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. Alexander Mather coined the term 'forest transition' to describe one of the first empirical generalizations to emerge from research seeking global empirical regularities relevant to the transition to a sustainable society (Kates *et al.* 2002). Derived from historical studies of forests, the idea is that forest cover changes in predictable ways as societies undergo economic development, industrialization and urbanization (Mather 1990; Walker 1993; Mather and Needle 1998). Specifically, a large decline in forest cover occurs; then the trend turns around, and a slow increase in forest cover takes place (Rudel 1998).

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 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.

Costa Rican program of payments for environmental services

Costa Rica established in 1997 the first long-term, large-scale payment for ecosystem services initiative for tropical forests, Costa Rican Program of Payments for Environmental Services (*Programa de Pago por Servicios Ambientales*, PSA). The Forestry Law 7575 from 1996 prepared the ground for the implementation of PSA. It explicitly recognizes four environmental services provided by forest ecosystems: (i) mitigation of greenhouse gas emissions; (ii) water protection for urban, rural or hydroelectric uses; (iii) protection of biodiversity for its conservation, sustainable, scientific and pharmaceutical uses; research and genetic improvement; protection of ecosystems and life forms; and (iv) provision of natural scenic beauty for tourism and scientific purposes. The law provides the regulatory basis to contract landowners for the services provided by their forests, and established the National Fund for Forest Financing (*Fondo Nacional de Financiamiento Forestal*, FONAFIFO) which is the governmental agency in charge of administering the program (Pagiola 2006). However, during the period from 1997 to 2000, there was no attempt to measure all four environmental services (i.e. mitigation of greenhouse gas emissions, watershed protection, biodiversity conservation and landscape beauty) on a given parcel at once; rather the assumption was that an identically valued bundle of these services was provided by each hectare of enrolled parcel (Sánchez-Azofeifa *et al*. 2007).

In terms of priority areas to be enrolled in the program, during the initial years (1997-1998), PSA established that the whole national territory would be considered priority, but the different conservation areas administered by the National System of Conservation Areas (*Sistema Nacional de Areas de Conservación*, SINAC). SINAC could evaluate and define areas that could have special priority. Specifically, in order to prioritize specific areas to be included in forest protection, SINAC could consider the following criteria: (i) protection of hydrological resources, (ii) protection of areas with endangered plant and animal species, (iii) areas close to Protected Areas, (iv) private land located inside Protected Areas, (v) areas to be part of the Mesoamerican Biological Corridor efforts (known as GRUAS), (vi) areas voluntarily enrolled in the Forest Regime with protection purposes, (vii) privates and public refuges of natural life, (viii) areas with forest land use capacity, (ix) fallow pastures, (x) areas being recognized as carbon storages, (xi) areas with forest land use capacity and high fire risk, (xii) indigenous reserves and archaeological sites, (xiii) areas where conservation of other natural resources beside forest was being promoted, (xiv) areas potentially important to produce raw materials, and (xv) other areas considered important by SINAC (MINAE 1998).

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

Given the stated hypothesis of this study, it is expected that PSA has a positive impact on forest gain and net deforestation, and a negative impact on forest loss. Outcome data were obtained from Landsat satellite images originally classified by a team of researchers from the Earth Observation Systems Lab at University of Alberta, *Centro Científico Tropical* and Fonafifo (EOSL-CCT-FONAFIFO 2003). For the purposes of this study, Cordero (2008) created a Land Use Land Change (LULC) dataset during two time periods (1992-1997 and 1997-2005) to determine program outcomes and develop transition land use matrices for the periods under study.

