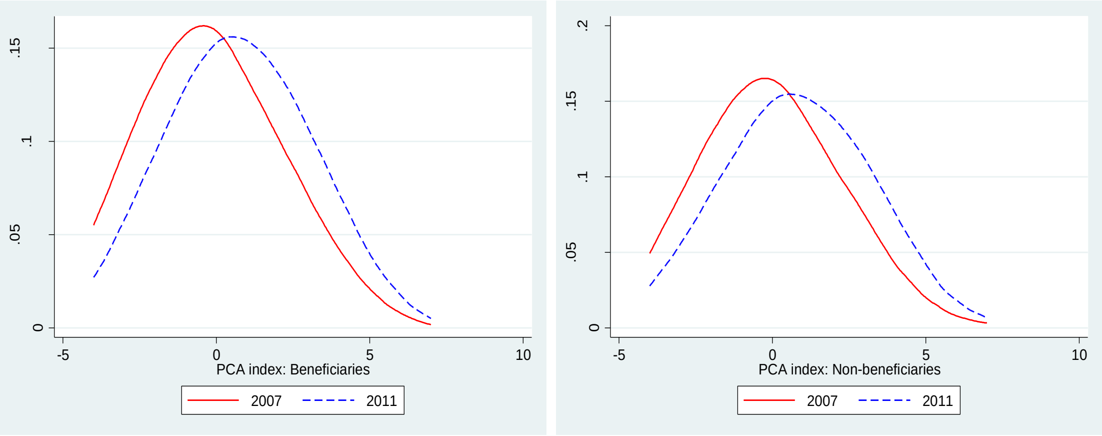
Figure 4: Distributions of assets over time for Beneficiaries and Non-beneficiaries

Graphs show the density of the PCA index in 2007 (red) and 2011 (dashed blue) for beneficiaries (left) and non-beneficiaries (right). Kernel density graphs with bandwidth = 1.5

a. Ejidatarios



b. Non-Ejidatarios



c. Private properties

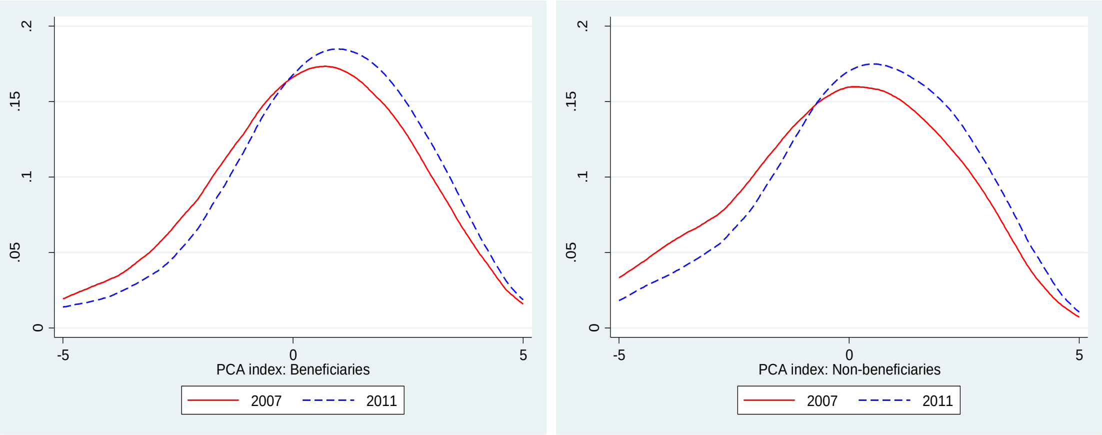


Table 1: PSAH Payment Rates per hectare 2004-2009 (in Mexican pesos)

Payment Rates	2004	2005	2006	2007	2008	2009
Rate per hectare for bosque mesófilo (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.

Table 2: 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 > 5000 (km)	32.94	22.06	38.76	26.00	-0.167	38.11	27.36	-0.147
Muni poverty index	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
Manglar	0.0067	0.081	0.0203	0.141	-0.084	0.0090	0.0946	-0.019
Bosque encino	0.213	0.409	0.267	0.443	-0.091	0.225	0.418	-0.021
Bosque mesófilo	0.0900	0.286	0.0422	0.201	0.137	0.0314	0.1745	0.175
Selva alta	0.143	0.350	0.150	0.357	-0.014	0.154	0.361	-0.023
Selva baja	0.144	0.351	0.180	0.384	-0.070	0.311	0.463	-0.289
Bosque coniferas	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	17881		18456			44104		

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 > 5000 (km)	32.99	21.97	32.97	21.92	0.001
Muni poverty index	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
Manglar	0.0064	0.080	0.0061	0.078	0.003
Bosque encino	0.213	0.409	0.261	0.439	-0.080
Bosque mesófilo	0.0834	0.277	0.0696	0.255	0.037
Selva alta	0.141	0.348	0.1090	0.312	0.069
Selva baja	0.146	0.353	0.1259	0.332	0.041
Bosque coniferas	0.411	0.492	0.4285	0.495	-0.026
Risk of defor	2.47	1.33	2.41	1.28	0.033
N	17137		5228		

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 5000, forest type, overlapping with an overexploited aquifer, the degree of water availability, being inside one of the priority mountains, and being in a municipio with majority indigenous population. Normalized difference is the difference in average covariate values, normalized by the standard deviation (Imbens and Wooldridge 2007). 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 16883,16691 and 37394 unmatched observations and 16142 and 4732 matched observations.

