PAYMENTS FOR ENVIRONMENTAL SERVICES AND THEIR IMPACT ON FOREST TRANSITION IN COSTA RICA

by

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Introduction

While tropical deforestation continues to receive immense attention as a case where the dictates of economic development and ecosystem conservation regularly clash, some researchers have noted a new dynamic in some tropical forest regions. According to Rudel *et al.* (2005), a 'forest transition' occurs when decline in forest cover ceases and recoveries in forest cover begin. These authors say that forest transitions have occurred in two, sometimes overlapping, circumstances. In some places, economic development has created enough non-farm jobs to pull farmers off of the land. In other places, a scarcity of forest products has prompted governments and landowners to reforest. Chazdon (2008) points out that despite continued forest conversion and degradation, forest cover is increasing in countries across the globe; new forests are regenerating on former agricultural land; and forest plantations are being established for commercial and restoration purposes.

Given the potential of forest transitions for slowing soil erosion, improving soil quality, and slowing climate change through carbon sequestration, can governments speed the transitions up, or, once they have begun, ensure that the transitions continue? Payments for ecosystem services (PES) represent a new, more direct way to promote conservation that can impact both existing and new forest. Theoretical assessments praise the advantages of PES over indirect approaches, but in the tropics PES has remained incipient (Wunder 2007). In the tropics, the most prominent PES system has been developed over a decade in Costa Rica (Robertson and Wunder 2005). In the Costa Rican system of PES, landowners enrolled in the scheme agree to conserve their forests, or establish reforestation, afforestation, or agroforestry areas. In return, they receive a per-hectare annual payment from a state-run national forest fund.

Previous attempts to estimate the causal impact of the Costa Rican system of PES (Sánchez-Azofeifa *et al.* 2007; Pfaff *et al.* 2008) have been based on the combination of remote sensing data with secondary data primarily on bio-physical characteristics such as road density and soil quality. Previous literature has also focused on the role of PES in reducing deforestation, or loss of existing forest cover. However, it is clearly also relevant to ask what impact PES

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has on the forest transition in Costa Rica, and given that this dynamic has been closely tied with socio-economic development, it is critical to incorporate socio-economic characteristics into the analysis. This paper contributes to understanding the causal impact of PES by analyzing the effect of the Costa Rican system of PES on several dimensions of forest cover (forest gain, forest loss and net deforestation), using census data at the tract level combined with remote sensing data on land use and biophysical land characteristics for the entire country. To isolate the causal impact of PES, matching estimators are applied to identify appropriate controls for census tracts that had land placed under PES contracts during the first eight years of the program. Tracts in the program are defined by a binary measure of whether any PES contracts were located in a given tract. The control tracts selected through various matching procedures are used to estimate the counterfactual (e.g. forest gain would have occurred had no land in the census tract been enrolled in the program). We found that the program has no statistically significant effect on existing forest (i.e. no effect on forest loss), but it does have a statistically significant and positive effect on the establishment of new forest (i.e. positive effect on forest gain and net deforestation). This suggests that in Costa Rica, PES is making a significant contribution to the forest transition.

Inputs, outputs and outcomes of PSA

Within the context of PSA, it can be defined *inputs* (e.g. number of hectares enrolled in PSA forest conservation), *outputs* (e.g. number of hectares conserved after participation in PSA) and *outcomes* (ecosystem services). The implementation of PSA is driven by the assumption that direct conservation payments will generate a net increase in protected ecosystems (i.e. an increase in the provision of the PSA outcome, ecosystem services). However, for the purpose of this paper, we will stick with FONAFIFO's definition of area of forest as relevant outcome to evaluate, even though we recognize that this is really just an output that generates the desired final outcome of ecosystem services. Thus, the hypothesis of this research is that "*PSA forest conservation payments generate a net increase in the area of forest*".

For the purposes of this study, three outcome variables will be analyzed:

1) *Forest gain*: sum of hectares that were not forest but regenerated later into natural forest
2) *Forest loss*: sum of all area transitions from natural forest classes (continuous and fragmented) to all other land use classes
3) *Net deforestation*: forest gain minus forest loss

Research methodology

In the context of a conservation initiative that pays landowners to conserve their forest resources (e.g. PSA), we can observe how the conservation outcome (e.g. forest cover) varies between regions with landowners who are receiving payments as compared to regions where no landowners are enrolled in the program. In the prototypical model of the evaluation literature, we can say that either the region is treated or not. There is a hypothetical (potential) forest cover outcome for both states of the world (i.e. treated vs. non-treated). The "causal effect" is defined then as the difference between these two *potential outcomes*. To truly know the effect of PSA, we should compare the forest cover of PSA regions with the forest cover that would have resulted had that region not participated in the program. The impossibility of observing this so-called *counterfactual outcome* creates the evaluation problem.

The goal of program evaluation is to solve the problem of missing data on the counterfactual. In statistical jargon, avoided deforestation from PSA is the Average Treatment Effect on the Treated (ATT). However, PSA is a voluntary program and is likely that participants differ from non-participants. In the context of PSA, we can say that decisions to participate are determined by observable characteristics. Thus, protected and unprotected lands, on average, differ in characteristics that may also affect forest cover after participation.