After the initial years of PSA implementation (1997-1998), the PSA has been moving towards a greater degree of targeting. In fact, since 2002 MINAE publishes an annual Executive Decree that defines every year the PSA prioritization criteria per conservation area which is applied for the selection of applicants. For example, the 2003 PSA decree established that the areas included in the Ecomarkets project will receive higher priority including the areas located inside the Mesoamerican Biological Corridor. [1,2] The 2008 PSA decree gives priority to all biological corridors included in GRUAS II.[3] Different agreements with private and public companies also have influenced areas to be targeted by the program. The move towards a more targeted program responds also to a move towards a more market-based payment system, since donors are directing payments towards areas of higher environmental value according with their own conservation interests. In order to isolate the causal effect of PSA is important to incorporate these variations in the implementation of PSA throughout the years that can capture differences in program implementation and impact around the country. In relation to the program outcomes to be analyzed in this paper, forest gain and net deforestation for example relate to policy goals of stakeholders interested in promoting land uses related with carbon sequestration. Impact on forest loss is relevant for stakeholders more interested in protecting mature forest to secure water provision from nearby watersheds.

In order to capture regional variation in the implementation of PSA, we grouped conservation areas where it is believed PSA could have a similar impact.[4] This stratification will allow later to estimate not only national estimates of program impact but also identify regional impacts on program outcome. Conservation areas were grouped as follows:

- Group I: *Arenal-Huetar Norte* (ACHN)
- Group II: *Tempisque* (ACT) - *Arenal Tilarán* (ACAT) - *Guanacaste* (ACG)
- Group III: *Cordillera Volcánica Central* (ACCVC)
- Group IV: *La Amistad Caribe* (ACLAC) - *Tortuguero* (ACTO)

[1] The World Bank-funded Ecomarkets Project for Costa Rica aims to increase forest conservation by supporting the development of markets and private sector providers for environmental services supplied by privately owned forests including protection of biological diversity, greenhouse gas mitigation, and provision of hydrological services (source: www.worldbank.org). The first Ecomarkets payments started in 2001.

[2] The Mesoamerican Biological Corridor is a large habitat corridor in Mesoamerica, stretching from Mexico southeastward through most of Central America, connecting several national parks. It was started in 1998 to keep 106 critically endangered species from going extinct.

[3] GRUAS is an ecosystem mapping participative process directed by MINAE and carried out between 1995 and 1997 (Wo Ching 2006). The proposed GRUAS biodiversity corridors resulted from government efforts to identify national priorities for sites on which the state could invest in biodiversity protection, including as part of the Mesoamerican Biological Corridor (Powell *et al.* 2000). In 2007, GRUAS II was launched presenting some updates with the main purpose of filling the existing gaps in the current Costa Rican conservation system (SINAC-MINAE 2007).

[4] Costa Rica is under the jurisdiction of eleven large Conservation Areas which were created in 1998, overseen by divisions of SINAC. Over 25% of the national territory i.e. 3,221,636 acres (13,037 km²) is included in the national parks, refuges and protected zones within these eleven Conservation Areas (source: www.sinaccr.net). For the purposes of this study, *Isla del Coco* won't be included.

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.

We use a maximum likelihood logit model to estimate the probabilities. In the general framework of probability model we have: $Prob$(PSA participation) = $Prob(D=1)$ = F[relevant effects, parameters]. In this case, the probability of participation in PSA is a cumulative distribution function *F* evaluated as a function of a set (*X*) of explanatory variables that include tract socio-economic and biophysical characteristics, and a vector β of unknown parameters. The probability of participation model can be written as:

$$Prob(D_i = j) = \frac{e^{\beta' x_{ij}}}{e^{\beta' x_{i0}} + e^{\beta' x_{i1}}} \; for \; j = 0, 1. \qquad (1)$$

We estimate the ATT using three matching algorithms: (i) nearest-neighbor propensity score matching (NN); (ii) radius propensity score matching (RM); and (iii) Kernel (Gaussian) propensity score matching (KM). For RM, we use a radius of 2.5 standard deviations, meaning that any control unit outside the range of this radius in the space of the distance metric is dropped when the counterfactual mean is calculated.[5] For the case of KM, we use weighted averages of all census tracts in the control group where the weights depend on the distance between each tract from the control group and the participant tract for which the counterfactual is estimated. For NN, we present results with bootstrap standard errors using 999 repetitions and Abadie-Imbens bias corrected standard errors (see Abadie and Imbens 2006a). For RM and KM, we only use bootstrap standard errors using 999 repetitions.[6]