Table 3. Impacts of PSAH 2004-2009 on forest cover: property fixed effects

	Dependent variable: mean NDVI					
	(1)	(2)	(3)	(4)	(5)	(6)
Beneficiary	0.0041***	0.0038***	0.0069***	0.0078***	0.0047***	-0.0014
	(0.0008)	(0.0010)	(0.0012)	(0.0021)	(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 log(slope)				-.0017***		
				(0.0008)		
Benef x municipal poverty index					-0.0030*** (0.0005)	
Benef x common property						0.0063*** (0.0018)
N properties	3644	3644	3644	3644	3644	3644
N total	201285	201285	201285	201285	201285	201285
Rsq	.253	.253	.253	.261	.254	.253

* 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 to Table 1.

Table 4. Impacts of PSAH 2004-2009 on forest cover: robustness checks

	Dependent variable: mean NDVI				
	(1) no lag	(2) approved w/o funds	(3) inside eligible zones	(4) rejected once	(5) unmatched data
Beneficiary (no lag)	0.0028*** (0.0007)				
Beneficiary		0.0027*** (0.0008)	0.0043*** (0.0008)	0.0042*** (0.0008)	0.0033*** (0.0009)
N properties	3644	3061	3519	3344	4553
N total	201285	175932	193410	187110	327033
R2 overall	0.253	0.257	0.255	.257	.253

* 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 dry season mean NDVI (ranges from 0 to 1). Columns 1-4 use data from program beneficiaries and matched rejected applicants, as described in the footnote to Table 1. Column 1 does not lag the beneficiary status. Column 2 uses as controls applicants which met all the criteria for eligibility but were rejected due to lack of funds. Column 3 uses as controls only applicants which were inside the eligible zones. Column 4 uses as controls points which were rejected only once (and did not reapply). Column 5 uses data from all program beneficiaries and rejected applicants (no matching).

Table 5. 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 6: Summary statistics: beneficiary and non-beneficiary households

a. Households living in common property communities

Variables	Beneficiaries		Non-beneficiaries		Norm diff
	mean	sd	Mean	sd	
Inverse proportion wealth index 2007	1.913	1.079	1.906	1.032	0.005
Inverse proportion wealth index 2011	2.355	1.023	2.299	0.975	0.040
Price wealth index 2007	11.786	5.989	11.750	5.518	0.004
Price wealth index 2011	12.815	6.069	12.583	5.705	0.028
PCA wealth index 2011	-0.080	1.883	0.092	1.868	-0.065
PCA wealth index 2007	0.828	1.950	0.924	1.885	-0.035
Log (Elevation)	6.795	1.396	6.581	1.706	0.097
Log (Distance locality>=5000 people)	3.366	0.548	3.276	0.547	0.116
Minutes to nearest town (reported by households)	71.59	70.03	68.90	65.30	0.028
Locality poverty 2005	0.675	0.855	0.512	0.952	0.127
Municipal poverty 2005	0.724	0.881	0.752	1.091	-0.020
Log (Area)	6.436	1.135	6.710	0.991	-0.182
Household size	4.876	2.337	4.578	2.289	0.091

b. Private landowners

Variables	Beneficiaries		Non-beneficiaries		Norm diff
	mean	sd	Mean	sd	
Inverse proportion wealth index 2007	2.348	0.476	2.223	0.562	0.170
Inverse proportion wealth index 2011	2.482	0.372	2.391	0.468	0.152
Price wealth index 2007	21.477	12.852	19.186	6.515	0.159
Price wealth index 2011	22.219	12.633	19.881	6.618	0.164
PCA wealth index 2011	0.251	1.841	-0.284	2.007	0.196
PCA wealth index 2007	0.653	1.645	0.275	1.771	0.156
Log (Elevation)	6.472	1.553	6.602	1.445	-0.061
Log (Distance locality>=5000 people)	3.137	0.634	3.255	0.616	-0.133
Minutes to nearest town (reported by households)	61.39	61.30	58.67	65.06	0.030
Locality poverty 2005	0.463	0.876	0.640	1.109	-0.125
Municipal poverty 2005	0.908	1.008	0.660	1.083	0.168
Log (Area)	4.373	0.838	4.368	1.014	0.004
Household size	4.328	1.947	3.860	2.150	0.161

The price index is measured in 10,000's of pesos. For households living in ejidos, the PCA index ranges from -3.07 to 6.40 and the inverse proportion index ranges from 0 to 4.28. For private households, the PCA index ranges from -5.90 to 3.48 and the inverse proportion index ranges from 0.66 to 2.96.