The causal effect of PSA on forest cover changes was estimated using PSA forest conservation contracts signed between 1998 and 2004 in the whole country. PSA and Non-PSA census tracts were defined and compared after controlling for pre-PSA (i.e. predetermined) observable socio-economic and biophysical characteristics which determined selection into the program and targeting, and are likely to have affected outcomes (i.e. changes in forest cover). We generate estimates of program impact with a binary definition of treatment (i.e. PSA tracts vs. non-PSA tracts) and using propensity score matching and mixed methods to improve covariate balance and relax functional form assumptions.

In the context of PSA, the propensity score is the probability of being a PSA census tract, conditional on a number of control variables: $\Pr(D=1|X)$. In that sense, the propensity score is a function of the control variables. Let's imagine a formula where you plug in the values of the covariates (e.g. tract size, tract population, tract soil quality, etc.) to obtain the probability that the tract will be a PSA tract (i.e. a census tract that contains at least one PSA forest conservation contract). Because participation in PSA requires allocation of land to forest, the biophysical and socio economic tract characteristics that determine participation in PSA are also likely to determine land use, including changes in forest cover, which is the program outcome being analyzed in this study. Therefore, in the estimation of propensity scores, it is most important to include variables that influence simultaneously the participation decision and the outcome variable.

Unit of observation

In order to apply any of the evaluation methods proposed in this paper, it is critical to gather information on both program participants and a large pool of landowners who were eligible to participate but did not sign up for the program. Availability of national census data combined with biophysical data organized at the census tract-level makes logical the selection of census tract as the unit of observation, especially when one is interested in estimating the causal impacts of PSA at the country level. Another important advantage of using census tracts for the analysis of PSA stems from an important characteristic that program evaluation techniques share: they ignore the impact a program may have on outcomes and behavior of non-participants. These effects, known as general equilibrium effects, may arise where participants benefit also affect non-participants (Bryson *et al*. 2002). The use of a higher scale of analysis would allow embedding these effects. [1]

During the year 2000, the National Institute of Statistics and Census (*Instituto Nacional de Estadística y Censos,* INEC) implemented the IX National Population Census and V National Housing Census. According to these censuses, Costa Rica is divided into 17,269 census tracts located in urban and rural areas.[2] In this study, we only include census tracts located in rural areas (i.e. concentrated and disperse). We did not include census tracts located in urban areas because the probability of finding PSA protection contracts is very low.

Treatment

Given that this paper is using census tracts as the unit of observation and a binary definition of treatment, it is necessary to define the variable that will allow to construct treatment (i.e. PSA census tracts) and control groups (i.e. non-PSA census tracts). There are 4,574 PSA contracts signed between 1998 and 2004. 72% (3,304 contracts) corresponds to forest protection. There are 1,065 census tracts that contain at least one PSA forest conservation contract signed between 1998 and 2004. Based on census tract size and number of hectares protected by the program per tract, we estimated what is the percent of the total segment area that is protected by PSA. In this case the % will be estimated as follows:

$$\%\ tract\ area\ under\ PSA = \frac{\text{Per tract hectares protected by PSA conservation}}{\text{Tract area (ha)}} \quad (1)$$

Confounders

A key problem that often plagues observational studies is the lack of randomization in assigning individuals (in this case census tracts) to either treatment or control groups. Because of this, the estimation of the effects of treatment may be biased by the existence of confounding factors (Baser 2006). Then, selection of covariates is an important step before matching. In the context of PSA, it is important to control for observable covariates that affect program participation, but can also affect program outcome (e.g. deforestation). For the purpose of controlling confounders that can be related with PSA outcome, we base on the existing literature on tropical deforestation and previous studies of deforestation in Costa

[1] Sánchez-Azofeifa *et al.* (2007) used 5x5 km grid cells in their evaluation of PSA, Pfaff *et al.* (2008) used pixel-level units randomly selected throughout Costa Rica, and Sills *et al*. (forthcoming) used district-level data.
[2] For organization purposes, INEC divides Costa Rica in four different areas: urban, periphery urban, concentrated rural, and disperse rural following a method developed by the Ministry of Planning.

Rica. These previous studies present immediate and underlying causes of deforestation that systematically have been included in the literature on tropical deforestation. The variables to be included in this study are as follows:

- Immediate causes of deforestation
- Determinants of program participation
- Underlying causes of deforestation
- PSA targeting

Results

Table 3 shows the marginal effects on the propensity of a rural census tract to have at least one PSA forest conservation contract signed between 1998 and 2004. These results represent what we called the propensity score in previous sections estimated using the participation probability model shown in (1). The logit I specification (column 2) includes only the immediate determinants of tropical deforestation as described in footnote 10 and logit II includes also underlying determinants of deforestation and explanatory variables associated with PSA targeting (i.e. per-tract hectares of non-eligible area for PSA, distance to IDA settlements, proportion of tract in aquifers, proportion of tracts located in Ecomarket or GRUAS zones). Logit II specification also includes the groups of conservation areas as explained in previous sections.