A number of approaches have been proposed that combine regression with different matching algorithms. According with Imbens (2004), these methods appear to be the most attractive in practice and the motivation for these combinations is that incorporating regression may eliminate remaining bias and improve precision. This is also useful because neither matching nor the propensity score methods directly address the correlation between the covariates and the outcome. Similarly, because matching is consistent with few assumptions beyond strong ignorability, thus methods that combine matching and regressions are robust against misspecification of the regression function (Imbens 2004). In this study, we use weighting and regression, and matching and regression to test the robustness of the results when comparing estimates from more traditional matching methods.

Unit of observation

Previous studies of PSA impact and participation (e.g. Zbinden and Lee 2005; Sierra and Russman 2006; Arriagada *et al.* forthcoming; Sills *et al.* forthcoming) recognized that

[5] Reducing the radius size bellow 2.5 standard deviations did not affect the observations dropped for being outside the common support. 2.5 standard deviation was considered appropriate given variation in observable characteristics between PSA and non-PSA tracts (a higher radius would increase the bias of the estimates because more observationally different control tracts would be used in the matching). Note, however, that for the case of forest gain, reducing the radius successively to 2.0, 1.5 and 1 decreases the treatment effect estimates making them to look more similar to NN results. For the case of net deforestation, changes in the radius size did not affect much the results.

[6] Abadie and Imbens (2006b) prove that the bootstrap is not valid for the standard nearest-neighbor matching estimator with replacement although empirical applications of the method still use it (see, for example, Ferraro *et al*. 2007). However, if the number of neighbors increases (as it is the case for RM and KM) the matching estimator does become asymptotically linear and sufficiently regular for the bootstrap to be valid.

landowners make decisions about program participation and program outcome (i.e. forest cover), and thus they are the ideal unit of analysis to analyze its causal impact. From these studies results, obtained using household surveys, in-depth case studies, interviews with government officials and forest professionals, and review of previous literature, it can be said that the factors that drive land use include a range of socioeconomic and biophysical characteristics that can only be obtained through combination of household surveys and either field data on land use or secondary spatial data.

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. [7]

The availability of enough number of control units to be used during the matching process also limits the policy relevance when analyzing the PSA program at the household level. That is because the policy analyst wishes to know the effect of the program on those who participate, not just a sample from where you have available data on outcome and confounders. A region-level analysis may allow better inferences based on a more extended sample of census tracts (in fact, this study includes all the rural census tracts of Costa Rica).

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.[8] 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.

According to the census, we found there are 8,214 rural census tracts with a mean size of 616 ha and standard deviation of 1,809 ha (coefficient of variation equals to 294%). The smallest rural tract is 0.45 ha and the biggest is 74 ha. From the 8,214 census tracts, only 11 (0.13%) are bigger than 17,000 ha, and then represent outliers that will be dropped from the analysis.

[7] 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.
[8] 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.

7 out of these 11 tracts contain a total of 96 PSA protection contracts signed between 1998 and 2004 which will also be dropped from the analysis (these 96 PSA protection contracts represent only 3% of the total number of PSA protection contracts signed between 1998 and 2004). Table 1 shows some descriptive statistics of the census tracts included in this study.

Treatment

This study will analyze the causal impact of PSA forest conservation contracts signed between 1998 and 2004 on deforestation at the level of rural census tracts. The three concepts associated with forest cover changes (forest gain, forest loss and net deforestation) will be used as part of this study. From Cordero (2008) a LULC dataset was obtained for Costa Rica during two time periods: 1992-1997 and 1997-2005. The complete methodology to estimate LULC for this study is described in Cordero (2008).