Table 7. Impacts of PSAH on individual assets: household fixed effects, linear model, binary treatment

	TV	Refrigerator	Computer	Car	Stove	Phone	Cell phone	Wall	Floor	# Rooms
Ejidatarios										
Beneficiary	-0.056	0.004	0.034*	0.051*	-0.019	0.026	0.033	-0.007	0.003	0.076*
	(0.037)	(0.033)	(0.020)	(0.028)	(0.030)	(0.021)	(0.041)	(0.079)	(0.048)	(0.043)
N	1423	1425	1426	1426	1425	1426	1426	1418	1424	1424
Baseline mean	0.499	0.369	0.031	0.254	0.350	0.135	0.191	4.336	1.64	1.963
Non-ejidatarios										
Beneficiary	-0.032	-0.034	0.004	-0.033	0.056	-0.005	0.084	0.070	0.033	-0.029
	(0.049)	(0.048)	(0.023)	(0.033)	(0.037)	(0.029)	(0.056)	(0.092)	(0.068)	(0.070)
N	762	761	762	762	762	762	761	761	760	759
Baseline mean	0.501	0.346	0.045	0.215	0.394	0.097	0.228	4.291	1.642	1.81
Households in common properties (weighted)										
Beneficiary	-0.045	-0.022	0.028	-0.000	0.047	0.002	0.124***	0.104	0.042	0.016
	(0.054)	(0.043)	(0.017)	(0.025)	(0.030)	(0.028)	(0.047)	(0.091)	(0.065)	(0.057)
N	2035	2036	2038	2038	2037	2038	2037	2029	2035	2034
Baseline mean	0.461	0.349	0.053	0.227	0.363	0.122	0.21	4.235	1.648	1.862
Private landowners										
Beneficiary	-0.021	-0.054	-0.027	0.063	-0.021	-0.020	-0.138*	0.033	0.063	-0.114
	(0.044)	(0.037)	(0.065)	(0.052)	(0.038)	(0.051)	(0.079)	(0.080)	(0.046)	(0.090)
N	236	236	236	236	235	236	235	236	236	234
Baseline mean	0.863	0.829	0.308	0.675	0.812	0.547	0.457	5.12	2.197	3.44

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

Coefficients and standard errors in parentheses for household fixed effects model as described in equation (2). Mean at baseline gives the mean proportion of the asset owned among all households in 2007. The first set of estimates is for households in common properties with full voting rights (ejidatarios) and the second set is for other households in common properties (non-ejidatarios). The third set of estimates is for all households in common properties, with weights determined by the proportion of ejidatarios and non-ejidatarios in each community. The final set of estimates is for private households.

Table 8: Impacts of PSAH on asset indices: household fixed effects, linear model, binary treatment

Dependent variable:	Index (PCA)	Index (Inverse proportion)	Index (Prices)
Ejidatarios sample			
Beneficiary	0.072	0.050	0.225
	(0.098)	(0.052)	(0.156)
N	1412	1414	1412
Baseline mean	-0.009	1.885	11.96
Non-ejidatarios sample			
Beneficiary	0.080	0.041	-0.112
	(0.132)	(0.075)	(0.186)
N	753	758	757
Baseline mean	-0.088	1.912	11.184
Weighted sample			
Beneficiary	0.158	0.058	0.092
	(0.122)	(0.072)	(0.153)
N	2017	2022	2020
Baseline mean	-0.121	1.875	11.306
Private landowners			
Beneficiary	-0.168	-0.041	0.241
	(0.145)	(0.045)	(0.265)
N	232	234	232
Baseline mean	0.00	2.289	20.401

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

Coefficients and standard errors in parentheses for household fixed effects model as described in equation (2). Mean at baseline gives the mean of the relevant index among all households in 2007. See Table 7 notes for explanation of groups.