According with logit I, having a higher percent of tract area with soil class I or II, higher percent of tract area with slope 0-30%, more off-farm employment, more number of roads per tract, more hectares of non-eligible land for PSA, and been further from ports significantly reduce the propensity of a census tract to have at least one PSA contract. Having a higher % of tract area with soil class VII or VIII, higher percent of tract area with slope greater than 45%, more precipitation, higher proportion of tracts in very humid (tropical), dry (tropical) and rainy life zones compared with humid ones, more hectares per tract, more forest stock in 1992 and older people significantly increase the propensity. The logit II specification adds to the group of significant positive determinants of propensity of a census tract to have at least one PSA contract the tract-level proportion of immigrants and of household that use fuel-wood for cooking, distance to IDA settlements, and proportion of tracts located in Ecomarket zones. The logit II specification also adds significant negative determinants of propensity of a census tract to have PSA contracts including population density, and proportion of tracts in aquifers. Compared with *Tempisque- Arenal Tilarán-Guanacaste* (Group II), being in Groups III, IV, V or VI significantly reduces the propensity of a census tract to have PSA contracts. All these results are consistent with literature on tropical deforestation and previous studies of program participation.

Table 4 shows the estimates of program impact using propensity score matching (i.e. nearest neighbor, radius, kernel and blocking). All propensity score methods using logit I(II) suggest a positive and significant impact between 17.3(17.7) ha and 31.5(32.1) ha on the sum of hectares that were not forest in 1997 but recovered to forest during 2005. Logit I(II) propensity score methods also show negative and significant impact between -21.7(-21.2) ha and -38.2(-34.1) ha on net deforestation between 1997 and 2005.[3] For the case of forest loss, only blocking on the propensity score based on logit II found a significant impact at the 10% confidence level of PSA equal to 10.9 ha.

According with Table 4, the magnitude of the impact varies according with the matching estimator being used, but the impact goes from 17.7 ha to 32.1 ha more of forest gain on average in the PSA census tracts vs. tracts with no PSA. These numbers represent between 0.92% and 1.67% of the average size of PSA tracts, 6.06% and 10.98% of the average land enrolled in PSA and 2.24% and 4.07% of the average forest cover in 1997 in PSA tracts.

Table 4 also shows the estimates of PSA impact using mixed methods. These estimates correspond to the average treatment effect (ATE) and not to the effect of PSA on census tracts that in fact have at least one PSA contract (ATT). However, using logit I and II, estimates of ATE also suggest a positive and significant impact of PSA on sum of hectares that were not forest in 1997 but recovered to forest during 2005, and a negative and significant impact of PSA on net deforestation between 1997 and 2005. Regarding forest loss, between 1997 and 2005, logit I did not find statistically significant estimates of program impact, however logit II found statistically significant impacts (10% confidence level) but that differ in sign depending on the method (positive and significant impact using weighting and regression, and negative and significant impact using matching and regression).

Unconfoundedness refers to the case where (non-parametrically) adjusting for differences in a fixed set of covariates removes biases in comparisons between treated and control units, thus allowing for a causal interpretation of those adjusted differences. Logit I specification of propensity score implies less bias in the estimation of casual effect because we match only on the immediate determinants of deforestation, but sacrifice plausibility of unconfoundedness in the treatment assignment because we are not including underlying determinants of deforestation and covariates that explain PSA participation, targeting and regional variation of PSA implementation. Logit II specification of propensity score makes the Conditional Independence Assumption (CIA) more plausible, but increase bias given the potential remaining covariate imbalance left after the matching because logit II tries the balance all the covariates judged to be important in predicting deforestation, PSA participation, targeting and regional variation of program implementation. Table 5 shows the balance after matching using NN, RM and KM. NN using logit II is the method that achieves the best balance,

[3] An impact of PSA on net deforestation equals to -21.695 ha means that on average PSA census tracts have 21.695 ha more of forest compared with non-PSA census tracts.

however even in this case 9 covariates remained unbalance after matching. However, in terms of percent of reduction in bias after matching Table 5 also shows the % of bias reduction. In general, across the methods the percent is high indicating that although some variables remain unbalanced after matching the percent of bias reduction is significant. In fact, using logit II and NN the mean of the distribution of the absolute bias was 42.300 and the mean after matching was 5.874 which indicate a significant gain in reducing bias due to differences in observable characteristics used during the matching.

Conclusions

Currently, the core element of Costa Rican forest policy is PSA, which is the first long-term, nation-wide PES program in the tropics. Since the inception of PSA in 1997, almost 600,000 ha (12% of the national territory) have been enrolled in the program. Almost 532,000 ha (89% of the total land enrolled in PSA) corresponds to forest conservation contracts where landowners, after making a voluntary decision to participate, receive a direct payment for the protection of their forest.