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:

$$\%\,tract\ area\ under\ PSA = \frac{\text{Per tract hectares protected by PSA conservation}}{\text{Tract area (ha)}} \qquad (2)$$

In terms of percent of segment area under PSA protection, the average percent is 15.3% with a standard deviation of 15.4% ha (coefficient of variation equals to 101%). In this study, we will use the percent of tract area under PSA as the variable that will define PSA and non-PSA census tracts. Then, PSA tracts (i.e. treatment group) will contain all tracts with more than 0% of tract area under PSA protection (i.e. it will contain census tracts with at least one PSA forest conservation contract signed between 1998 and 2004). Accordingly, non-PSA tracts (i.e. control group) will contain tracts with 0% of tract area under PSA protection.

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 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

- Land use capacity: we use Costa Rica's land use capacity classes, which are determined by slope, soil characteristics, life zones, risk of flooding, dry period, fog, and wind influences (see Decree 23214 from the Ministry of Agriculture and MINAE). These data will be obtained from the Costa Rica Digital Atlas 2004 (*Atlas Digital de Costa Rica 2004*, ACR).
- Off-farm employment: we proxy for off-farm employment using the Costa Rica Census 2000 that recorded number of salaried people and employment status when the census was carried on (i.e. people were asked about employment status one week before the actual census in 2000).
- Distance to roads: we measure the number of roads per census tract (ACR contains 8 types of roads which separate primary and secondary urban and rural roads). I also used density of roads to proxy for access to markets.
- Distance to markets: we proxy for access with the minimum linear distance from the center of the census tract to the nearest major city (i.e. *poblado* in ACR), to *San José* (i.e. the country's capital) and to *Puntarenas* and *Limón* (i.e. the two main ports in Costa Rica).
- Scale factor: we use the size of each tract and forest stock in each census tract.

There are also important confounders that determine program participation that need to be included in the estimation of the propensity score. These confounders include:

Determinants of program participation

- Age: using the census, we calculate the average age per tract
- Educational level: we count the per-tract number of people that have at least secondary education (*secundaria académica* and *secundaria técnica*)
- Distance to MINAE/SINAC regional offices: we calculate the distance of each tract to the nearest MINAE/SINAC regional office
- % population born inside the tract: we count the number of people per tract that were born inside the *cantón* (equivalent to a US county) where they live when the census was implemented

Immediate causes of deforestation and determinants of program participation will serve the purpose of estimating the propensity score (i.e. the probability of having at least one PSA forest conservation contract signed between 1998 and 2004 in a rural census tract). These confounders will constitute the core group of confounders to be used in the estimation of program causal impacts.[9]

Previous studies of tropical deforestation have also identified underlying causes of deforestation that will be included in an extended specification of the propensity score together with the variables that have determined PSA targeting by FONAFIFO and SINAC as explained in previous sections. The extended set of confounders to be included in the estimation of the propensity score are:[10]

Underlying causes of deforestation

- Population: we measure population density at tract-level from the census
- Proportion of immigrants: we measure immigration by counting the per-tract number of people older than 5 years old in 2000 that were not living in Costa Rica in 1995 using the census
- Proportion of households using fuel-wood for cooking: fuel-wood use is a proxy for the use of forest resources by residents, which would affect deforestation (see Ferraro 2007). We count the per-tract number of households that use fuel-wood for cooking purposes

PSA targeting:

- Distance to the Costa Rican Institute of Agrarian Development (*Instituto de Desarrollo Agrario*, IDA) settlements: we calculate the distance of each tract to the nearest IDA settlement
- Proportion of tracts located in aquifers
- Proportion of tracts located in Ecomarket areas
- Proportion of tracts located in GRUAS areas

Results

Program participants vs. non-participants

The rural census tracts included in this study area characterized in Table 2 which reports descriptive statistics for biophysical and socio economic tract characteristics, and for variables that explain PSA targeting efforts. The table compares non-PSA rural census tracts (column 4) (i.e. rural census tracts that do not contain PSA contracts) with PSA tracts (column 5). Table 2 also shows the p-value for the difference in means (column 6). Although these descriptive statistics are descriptive and not inferential, they represent 98.4% of Costa Rican rural census tracts according with the 2000 census. According with Table 2 PSA and non-PSA tracts are significantly different on many counts. Within the group of biophysical

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[9] This core group of confounders will allow estimating the propensity score using a logit specification referred as *Logit I* in the results section.