Table 9. Heterogeneous effects across region, distance, and poverty

	Dependent variable: PCA index				**Dependent variable: Price index**			
	Ejidatarios	Non-ejidatarios	Weighted sample	Private landowners	Ejidatarios	Non-ejidatarios	Weighted sample	Private landowners
Interaction with region								
Beneficiary	-0.077	0.209	0.288*	-0.053	0.200	-0.024	0.246	0.638
	(0.124)	(0.199)	(0.167)	(0.227)	(0.269)	(0.217)	(0.202)	(0.416)
Benef x center	0.208	-0.024	-0.105	0.065	0.032	-0.046	-0.117	-0.473
	(0.180)	(0.223)	(0.224)	(0.284)	(0.365)	(0.333)	(0.321)	(0.521)
Benef x southwest	-0.053	-0.449**	-0.321	-0.162	-0.483*	-0.361	-0.432*	-0.412
	(0.122)	(0.217)	(0.213)	(0.280)	(0.272)	(0.258)	(0.221)	(0.513)
Benef x southeast	0.378*	-0.158	-0.055	-0.357	0.488	0.057	0.015	-0.702
	(0.193)	(0.267)	(0.227)	(0.284)	(0.373)	(0.357)	(0.312)	(0.521)
Interaction with distance to locality with >= 5000 people								
Beneficiary	0.006	0.019	0.094	-0.195	0.040	-0.155	-0.012	0.112
	(0.097)	(0.135)	(0.129)	(0.156)	(0.161)	(0.205)	(0.160)	(0.282)
Benef x distance	.297	0.339	0.350*	0.119	0.801***	0.238	0.523**	0.562
	(0.189)	(0.247)	(0.203)	(0.238)	(0.291)	(0.268)	(0.261)	(0.431)
Interaction with municipal poverty 2005								
Beneficiary	0.238	0.129	0.174	-0.040	0.499*	0.038	0.130	0.189
	(0.148)	(0.189)	(0.206)	(0.169)	(0.264)	(0.311)	(0.254)	(0.364)
Benef x muni poverty index	-0.279**	-0.073	-0.023	-0.010	-0.463*	-0.224	-0.056	0.170
	(0.136)	(0.223)	(0.227)	(0.183)	(0.276)	(0.308)	(0.263)	(0.394)
N	1412	753	2017	232	1412	757	2020	232

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

Coefficients and standard errors in parentheses for household fixed effects model as described in equation (2) with interactions. See note to Table 7 for explanation of groups.

Table 10: Within community heterogeneity in impact (households in common properties)

	TV	Refrigerator	Computer	Car	Stove	Phone	Cell phone	Wall	Floor	# Rooms
Interaction with PCA index										
Beneficiary	-0.046	-0.008	0.021	0.020	0.007	0.011	0.061*	0.005	0.009	0.063
	(0.031)	(0.029)	(0.016)	(0.022)	(0.024)	(0.019)	(0.035)	(0.064)	(0.040)	(0.043)
Benef x index	-0.030***	-0.024**	0.019***	-0.013	-0.022***	-0.005	0.012	-0.051*	-0.068***	-0.045*
	(0.009)	(0.010)	(0.007)	(0.009)	(0.008)	(0.008)	(0.011)	(0.030)	(0.013)	(0.024)
Interaction with price index										
Beneficiary	0.042	0.018	-0.034	-0.114**	0.064*	0.007	0.012	0.071	0.109	-1.201***
	(0.044)	(0.048)	(0.024)	(0.044)	(0.038)	(0.037)	(0.050)	(0.139)	(0.066)	(0.116)
Benef x index	-0.007***	-0.002	0.005**	0.011***	-0.005*	0.000	0.004	-0.005	-0.008**	0.107***
	(0.002)	(0.003)	(0.002)	(0.003)	(0.003)	(0.003)	(0.003)	(0.010)	(0.004)	(0.008)
N	2214	2213	2214	2213	2214	2214	2213	2213	2213	2214

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

Coefficients and standard errors in parentheses. Regressions include ejido-level fixed effects and interaction with baseline household wealth index.

APPENDIX: CONSTRUCTION OF WEALTH INDICES

We construct different wealth indices to summarize the socioeconomic status of households based on a set of variables about household ownership of several assets and characteristics of household's dwelling (floors, wall, number of rooms). As Moser and Felton (2007) indicate, there are two advantages of using an asset index in comparison to using traditional consumption expenditure data to measure household's welfare. First, there is less possibility of recall or measurement problems. Second, assets can provide a better picture of long-term living standards. Despite these benefits, the construction of wealth indices involves several challenges. In particular, we need to take decisions about how to aggregate and weight each asset. In general, an index takes following form:

$$A_i = \hat{\gamma}_1 a_{i1} + ... + \hat{\gamma}_2 a_{i2}$$

where A_i is the asset index for household i, a_{ik} are the individual assets k that household i owns and $\hat{\gamma}_k$ are the weights given to asset k, which we must estimate. There are several approaches to constructing these weights and each of them has it own limitations and benefits. In this paper, we adopted three different methods, trying to find an adequate balance between the limitations and how intuitive or easy to understand the measure is. We explain them in detail in this appendix.

