The B.E. Journal of Economic Analysis & Policy

Contributions

Volume 9, *Issue* 2 2009 *Article* 5

ECONOMIC GEOGRAPHY AND COLOR MAPS

Park Location Affects Forest Protection: Land Characteristics Cause Differences in Park Impacts across Costa Rica

Alexander Pfaff* Juan Robalino† G. Arturo Sanchez-Azofeifa‡
Kwaw S. Andam** Paul J. Ferraro††

*Duke University, alex.pfaff@duke.edu
†CATIE, robalino@catie.ac.cr
‡University of Alberta, sanchez@ualberta.ca
**International Food Policy Research Institute, k.andam@cgiar.org
††Georgia State University, pferraro@gsu.edu

Recommended Citation
Alexander Pfaff, Juan Robalino, G. Arturo Sanchez-Azofeifa, Kwaw S. Andam, and Paul J. Ferraro (2009) "Park Location Affects Forest Protection: Land Characteristics Cause Differences in Park Impacts across Costa Rica," *The B.E. Journal of Economic Analysis & Policy*: Vol. 9: Iss. 2 (Contributions), Article 5.
Available at: http://www.bepress.com/bejeap/vol9/iss2/art5

Park Location Affects Forest Protection: Land Characteristics Cause Differences in Park Impacts across Costa Rica*

Alexander Pfaff, Juan Robalino, G. Arturo Sanchez-Azofeifa, Kwaw S. Andam, and Paul J. Ferraro

Abstract

To support conservation planning, we ask whether a park's impact on deforestation rates varies with observable land characteristics that planners could use to prioritize sites. Using matching methods to address bias from non-random location, we find deforestation impacts vary greatly due to park lands' characteristics. Avoided deforestation is greater if parks are closer to the capital city, in sites closer to national roads, and on lower slopes. In allocating scarce conservation resources, policy makers may consider many factors such as the ecosystem services provided by a site and the costs of acquiring the site. Pfaff and Sanchez 2004 claim impact can rise with a focus upon threatened land, all else equal. We provide empirical support in the context of Costa Rica's renowned park system. This insight, alongside information on eco-services and land costs, should guide investments.

KEYWORDS: forest, deforestation, protected area, evaluation, Costa Rica

*Pfaff and Robalino are co-lead authors. For financial support we thank: the Tinker Foundation; the IAI; the National Science Foundation (Methods and Models for Integrated Assessment); the National Center for Ecological Analysis and Synthesis; the Social Science and Humanities Research Council of Canada; the CEES / Earth Institute and ISERP at Columbia University, and EfD. For helpful comments (without implication in remaining errors), we thank seminar participants at Yale, Harvard, RFF, ETH Zurich, ISTF (chapter at NCSU) and the EfD initiative.

1. Introduction

Protected areas such as national parks and forest or biological reserves have long been the most common approach to forest conservation. Every year around $6 billion is spent on more than 100,000 protected areas around the world (James et al. 1999, 2001; Pearce 2005). Looking ahead, protection's importance seems likely to continue. For instance, the Convention on Biological Diversity's Work Program on Protected Areas, or "2010 targets" (www.cbd.int/protected/targets.shtml), suggests an expansion of protected areas.

Despite increased attention to alternative policies such as ecopayments[1], plans to expand protected areas may find support in recent climate-policy developments. To earn avoided deforestation credits, tropical nations could lower deforestation relative to an agreed baseline. Such attempts to earn tradeable credits for reducing emissions (REDD) may well feature new protection, since that is a familiar tool. We show that where such new protection is placed will affect the size of shifts in deforestation relative to baseline. Assuming precise monitoring, larger shifts permit larger earnings by the forested country. Thus policy makers have incentives to consider where protection will slow clearing most.

Much of the protected-area literature simply assumes protected areas will lower deforestation. For example, the literature on optimal reserve location focuses on species' locations.[2] This literature implicitly assumes that if the high priority locations are offered legal protection, conservation impacts will be realized. Little attention has been given to whether the legal protection indeed leads to the conservation impacts that are assumed.

In Costa Rica, most of the area under protection remains essentially uncleared.[3] This might mean that protected areas are effective in reducing deforestation. However, to what should one compare such an outcome in order to best infer protection's impact? Much unprotected forest also remains uncleared. Perhaps protection did little or nothing? Generally, in order to infer protection's impact we want to use unprotected outcomes to estimate what would have happened to forest in protected areas had it not been protected.

Existing impact analyses have used average deforestation in unprotected forest, and often specifically spatial buffers around protected areas, to estimate the

---

[1] See, e.g., Chomitz et al. 1998, Ferraro 2001, Pagiola 2002, Miranda et al. 2003, Sierra and Russman 2006.

[2] Some examples of reserve siting analyses of increasing complexity include Tubbs and Blackwood 1971, Gehlbach 1975, Williams 1980, Kirkpatrick 1983, Saetersdal et al. 1993, Cocks and Baird 1989, Church et al. 1996, Csuti et al. 1997, Polasky et al. 2000, Polasky et al. 2001 and Camm et al. 2002 to name a few.

[3] Sanchez et al. 2003. Some encroachment is starting to occur at the edges of some national parks.

deforestation protected areas would have experienced if not protected.[4] This approach can fail, and grossly so, if protected lands' characteristics differ significantly as some have suggested.[5]

Why would protected lands be different? If maximizing impact on deforestation, an agency might prioritize sites with high deforestation threat (Pfaff and Sanchez 2004). In contrast, so that a protected area remains forested as long as possible, an agency might prize low-threat lands. If focusing on valued species one may prioritize relatively pristine locations, which may be lands that face lower pressure. Thus, conservation planners may locate protected areas based on observable characteristics thought to affect deforestation. Joppa and Pfaff 2009b show, globally, that in fact protection goes to less threatened land.