[10] This extended set of confounders will allow estimating the propensity score using a logit specification referred as *Logit II* in the results section.

tract characteristics, PSA tracts are significantly bigger, with more 1992 forest stock, worst soil quality, more steeper slopes, more precipitation, fewer number of roads, lower road density, more distant to markets and ports, and more distant to MINAE regional offices. These results are consistent with main determinants of tropical deforestation as explained in previous sections and show already an important correlation between deforestation determinants and PSA participation. Within the group of socioeconomic tract characteristics, PSA tracts have significantly less off-farm employment opportunities, are less populated, have fewer immigrants, more educated, and contain more people that use fuelwood. In terms of the variables that explain PSA targeting, PSA tracts contain less non-eligible area for PSA, are more located further from IDA settlements, further from aquifers, and closer to Ecomarket and GRUAS zones.

This initial comparison of PSA vs. non-PSA tracts differences indicate already the extent of biased comparisons of outcomes due to different distributions of observed covariates in both groups. In fact, Table 2 reports land use changes for PSA and non-PSA tracts. PSA tracts gained more forest between 1997 and 2005; report a more positive forest loss and a more negative net deforestation between 1997 and 2005.

Estimates of program impact

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.[11] 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.

Results of PSA impact using propensity score methods are fairly consistent in terms of size and significance across the methods for the analyzed PSA outcomes presented in Table 4. However, in order to properly compare propensity score methods, it is important to consider the percent of non-PSA tracts used during the matching process. For the case of NN, out of the total population of non-PSA rural census tracts, only 8.4% (i.e. 593 non-PSA tracts) and 8.5% (i.e. 594 non-PSA tracts) were used as matches during the matching process for the case of logit I and II respectively. RM uses the controls lying within the defined radius to find the matches for the treated observation, then in that sense uses a restrictive group of non-PSA tracts comparable with NN. KM is not as restrictive as NN and RM because all controls are used as matches during the matching process resulting in a much bigger sample of controls being used as matches (basically all on-support controls are used during the matching). This explains why the magnitudes of the estimates of PSA impact using KM are comparable with NN and RM, but the significance levels tend to be bigger across the logit specifications and the different program outcomes (as a result of the tradeoff between bias and variance made when using more controls as matches). Regarding propensity score blocking, for the estimation of ATT each block is weighted according with the number of PSA tracts in each block. In order to avoid overweighting the blocks with higher values of

[11] 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.

propensity, I defined 10 blocks.[12] The tenth block with the highest values of propensity contains 53% of the total number of PSA census tracts and only 5% of the total number of non-PSA tracts. This helps to explain why blocking gives results of PSA impact that lie between RM and KM estimates because blocking uses all the non-PSA census tracts during matching, but it weights more the ones that have higher propensity values which in this case results in a reduced number of non-PSA tracts (i.e. 5% of total non-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, 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 unbalance 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.

[12] Following Cochran (1968) recommendation, I started with five blocks and 79% of PSA tracts were included in the fifth block (i.e. the block with the highest propensity scores) which is the block that would receive the highest weight in the calculation of ATT.

Program implementation differs across regions in Costa Rica. Table 6 shows the treatment effect estimates by group. A significant impact of PSA on forest gain was found for all the groups and across all the propensity score matching methods (except for *Osa*). However the direction of the impact was not the expected in several groups. A negative and significant impact of PSA on forest gain could indicate that areas outside PSA are attracting the regeneration of new forests which is consistent with the current forest transition in Costa Rica. The negative impact could also indicate the presence of other forest incentives designed specifically for forest regeneration (e.g. PSA reforestation contracts). *Tempisque-Arenal Tilarán-Guanacaste* and *Pacífico Central-La Amistad Pacífico* show the anticipated direction of PSA impact on forest gain. In terms of forest loss, none of the groups show a clear trend for the impact of PSA in terms of impact direction and significance. This result is not surprising given the deforestation rate in Costa Rica in the last two decades. In that sense, PSA does not have much room for contributing some additionality to the current situation that affect more mature natural forest. For the case of net deforestation, there are mixed results given the PSA impacts on forest gain and loss. *Tempisque-Arenal Tilarán-Guanacaste* and *Pacífico Central-La Amistad Pacífico* are again the groups that show the expected direction of PSA impact. These results provided evidence that PSA impact differs across the country. Variations in the implementation of the program may be playing an important role in the estimation of program impact across regions.