A.1 Inverse proportion index

This is probably one of the most simple and intuitive approaches. It is based on a method suggested by Townsend (1979) and constructs the weights as the inverse of the proportion of households that owned each asset. The assumption is that assets owned by a smaller proportion of households indicate higher wealth and, therefore, should havea higher weight. This method can only be applied to binary variables and the index takes the following form:

$$A_i = \frac{1}{\sum_{i=1}^{N} a_{i1} \big/ N} a_{i1} + ... + \frac{1}{\sum_{i=1}^{N} a_{ik} \big/ N} a_{ik}$$

where a_{ik} is a binary variable taking the value of 1 when household i owns asset k, and N is the total number of households in the sample. We can see that the weight for asset k in this case is given by $\hat{\gamma}_k = N \big/ \sum_{i=1}^{N} a_{ik}$. One limitation with this method is that not all assets show a linear relationship with living standards, for example, ownership of a motorbike may tend to increase up to a certain income and subsequently decrease in richer households (Howe et al. 2008). Also, for categorical data, such as walls' material, we are using binary variables representing the best categories; therefore, any order implicit in these categorical variables is lost.

A.2 Price index

This method uses prices to weight assets, this means $\hat{\gamma}_k = p_k$. The index then represents the total monetary value of the household's asset wealth and it is expressed as follows[28]:

$$A_i = p_1 a_{i1} + ... + p_k a_{ik}$$

Although this approach is very intuitive it has also limitations. First, price data can be difficult to obtain, even more, local price information. Ideally, an accurate monetary valuation of households' assets will require detailed information about the date of purchase, the market or area where the asset was purchased, and the current condition of the asset (Howe et al. 2008). Second, it is difficult to impute prices for non-market commodities. As Ravallion (2011) suggests, missing prices need to be assigned on a priori grounds or estimations.[29]

A.3 Principal Components Analysis (PCA) Index

Principal Components Analysis (PCA) was recommended as a method for determining weights for variables in a wealth index by Filmer and Pritchett (2001). PCA is a data reduction procedure, which involves extracting from a large number of variables those few orthogonal linear combinations ("principal components") of the variables that best capture the common information. The first principal component explains the largest proportion of the total variance. Weights are derived from the correlation matrix of the data and assets that are more unequally distributed across the sample will have a higher weight in the first principal component. The index is constructed in the following way:

$$Index_j = f_1 \frac{(a_{j1} - a_1)}{s_1} + ... + f_N \frac{(a_{jN} - a_N)}{s_N}$$

where, f_1 is the scoring factor for the first asset which is determined by the PCA procedure, a_{j1} is the j th household's value for the first asset and a_1 and s_1 are the mean and standard deviation of the first asset over all households in the sample. The main assumption in this method is that household long-run wealth is what causes the most common variation in asset variables.

PCA is designed for use with continuous and normally-distributed data; therefore, its application to discrete data, as proposed by Filmer and Pritchett, can be problematic. For example, for household dwelling characteristics, such as the type of floors, which can be recorded in a scale with n categories, Filmer and Pritchett propose splitting them into n binary variables. This procedure introduces distortion in the correlation matrix as variables are perfectly

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[28] The following values were used for each good (Mexican pesos): tv 4805 , refrigerator 3969, computer 7660, car 46462, stove 3269, phone 384, cell phone 3605, room 36000, dirt floor 6000, cement floor 12000, wood/tile floor 24000, bamboo or other walls 6000, adobe or wood walls 12000, concrete or brick walls 24000. Consumer goods were priced based on reports from Mexico's "Procuraduría Federal del Consumador" (PROFECO).

[29] Consumer goods prices were assigned by a research assistant who did not have knowledge of the survey results.

negatively correlated with each other. Moreover, if there is any particular order this is lost since PCA treats every binary variable in the same way (Moser and Felton, 2007). More recently, some authors have suggested the use of polychoric PCA (Kolenikov and Angeles, 2009), which improves on PCA and it is also designed for categorical data. The weights in this case come from polychoric or polyserial correlations which are maximum likelihood estimates of the correlation between unobserved normally distributed continuous variables underlying their discretized versions.

Kolenikov and Angeles (2004) argue that the gain from using polychoric correlations, which are computationally more intensive than PCA applied on ordinal data, is only related to more accurate estimation of the proportion of explained variance that PCA tends to underestimate. In spite of this, the misclassification rates, as well as rank correlations of indices constructed with these two methods seem to be not substantially different. For this reason, we construct the third index in this paper using PCA on ordered data. It is important to mention some limitations related to this method. First, it requires assumptions about how to rank different categories of the data. Second, it assumes that categories are equally spaced from each other in terms of their relationship with a household's socioeconomic status. Finally, PCA is a fairly complex method and it is likely to be difficult to understand by less technical readers. This is the reason why we also construct the price and inverse proportion index, which seem to be more intuitive.