In this study, we applied matching methods using a binary definition of treatment (e.g. rural census tracts that contain at least one PSA contract) to evaluate the impact of PSA forest protection contracts signed between 1998 and 2004 on program outcomes. Three program outcomes (i.e. forest gain, forest loss and net deforestation) are considered. These outcomes are all important dimensions of forest cover in Costa Rica, although they have different implications for the bundle of ecosystem services produced and consequently are viewed differently by various stakeholder groups (e.g. stopping loss of existing mature natural forests is the priority of many environmental groups, while others interested in climate change and carbon sequestration are most likely to focus on net change in total forest cover). By obtaining and linking census data at the tract level to remote sensing data on land cover, we obtained a large enough sample size (approx. 8,000) to employ a binary treatment method. Socioeconomic characteristics at the tract level also provide a more accurate representation of conditions driving decisions about program participation and land use, as compared to previous work that relied on district-level data (which provided only 500 observations for all of Costa Rica). Given that we do not observe all the factors that drive local deforestation rates, the expanded data also permit the inclusion of other fixed effects (e.g. conservation area groups fixed effects) which is a major gain in controlling for the effects of potential unobserved drivers.

We found that PSA has had different impacts on each dimension of forest cover change. The most robust result is a positive and statistically significant impact on forest gain in the census tracts that contain at least one PSA forest conservation contract signed between 1998 and 2004. This positive and significant effect is robust to all propensity score and mixed methods using the full specification of the probability of having PSA in a tract.

All these results indicate that PSA is having an important impact on the forest transition underway in Costa Rica. It is also important to highlight that this paper presents an analysis of the causal effect of PSA contracts signed for natural forest conservation, and the results indicate significant and positive results in the establishment of new forests. In light of these results, PSA should be evaluated beyond its impact on tropical deforestation per se. There is evidence from many tropical countries that new forests are being established on former agricultural land, even as deforestation of existing mature forest proceeds. However, there is almost no empirical analysis of the impact of PES and in particular of PSA on the forest transition underway in Costa Rica. In that sense, this paper constitutes an important contribution to the literature on the evaluation of causal effect of PES using state-of-the art matching methods, and in particular to the impact that PSA has on the ongoing forest transition in Costa Rica.

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Table 1: Descriptive statistics of census tracts included in the PSA analysis

Statistic	***Total segments***	***PSA Segments***[a]	***Non-PSA segments***
Total number	8,203	1,065	7,138
Mean size (ha)	571	1,928	369
Standard deviation (ha)	1,118	1,920	757
Coefficient of variation	196%	100.4%	48.7%
Min (ha)	0.5	7	0.5
Max (ha)	15,316	13,951	15,316

[a] It refers to rural segments with at least one PSA protection contract signed between 1998 and 2004.

Table 2: Comparison of pre-matched non-treated and continuously treated census tracts

Variable	*Name*	*Description*	*Non-Treated Mean (SD)*[a]	*Continuously Treated Mean (SD)*[b]	*P value*
Tract size (ha)	TRACT	Size in hectares of each rural census tract as defined in Costa Rican Census 2000	368.62 (756.74)	1,927.63 (1,919.80)	0.000
Size of forest stock 1992	FOREST 92	1992 per tract forest stock size in hectares obtained from Landsat satellite images	72.472 (2.666)	787.92 (1,022.23)	0.000
% of tract area with soil class I or II	CLASS I	Class I: agricultural production. Class II: suitable for agriculture requiring land and crop management practices such as water conservation, fertilization, irrigation, etc.	13.67 (30.46)	5.24 (14.10)	0.000
% of tract area with soil class VII and VIII	CLASS II	Class VII: strong limiting factors on agricultural production; land is only suitable for forest plantations or natural forest management. Class VIII: land is suitable only for watershed protection	10.32 (25.84)	30.10 (37.35)	0.000
% of tract area with slopes 0-30%	SLOPE I	% of tract area with slopes 0-30%	93.67 (37.36)	81.70 (35.66)	0.000
% of tract area with slope > 45%	SLOPE II	% of tract area with slope > 45%	5.58 (11.64)	12.24 (15.81)	0.000
Precipitation (mm)	PP	Average precipitation at the centroid of each tract obtained from Atlas Costa Rica 2004	3,146.37 (1,008.98)	3,430.70 (951.31)	0.000
Proportion of tracts in humid lifezones	GOOD LZ	Proportion of tracts where centroid is in one of the Holdridge (1993) humid life zones: pre-montane, lower montane, montane and tropical	0.35 (0.48)	0.30 (0.46)	0.001
Proportion of tracts in very humid and montane life zones	MEDIUM LZ	Proportion of tracts where centroid is in one of the Holdridge (1993) very humid life zones: pre-montane, lower montane and montane	0.50 (0.50)	0.29 (0.46)	0.000
Proportion of tracts in very humid (tropical), dry (tropical), and rainy lifezones	BAD LZ	Proportion of tracts where centroid is in one of the Holdridge (1993) tropical life zones: very humid, dry and rainy life zones	0.15 (0.35)	0.40 (0.49)	0.000
Off-farm employment	JOB	Number of salaried people (*asalariado*) out of the total labor force per tract	0.41 (0.23)	0.27 (0.26)	0.000
Roads per tract (number/ha)	ROADS	Number of roads from the Atlas Costa Rica 2004	0.20 (0.50)	0.02 (0.041)	0.000
Road density per tract (kms/ha)	DENSITY	Road density from the road network Atlas Costa Rica 2004	72.77 (109.84)	15.71 (13.14)	0.000
Distance to market (kms)	MARKET	Minimum linear distance from the center of the census tract to the nearest major city	9.74 (7.97)	15.81 (9.14)	0.000