Conclusions

Direct incentives to conserve forests in the form of payments for ecosystem services have become a popular conservation intervention over the past decade (Bulte *et al*. 2008). While economists were instrumental in promoting this approach (Ferraro and Kiss 2002), they are now raising the concern that PES programs are being implemented globally in much the same way previous conservation interventions were implemented: with an unwavering faith in the connection between interventions and outcomes and without a plan to judge the effectiveness of such interventions (Ferraro and Pattanayak 2006).

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.

However, PSA was not developed from scratch but grew out of a history of reforestation and forest protection efforts, dating from at least 1969. Whether as a result of these efforts or other changes in the Costa Rican society and economy, deforestation rates started falling in the 1990s, at least several years before the PSA program began. Thus, to evaluate the impact of PSA, the analyst must disentangle the effects of previous government forestry incentives and economy-wide changes that made deforestation less appealing, as well as adjusting for the non-random assignment of contracts.

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). The effect of temporal and spatial variation in program implementation is also considered by estimating program impact by regions and years. 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.

In terms of PSA impact on forest loss, propensity score matching estimates indicate no program impact, although blocking and mixing methods suggest some small impacts. This result is not surprising given the deforestation trend in Costa Rica in the last two decades. Consistent with the recent literature on forest cover in Costa Rica, forest loss is defined here as the sum of all area transitions from natural forest classes (continuous and fragmented) to all other land use classes. Part of the explanation for the lack of impact of PSA on forest loss could be simply that there has not been much transition from natural forest classes to other land uses in the last two decades, due to a wide array of social, economic, and policy factors as well as the location and biophysical characteristics of the forest that remained after the previous half a century of rapid deforestation.

For the case of net deforestation, PSA shows a positive and significant impact across all propensity score and mixed methods. This result indicates that PSA has caused forest gains greater in magnitude than any forest losses in the census tracts that contain at least one PSA forest conservation contract signed between 1998 and 2004. The magnitude of this impact varies according with the matching estimator being used, but the impact goes from 21.2 ha to 34.1 ha more of forest gain on average in the PSA census tracts vs. tracts with no PSA. These numbers represent between 1.1% and 1.7% of the average size of PSA tracts, 2.7% and 4.4% of the average forest cover in 1997 in PSA tracts, and 7.3% and 11.6% of the average land enrolled in PSA.

Further insight can be gained by considering regional variation in the implementation of PSA. Program impact was expected to vary across regions defined by how intense the protection has been in a particular region (e.g. by the number of signed PSA contracts), the organizational strength of the implementing agency in the region, among other factors (e.g. presence of active NGOs promoting PSA). Preliminary results on regional program impacts shows that in *Tempisque-Arenal Tilarán-Guanacaste* PSA has a positive and significant impact on forest gain and net deforestation and a negative impact on forest loss (although for this case, results were not significant for all methods). This conservation area group represents the most intensively treated in terms of number of PSA contracts, area under PSA protection and number of PSA tracts. Counterintuitive results (e.g. negative impact on forest gain and net deforestation, and positive impact on forest loss) were obtained in some cases where the intensity of PSA protection is lower. These preliminary results suggest that further research is needed that can take into account treatment intensity and effects of PSA contract distribution. Future evaluations should also consider other possible confounders that might drive reforestation as well as deforestation, as well as possible interaction effects in policy implementation (e.g. evaluating the impact of different PSA modalities as multiple treatments). Further study of regional variations in PSA implementation and impact could lead to valuable recommendations for development of PES in other countries.

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%.