REFERENCES

Alix-Garcia, J., A. de Janvry and E. Sadoulet (2005) “A Tale of Two Communities: Explaining Deforestation in Mexico” *World Development* 33 (2): 219-235.

Alix-Garcia, J. (2007). "A spatial analysis of common property deforestation." *Journal of Environmental Economics and Management* 53(2): 141-157.

Alix-Garcia, J. (2008a). "An exploration of the positive effect of inequality on common property forests." *Journal of Development Economics* 87(1): 92-105.

Alix-Garcia, J., A. De Janvry and E. Sadoulet (2008b). "The role of deforestation risk and calibrated compensation in designing payments for environmental services." *Environment and Development Economics* 13(3): 375-394.

Alix-Garcia, J., E. N. Shapiro and K. R. E. Sims (2012). "Forest Conservation and Slippage: Evidence from Mexico's National Payments for Ecosystem Services Program." *Land Economics*, forthcoming.

Angelsen, A. (2008). *Moving Ahead with REDD: Issues, Options, and Implications*. Bogor, Indonesia, CIFOR.

Angelsen, A. (2010). "Policies for reduced deforestation and their impact on agricultural production." *Proceedings of the National Academy of Sciences* 107(46): 19639-19644.

Arriagada, R., P. J. Ferraro, S. Pattanayak, E. O. Sills and S. Cordero (2011). "Do payments for environmental services reduce deforestation? A farm-level evaluation from Costa Rica." Working Paper, Georgia State University.

Arriagada, R. and C. Perrings (2011). "Paying for International Environmental Public Goods." *AMBIO: A Journal of the Human Environment* 40(7): 798-806.

Arriagada, R. A. (2008). "Private provision of public goods: applying matching methods to evaluate payments for ecosystem services in Costa Rica." Doctoral Thesis, Latin American and Caribbean Environmental Economics Program, North Carolina State University.

Assies, W. (2008). “Land Tenure and Tenure Regimes in Mexico: An Overview.” Journal of Agrarian Change 8 (1): 33-63.

Bray, D. B. and P. Klepeis (2005). "Deforestation, Forest Transitions, and Institutions for Sustainability in Southeastern Mexico, 1900-2000." Environment and History 11(2): 195-223.

Bruijnzeel, L. A. (2004). "Hydrological functions of tropical forests: not seeing the soil for the trees?" Agriculture, Ecosystems & Environment 104(1): 185-228.

Bulte, E. H., L. Lipper, R. Stringer and D. Zilberman (2008). "Payments for ecosystem services and poverty reduction: concepts, issues, and empirical perspectives." *Environment and Development Economics* 13(03): 245-254.

Burgess, R., B. Olken, M. Hansen, P. Potapov and S. Sieber (2011). "The Political Economy of Deforestation in the Tropics." Working paper, MIT, LSE, World Bank and SDSU.

Chomitz, K. M. and D. A. Gray (1996). "Roads, Land Use, and Deforestation: A Spatial Model Applied to Belize." *World Bank Economic Review* 10(3): 487-512.

CONAFOR (2011). "Sistema Nacional de Información Forestal - Monitoreo Forestal de México: Aspectos Metodologicos ", Online documentation, accessed March 18. (http://148.223.105.188:2222/gif/snif_portal/index.php?option=com_content&task=view&id=2&Itemid=3#5).

CONAFOR (2012). "National Forestry Commission and the Payments for Ecosystem Services in Mexico." Presentation at University of Wisconsin-Madison, January 2012.

Corbera, E., M. Estrada, P. May, G. Navarro and P. Pacheco (2011). "Rights to Land, Forests and Carbon in REDD+: Insights from Mexico, Brazil and Costa Rica." *Forests* 2(1): 301-342.

Deininger, K. W. and B. Minten (1999). "Poverty, Policies and Deforestation: The Case of Mexico." *Economic Development and Cultural Change* 47(2): 313-344.

Deininger, K. W. and B. Minten (2002). "Determinants of Deforestation and the Economics of Protection: An Application to Mexico." *American Journal of Agricultural Economics* 84(4): 943-960.

Díaz-Gallegos, J. R., J.-F. Mas and A. Velázquez (2009). "Trends of tropical deforestation in Southeast Mexico." *Singapore Journal of Tropical Geography* 31(2): 180-196.

Ferraro, P. J., M. M. Hanauer and K. R. E. Sims (2011). "Conditions associated with protected area success in conservation and poverty reduction." *Proceedings of the National Academy of Sciences* 108(34): 13913-13918.

Ferris, J. and J. V. Siikamaki (2009). "Conservation Reserve Program and Wetland Reserve Program: Primary Land Retirement Programs for Promoting Farmland Conservation." RFF Backgrounder, Resources for the Future.