Table 2: Continued

Variable	*Name*	*Description*	*Non-Treated Mean (SD)*[a]	*Continuously Treated Mean (SD)*[b]	*P value*
Distance to ports (kms)	PORT	Minimum linear distance from the center of the census tract to the nearest port (Puntarenas or Limón)	77.25 (31.36)	81.61 (33.44)	0.000
Population density (number/ha)	POP	Number of inhabitants according to Costa Rican Census 2000 per census tract and per hectare	9.37 (29.64)	0.23 (1.23)	0.000
Tract-level proportion of immigrants	IMMIG	Per tract proportion of people that did not born in Costa Rica according to Costa Rican Census 2000	0.07 (0.09)	0.10 (0.13)	0.000
Tract-level proportion of people with least secondary education	EDUC	Tract-level proportion of people educated at least at the secondary level	0.93 (0.08)	0.96 (0.06)	0.000
Tract-level proportion of households using fuel-wood for cooking	WOOD	Tract-level proportion of households using fuel-wood for cooking	0.27 (0.24)	0.50 (0.26)	0.000
Distance to MINAE offices	MINAE	Minimum linear distance from the center of the census tract to the nearest Ministry of the Environment office	10.15 (6.84)	13.84 (7.53)	0.000
Age	AGE	Per tract population average age in years	26.13 (3.22)	26.31 (3.73)	0.099
Proportion of in tract-residents in 1995	RESID	Per tract proportion of people older than 5 years old that in 1995 lived in the same canton they were living in 2000	0.77 (0.11)	0.77 (0.12)	0.360
Per-tract number of hectares of non-eligible area for PSA	NONELEG	Non-eligible area for PSA includes protected areas and wetlands	70.82 (556.06)	308.49 (1,048.85)	0.000
Distance to IDA settlements	IDA	Minimum linear distance from the center of the census tract to the nearest IDA settlement	14.15 (11.83)	17.19 (12.42)	0.000
Proportion of tracts in aquifers	AQUIFER	Proportion of tracts where centroid is located in an aquifer	0.29 (0.45)	0.15 (0.35)	0.000
Proportion of tracts located in Ecomarket zone	ECOMARKET	Proportion of tracts where centroid is located in an Ecomarket zone	0.07 (0.25)	0.27 (0.44)	0.000
Proportion of tracts located in GRUAS zone	GRUAS	Proportion of tracts where centroid is located in a GRUAS zone	0.06 (0.23)	0.23 (0.42)	0.000
Forest gain 1997-2005	GAIN 9705	Sum of hectares that were not forest in 1997 but recovered to forest during 2005	15.106 (49.902)	111.708 (173.923)	0.000
Forest loss 1997-2005	LOSS 9705	Sum of all hectares transitions from natural forest in 1997 to other classes in 2005	9.646 (40.901)	55.917 (123.173)	0.000
Net deforestation 1997-2005	NETDEF 9705	Sum of all hectares transitions from natural forest in 1997 to other classes in 2005	-5.461 (56.865)	-55.792 (201.843)	0.000

[a] It refers to rural census tracts that do not contain forest conservation PSA contracts signed between 1998 and 2004
[b] It refers to rural census tracts that contain at least one forest conservation PSA contracts signed between 1998 and 2004

Table 3: Marginal effects on the propensity of a census tract to have PSA contract (dependent variable = 1 if tracts has at least one PSA contract)