Filmer, D. and L. Pritchett (2001). "Estimating Wealth Effects Without Expenditure Data—Or Tears: An Application To Educational Enrollments In States Of India." *Demography* 38(1): 115-132.

Foster, A. D. and M. R. Rosenzweig (2003). "Economic Growth and the Rise of Forests." *The Quarterly Journal of Economics* 118(2): 601-637.

Gauvin, C., E. Uchida, S. Rozelle, J. Xu and J. Zhan (2010). "Cost-Effectiveness of Payments for Ecosystem Services with Dual Goals of Environment and Poverty Alleviation." *Environmental Management* 45(3): 488-501.

Hawkins, S. (2011). "An Analytical Tool for Assessing Legal and Institutional Readiness for PES." Washington, D.C., Forest Trends Report.

Honey-Roses, J., K. Baylis and M. I. Ramirez (2011). "A Spatially Explicit Estimate of Avoided Forest Loss." *Conservation Biology* 25(5): 1032-1043.

Howe, L., J. Hargreaves and S. Huttly (2008). "Issues in the construction of wealth indices for the measurement of socioeconomic position in low income countries." *Emerging Themes in Epidemiology* 5(3).

Imbens, G. and J. Wooldridge (2009). "Recent Developments in the Econometrics of Program

Evaluation."*Journal of Economic Literature* 47 (1): 5-86.

IUCN International Union for Conservation of Nature (2009). "Reducing emissions from deforestation and forest degradation (REDD) in developing countries." *UNFCCC Climate Change Talks*. Bonn.

Jack, B. K., C. Kousky and K. R. E. Sims (2008). "Designing payments for ecosystem services: Lessons from previous experience with incentive-based mechanisms." *Proceedings of the National Academy of Sciences* 105(28): 9465-9470.

Jindal, R., B. Swallow and J. Kerr (2008). "Forestry-based carbon sequestration projects in Africa: Potential benefits and challenges." *Natural Resources Forum* 32(2): 116-130.

Kolenikov, S. and G. Angeles (2009). "Socioeconomic Status Measurement with Discrete Proxy Variables: Is Principal Component Analysis a Reliable Answer?" *Review of Income and Wealth* 55(1): 128-165.

Lipper, L. (2009). "Payment for environmental services in agricultural landscapes: Economic policies and poverty reduction in developing countries." Rome: Food and Agriculture Organization of the United Nations FAO.

Mansfield, C., S. K. Pattanayak, W. McDow, R. McDonald and P. Halpin (2005). "Shades of Green: Measuring the value of urban forests in the housing market." *Journal of Forest Economics* 11(3): 177-199.

Martínez, M. L., O. Pérez-Maqueo, G. Vázquez, G. Castillo-Campos, J. García-Franco, K. Mehltreter, M. Equihua and R. Landgrave (2009). "Effects of land use change on biodiversity and ecosystem services in tropical montane cloud forests of Mexico." *Forest Ecology and Management* 258(9): 1856-1863.

Meneses Tovar, C. L. (2009a). "Analysis of the normalized differential vegetation index (NDVI) for the detection of degradation of forest coverage in Mexico 2008-2009." Working Paper 173, Food and Agriculture Organization Forest Resources Assessment

Meneses Tovar, C. L. (2009b). "Analysis of the normalized differential vegetation index (NDVI) for the detection of degradation of forest coverage in Mexico 2008-2009." Presentation for the Technical Meeting of Forest Degradation. Rome. Sept. 8-10. , Food and Agriculture Organization Forest Resources Assessment

Moser, C. and A. Felton (2007). "The Construction of an Asset Index Measuring Asset Accumulation in Ecuador." CPRC Working Paper 87, The Brookings Institution.

Muñoz-Piña, C., A. Guevara, J. Torres and J. Braña (2008). "Paying for the hydrological services of Mexico's forests: Analysis, negotiations and results." *Ecological Economics* 65(4): 725-736.

NASA (2012). "Measuring Vegetation: Normalized Difference Vegetation Index (NDVI)." Online article, accessed Feb 20, 2012, http://earthobservatory.nasa.gov/Features/MeasuringVegetation/measuring_vegetation_2.php.

Naughton-Treves, L., J. Alix-Garcia and C. A. Chapman (2011). "Lessons about parks and poverty from a decade of forest loss and economic growth around Kibale National Park, Uganda." *Proceedings of the National Academy of Sciences* 108(34): 13919-13924.

Pagiola, S., A. Arcenas and G. Platais (2005). "Can payments for environmental services help reduce poverty? An exploration of the issues and the evidence to date from Latin America." *World Development* 33(2): 237-253.

Pagiola, S. and W. Zhang (2010). "Using PES to implement REDD." *4th World Congress of Environmental Economists*. Montreal, Canada.

Pattanayak, S. K., S. Wunder and P. J. Ferraro (2010). "Show Me the Money: Do Payments Supply Environmental Services in Developing Countries?" *Review of Environmental Economics and Policy* 4(2): 254-274.

Pfaff, A., S. Kerr, L. Lipper, R. Cavatassi, B. Davis,J. Hendy, and G. A. Sanchez-Azofeifa (2007). "Will buying tropical forest carbon benefit the poor? Evidence from Costa Rica." *Land Use Policy*24(3): 600-610.

Pfaff, A. and J. Robalino (2012). "Protecting Forests, Biodiversity and the Climate: Explaining Observed Spatial Variation in Policy Impacts." Duke University, working paper.

Pfaff, A., J. Robalino and G. A. Sanchez-Azofeifa (2011). "Changing the deforestation impacts of Ecopayments: Evolutions (2000-2005) in Costa Rica's PSA." Duke University, working paper.

Pfaff, A., J. Robalino, G. A. Sanchez-Azofeifa, K. S. Andam and P. Ferraro (2009). "Park Location Affects Forest Protection: Land Characteristics Cause Differences in Park Impacts across Costa Rica." *B.E. Journal of Economic Analysis and Policy* 9(2).

Pfaff, A. S. P. (1999). "What Drives Deforestation in the Brazilian Amazon? Evidence from Satellite and Socioeconomic Data." *Journal of Environmental Economics and Management* 37: 26-43.

Ravallion, M. (2011). "On multidimensional indices of poverty " Policy Research Working Paper 5580, The World Bank.

Robalino, J. and A. Pfaff (2011). "Eco-payments and Forest Loss in Costa Rica: all dressed up but nowhere to avoid deforestation." CATIE and Duke University, Manuscript.

Robalino, J. A. (2007). "Land Conservation Policies and Income Distribution: Who Bears the Burden of our Environmental Efforts?" *Environment and Development Economics* 12(4): 521-533.

Samuelson, P. A. (1983). "Thünen at Two Hundred." *Journal of Economic Literature* 21(4): 1468-1488.

Sánchez-Azofeifa, G. A., A. Pfaff, J.A. Robalino, and H. Boomhower (2007). "Costa Rica's Payment for Environmental Services Program: Intention, Implementation, and Impact." *Conservation Biology*21(5): 1165-1173.

Shapiro, E. (2010). Political Economy and Community-Level Impacts of the Mexican Federal Payment for Ecosystem Services Programs. Environmental Science, Policy & Management, University of California, Berkeley. Doctoral Thesis.

Shapiro, E. N. and S. Castillo (2012). "Evolution of Mexico's Payments for Ecosystem Services Program." Working paper, Duke University.

Sims, K.R.E. (2010). "Conservation and development: Evidence from Thai protected areas."

Journal of Environmental Economics and Management 60: 94-114.

Townsend, P. (1979). *Poverty in the United Kingdom: Survey of household resources and standards of living* England, Penguin Books Ltd.

Uchida, E., S. Rozelle and J. Xu (2009). "Conservation Payments, Liquidity Constraints, and Off-Farm Labor: Impact of the Grain-for-Green Program on Rural Households in China." *American Journal of Agricultural Economics* 91(1): 70-86.

Uchida, E., J. Xu, Z. Xu and S. Rozelle (2007). "Are the poor benefiting from China's land conservation program?" *Environment and Development Economics* 12(04): 593-620.

UNFCC United Nations Framework Convention on Climate Change (2009). "Copenhagen Accord." *Conference of the Parties Fifteenth Session*. Copenhagen.

United Nations REDD Programme (UN-REDD) (2011). "About REDD+." Accessed January 13, 2012. (http://www.un-redd.org/AboutREDD/tabid/582/Default.aspx).

Wunder, S. (2008). "Payments for environmental services and the poor: concepts and preliminary evidence." *Environment and Development Economics* 13(03): 279-297.

Wunder, S., S. Engel and S. Pagiola (2008). "Taking stock: A comparative analysis of payments for environmental services programs in developed and developing countries." *Ecological Economics* 65(4): 834-852.

Wunder, S. and S. Wertz-Kanounnikoff (2009). "Payments for Ecosystem Services: A New Way of Conserving Biodiversity in Forests." *Journal of Sustainable Forestry* 28(3-5): 576-596.

Wünscher, T., S. Engel and S. Wunder (2008). "Spatial targeting of payments for environmental services: A tool for boosting conservation benefits." *Ecological Economics* 65(4): 822-833.

Xu, Z., J. Xu, X. Deng, J. Huang, E. Uchida and S. Rozelle (2006). "Grain for green versus grain: conflict between food security and conservation set-aside in China." *World Development* 34(1): 130-148.

Zilberman, D., L. Lipper and N. McCarthy (2008). "When could payments for environmental services benefit the poor?" *Environment and Development Economics* 13(03): 255-278.