Characteristic	***Marginal Effect***	
	Logit I[a]	***Logit II***[b]
Intercept		-3.971 (1.043)***
CLASS I	-0.011 (0.002)***	-0.010 (0.003)***
CLASS II	0.008 (0.001)***	0.009 (0.001)***
SLOPE I	-0.008 (0.002)***	-0.007 (0.002)***
SLOPE II	0.009 (0.005)**	0.012 (0.005)**
PP	0.000 (0.000)***	0.000 (0.000)***
MEDIUM LZ	-0.130 (0.116)	0.002 (0.122)
BAD LZ	0.456 (0.137)***	0.546 (0.145)***
JOB	-0.014 (0.003)***	-0.006 (0.004)
ROADS	-9.640 (1.158)***	-8.387 (1.141)***
MARKET	0.008 (0.007)	-0.008 (0.007)
PORT	-0.007 (0.001)***	-0.004 (0.002)*
TRACT	0.001 (0.000)***	0.001 (0.000)***
FOREST 92	0.001 (0.000)***	0.001 (0.000)***
NONELEG	-0.001 (0.000)***	-0.001 (0.000)***
MINAE	-0.005 (0.007)	0.001 (0.008)
AGE	0.034 (0.014)**	0.030 (0.015)**
EDUC	0.672 (0.794)	0.531 (0.835)
RESID	0.032 (0.260)	0.219 (0.322)
POP	na	-0.002 (0.001)**
IMMIG	na	1.135 (0.524)**
WOOD	na	0.605 (0.233)***
IDA	na	0.024 (0.004)***
AQUIFER	na	-0.120 (0.118)
ECOMARKET	na	0.601 (0.241)**
GRUAS	na	-0.255 (0.252)
GROUP I	na	-0.233 (0.164)
GROUP III	na	-0.332 (0.172)*
GROUP IV	na	-0.439 (0.217)**
GROUP V	na	-0.967 (0.151)***
GROUP VI	na	-1.440 (0.300)***
Observations	8,073	8,073
Pseudo R-square	0.393	0.412
Log-likelihood	-1,892.647	-1,834.081

Standard errors in parenthesis. *** = 99% confidence, ** = 95%, * = 90%.

[a] Logit I includes the main determinants of tropical deforestation and PSA participation

[b] Logit II adds other determinants of tropical deforestation (POP, IMMIG, WOOD), determinants of PSA targeting (IDA, AQUIFER, ECOMARKET and GRUAS) and dummies for regions (GROUP I, GROUP III, GROUP IV, GROUP V, GROUP VI).

Table 4: Treatment effect estimates

PSA Outcome	*Propensity Score Methods (Average Treatment Effect on the Treated)*				*Mixed Methods (Average Treatment Effect)*	
	Nearest Neighbor matching	***Radius matching***	***Kernel matching***	***Blocking***	***Weighting and regression***	***Matching and regression***
			Logit I			
Forest gain 1997-2005	22.989 (0.007)*** [0.019]**	31.450 (0.000)***	17.310 (0.029)**	29.281 (0.000)***	29.814 {0.000}***	20.226 {0.000}***
Forest loss 1997-2005	-15.166 (0.149) [0.122]	7.930 (0.285)	-5.161 (0.605)	7.586 (0.241)	5.658 {0.137}	-5.664 {0.146}
Net deforestation 1997-2005	38.155 (0.011)** [0.009]***	23.519 (0.029)**	22.472 (0.097)*	21.695 (0.027)**	24.831 {0.000}***	25.890 {0.000}***
			Logit II			
Forest gain 1997-2005	19.113 (0.047)** [0.051]*	31.526 (0.000)***	17.658 (0.031)**	32.055 (0.000)***	27.791 {0.000}***	22.367 {0.000}***
Forest loss 1997-2005	-14.967 (0.329) [0.473]	7.206 (0.375)	-5.657 (0.610)	10.889 (0.100)*	7.019 {0.076}*	-7.075 {0.070}*
Net deforestation 1997-2005	34.080 (0.070)* [0.128]	24.320 (0.030)**	23.316 (0.109)	21.166 (0.025)**	21.301 {0.001}***	29.443 {0.000}***
Observations			8,073			
# PSA census tracts			1,050			
# PSA census tracts off common support		31		na	na	na
# PSA census tracts used in matching		1,019		1,050	1,050	1,050
# Non-PSA census tracts used in matching		519		7,138	7,138	7,138

P-values in round brackets using bootstrapped standard errors with 999 repetitions. *P*-values in squared brackets using Abadie-Imbens bias corrected robust standard errors. *P*-values in curly brackets from OLS robust standard errors. Trimming level for common support is 3 percent. *** = 99% confidence, ** = 95%, * = 90%. Five blocks were defined based on propensity score. Propensity score balance was not achieved in two blocks.

Table 5: Balance-checking criteria for matching on the propensity score

Characteristic	***Logit I***			***Logit II***		
	Nearest Neighbor	***Radius***	***Kernel***	***Nearest Neighbor***	***Radius***	***Kernel***
CLASS I	0.753 (97.6)	0.000*** (63.9)	0.074* (84.8)	0.298 (91.6)	0.001*** (66.6)	0.073* (84.7)
CLASS II	0.594 (95.5)	0.000*** (69.4)	0.218 (89.7)	0.189 (89.0)	0.000*** (70.0)	0.095* (86.1)
SLOPE I	0.990 (99.8)	0.028** (71.3)	0.443 (90.1)	0.826 (97.1)	0.018** (70.0)	0.211 (84.0)
SLOPE II	0.862 (98.1)	0.001*** (64.9)	0.071* (80.6)	0.563 (93.7)	0.001*** (69.2)	0.037** (78.0)
PP	0.180 (79.0)	0.000*** (38.2)	0.002*** (52.8)	0.021** (64.4)	0.001*** (48.7)	0.017** (63.0)
GOOD LZ	0.319 (60.4)	0.016** (3.4)	0.017** (3.8)	0.000*** (-48.8)	0.030** (12.7)	0.040** (17.5)
MEDIUM LZ	0.627 (95.3)	0.036** (79.0)	0.861 (98.3)	0.407 (91.9)	0.088* (83.0)	0.925 (99.1)
BAD LZ	0.617 (95.8)	0.000*** (63.8)	0.029** (82.0)	0.004*** (76.5)	0.000*** (68.9)	0.054* (84.1)
JOB	0.042** (92.6)	0.000*** (69.1)	0.013** (90.3)	0.443 (97.3)	0.000*** (71.8)	0.010*** (89.8)
ROADS	0.300 (98.9)	0.000*** (66.5)	0.001*** (88.0)	0.789 (99.7)	0.000*** (68.4)	0.001*** (88.1)
MARKET	0.225 (92.0)	0.000*** (72.9)	0.351 (93.9)	0.451 (95.2)	0.001*** (78.3)	0.627 (96.8)
PORT	0.236 (57.0)	0.590 (81.2)	0.134 (46.4)	0.139 (49.7)	0.492 (76.3)	0.083* (39.4)
TRACT	0.496 (96.0)	0.000*** (70.1)	0.097* (91.0)	0.038** (88.4)	0.000*** (77.9)	0.743 (98.3)
FOREST 92	0.176 (91.5)	0.000*** (63.0)	0.002*** (81.1)	0.484 (96.0)	0.000*** (69.4)	0.024** (87.4)
NONELEG	0.296 (78.4)	0.028** (58.4)	0.477 (85.5)	0.090* (63.8)	0.160 (73.2)	0.865 (96.6)
MINAE	0.214 (88.7)	0.003*** (72.0)	0.620 (95.4)	0.438 (93.1)	0.019** (78.1)	0.772 (97.3)
AGE	0.440 (31.0)	0.953 (94.8)	0.852 (83.4)	0.729 (68.9)	0.791 (76.3)	0.944 (93.6)
EDUC	0.471 (94.0)	0.000*** (65.0)	0.062* (83.7)	0.495 (94.1)	0.000*** (64.0)	0.015** (78.2)
RESID	0.055* (-97.9)	0.550 (38.8)	0.574 (42.1)	0.052** (-101.2)	0.529 (34.8)	0.593 (44.5)
POP	0.724† (98.0)	0.000***† (60.5)	0.001***† (79.6)	0.333 (94.5)	0.000*** (67.9)	0.013** (85.4)
IMMIG	0.002***† (47.5)	0.004***† (51.1)	0.023**† (60.8)	0.678 (92.6)	0.312 (81.8)	0.933 (98.5)
WOOD	0.659† (97.8)	0.000***† (67.5)	0.008***† (86.7)	0.200 (93.6)	0.000*** (73.8)	0.110 (91.9)
IDA	0.002***† (45.0)	0.000***† (27.9)	0.002***† (43.8)	0.279 (80.3)	0.084* (68.4)	0.787 (95.0)
AQUIFER	0.073*† (79.5)	0.000***† (52.5)	0.005***† (67.4)	0.229 (86.3)	0.000*** (58.5)	0.016** (71.8)
ECOMARKET	0.000***† (51.4)	0.000***† (39.9)	0.000***† (50.8)	0.038** (80.3)	0.000*** (60.5)	0.017** (77.6)
GRUAS	0.000***† (54.0)	0.000***† (43.2)	0.000***† (54.9)	0.083* (82.0)	0.000*** (60.3)	0.036** (78.4)
GROUP I	0.018**† (52.4)	0.007***† (46.4)	0.063*† (62.3)	0.277 (77.5)	0.036** (57.4)	0.145 (70.1)
GROUP II	0.222† (83.3)	0.010***† (66.5)	0.252† (84.4)	0.004*** (58.7)	0.699 (94.7)	0.165 (80.5)
GROUP III	0.106† (86.4)	0.013**† (76.2)	0.897† (98.9)	0.404 (92.9)	0.005*** (74.0)	0.553 (94.8)
GROUP IV	0.420† (71.1)	0.506† (76.1)	0.154† (49.8)	0.330 (65.9)	0.978 (99.0)	0.493 (75.8)
GROUP V	0.007***† (-1056.0)	0.091*† (-619.4)	0.079*† (-648.7)	0.288 (-336.2)	0.217 (-405.2)	0.072* (-631.7)
GROUP VI	0.000***† (-1243.0)	0.015**† (-648.6)	0.000***† (-1079.7)	0.833 (41.6)	0.094* (-397.3)	0.009*** (-714.1)

Table 5: Continued.

% of bias reduction in parenthesis. *P*-values from standard t-test. *** = 99% confidence, ** = 95%, * = 90%. † These covariates were not included in the specification of the propensity score used for the matching.

Table 6: Treatment effect estimates by conservation area groups

PSA Outcome	*Propensity Score Matching Logit I*			*Propensity Score Matching Logit II*		
	Nearest Neighbor	***Radius***	***Kernel***	***Nearest Neighbor***	***Radius***	***Kernel***
			Arenal Huetar Norte			
Forest gain 1997-2005	-47.375 (0.000)*** [0.000]***	-28.676 (0.001)***	-46.413 (0.000)***	-42.303 (0.004)*** [0.004]***	-32.229 (0.000)***	-47.392 (0.000)***
Forest loss 1997-2005	0.786 (0.964) [0.918]	9.629 (0.374)	-5.749 (0.667)	-2.426 (0.880) [0.956]	2.720 (0.808)	-10.713 (0.459)
Net deforestation 1997-2005	-48.161 (0.030)** [0.014]**	-38.305 (0.000)***	-40.664 (0.005)***	-39.877 (0.080)* [0.069]*	-34.949 (0.003)***	-36.678 (0.019)**
			Tempisque - Arenal Tilarán - Guanacaste			
Forest gain 1997-2005	74.916 (0.000)*** [0.000]***	93.469 (0.000)***	78.235 (0.000)***	66.278 (0.000)*** [0.000]***	85.299 (0.000)***	70.184 (0.000)***
Forest loss 1997-2005	-23.421 (0.021)** [0.003]***	-3.648 (0.550)	-14.937 (0.061)*	-48.152 (0.042)** [0.033]**	-9.114 (0.213)	-22.545 (0.043)**
Net deforestation 1997-2005	98.337 (0.000)*** [0.000]***	97.117 (0.000)***	93.172 (0.000)***	114.430 (0.000)*** [0.000]***	94.413 (0.000)***	92.729 (0.000)***
			Cordillera Volcánica Central			
Forest gain 1997-2005	-21.597 (0.072)* [0.043]**	-15.759 (0.023)**	-26.994 (0.000)***	-26.705 (0.033)** [0.011]**	-14.783 (0.023)**	-26.919 (0.001)***
Forest loss 1997-2005	-17.422 (0.317) [0.129]	-6.402 (0.522)	-17.694 (0.157)	-42.526 (0.042)** [0.033]**	-4.929 (0.621)	-16.944 (0.181)
Net deforestation 1997-2005	-4.175 (0.852) [0.713]	-9.357 (0.416)	-9.300 (0.504)	15.821 (0.524) [0.543]	-9.854 (0.386)	-9.975 (0.482)
			La Amistad Caribe-Tortuguero			
Forest gain 1997-2005	-16.239 (0.139) [0.147]	-23.868 (0.004)***	-37.502 (0.000)***	-27.589 (0.026)** [0.015]**	-27.729 (0.001)***	-42.377 (0.000)***
Forest loss 1997-2005	12.038 (0.628) [0.449]	46.065 (0.004)***	36.835 (0.027)**	33.280 (0.094)* [0.085]*	48.383 (0.005)***	38.104 (0.033)**
Net deforestation 1997-2005	-28.277 (0.337) [0.170]	-69.934 (0.000)***	-74.337 (0.000)***	-60.869 (0.015)** [0.006]***	-76.111 (0.000)***	-80.481 (0.000)***

Table 6: Continued.

PSA Outcome	*Propensity Score Matching Logit I*			*Propensity Score Matching Logit II*		
	Nearest Neighbor	***Radius***	***Kernel***	***Nearest Neighbor***	***Radius***	***Kernel***
	Pacífico Central- La Amistad Pacifico					
Forest gain 1997-2005	45.501 (0.020)** [0.009]***	47.623 (0.008)***	35.042 (0.071)*	46.087 (0.023)** [0.010]***	60.136 (0.001)***	46.973 (0.012)**
Forest loss 1997-2005	-44.649 (0.001)*** [0.002]***	-5.710 (0.478)	-20.661 (0.059)*	-1.826 (0.917) [0.989]	1.513 (0.853)	-11.966 (0.274)
Net deforestation 1997-2005	90.150 (0.001)*** [0.000]***	53.333 (0.016)**	55.703 (0.030)**	47.913 (0.076)* [0.124]	58.622 (0.008)***	58.939 (0.020)**
	Osa					
Forest gain 1997-2005	66.237 (0.024)** [0.058]*	45.959 (0.042)**	34.213 (0.147)	59.152 (0.016)** [0.005]***	45.823 (0.046)**	37.166 (0.121)
Forest loss 1997-2005	89.785 (0.144) [0.122]	113.620 (0.032)**	95.793 (0.078)*	74.232 (0.430) [0.292]	115.067 (0.033)**	99.554 (0.081)*
Net deforestation 1997-2005	-23.548 (0.348) [0.702]	-67.661 (0.242)	-61.580 (0.296)	15.079 (0.871) [0.880]	-69.244 (0.225)	-62.388 (0.302)

P-values in round brackets using bootstrapped standard errors with 50 repetitions. *P*-values in squared brackets using Abadie-Imbens bias corrected robust standard errors. Trimming level for common support is 3 percent.
*** = 99% confidence, ** = 95%, * = 90%.