Does this matter for understanding protection's impacts on rates of deforestation? Andam et al. 2008 show that it can matter a lot. Their location-corrected (i.e. matching) estimates of protection's impact on 1960-1997 deforestation are less than a third as large as the estimates derived using typical methods . Recent analyses of Costa Rica's payments-for-ecoservices program confirm the policy relevance of this point. The 1997-99 payments contracts were on lower-threat land and thus impact estimates that do not correct for non-random location overestimate the program's impact on deforestation.[6]

What could a policy maker do in light of this information? Target higher impact areas, which are those areas facing higher threats of deforestation. Here, then, to support conservation planning, while correcting for non-random location as in Andam et al. 2008, we add new analysis of how protected areas' impacts vary across potential reserve sites.[7] Each of our estimates uses the corrective matching method but the main point is that to consider best targeting, policy makers need to know where impacts *differ from average*.

We find that protected areas within 85 km of Costa Rica's capitol city, San Jose, prevented over 4% of their forest area from being cleared during 1986-1997. Those further away prevented under 1%. Protection within 7.5 km of national roads blocked the clearing of about 5% of the forest, and protection on land with slopes under 7.12 degrees avoided 14% deforestation, while essentially no protection (i.e., not statistically different from zero) resulted from the protected

[4] See Oliveira et al. 2007, Bruner et al 2001, Stern et al. 2001 and a review in Joppa and Pfaff 2009a.

[5] Analyses of distributions of protected areas and remaining gaps are in Oldfield et al. 2004; Fearnside and Ferraz 1995; Powell et al. 2000; Hunter and Yonzon 1993; Ramesh, et al. 1997, and Andam et al. 2008.

[6] Sanchez et al. 2007, Pfaff et al. 2007a, Robalino et al. 2008

[7] We focus on more recent clearing, 1986-1997. Underlying deforestation is slower on average than during the 1960-1997 period but the importance of addressing the non-random location of protected areas seems the same. As seen below, our overall matching estimate is also less than a third of an unmatched estimate.

areas far from national roads or those that were located on high slopes.[8] Such differences in protection's impacts are relevant for policy.

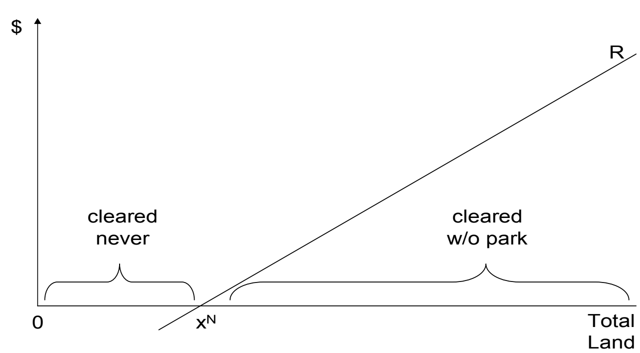
The paper proceeds as follows. Section 2 provides background on Costa Rican deforestation and protected areas, as well as a concisely sketched model of deforestation impacts from protection. The latter provides a simple illustration of the challenges faced when estimating impacts. In Section 3, we describe the data, as well as the matching methods that we apply. In Section 4 we present the results, and in Section 5, we discuss the policy implications.

2. Protected Areas & Costa Rican Deforestation

2.1 Protection's Impact

Figure 1 presents a simple but useful framework for considering protected areas' impacts on deforestation. Rents are determined by opportunity costs of keeping land in forest and forest land is ordered according to the rent it provides, from highest to lowest. Where rents are greater than zero, the land will be deforested in the absence of protection. Where rents are negative, the land will remain in forest even without any legal protection. Thus in the absence of protection, deforestation will take place only above x^N in Figure 1.

Figure 1 – land-use choice with and without park



[8] Methodologically, breaking protected areas into subsets highlights the fact that some protected areas have much poorer matches among the unprotected locations, as seen in Figures 2 and 3 and addressed below.

Put another way, protection can lower clearing only within the interval above x^N. Thus, a protected area's impact depends on the fraction of its land that is in that interval. If that fraction is 1, then every parcel that is protected represents avoided deforestation (here we leave aside any spillover effects on other lands, as predicted in Robalino 2007).

We estimate that fraction using unprotected locations that are similar to parcels in protected areas. If a large fraction of the unprotected locations similar to protected parcels were deforested, then protection will be estimated to have had a large impact upon forest cover.

Considering the challenges to estimation, if all lands and only the lands above x^N are protected, it would be impossible to find unprotected locations just like the protected ones other than in protected status. The same is true if all of and only the land below x^N has been chosen for protection. When applying matching methods, in order to find similar parcels, we will check whether even the most similar land is not very similar (see, e.g., Figure 2).

2.2 Protection in Costa Rica

2.2.1 Land-Use History

From the arrival of the Spanish until the middle of the 20^{th} century, thousands of hectares of forest were cleared for agriculture and cattle (Sader & Joyce 1988, Sanchez et al. 2001). Policies prioritized demographic and agricultural growth (see, among others, Harrison 1991, Solorzano et al. 1991, and Rosero-Bixby & Palloni 1998). Forest clearing depended upon biophysical features such as where coffee can grow or the coastal shape that facilitates a port, and thus a port city, which affects land demand.

Until the clearing boom in the mid-20th century, most of the clearing occurred in the central plateau and near one major western port. The boom involved trade growth that increased the influence of international commodity prices, yielding expansion of cattle in the north, coffee in the center, banana in the Atlantic region and sugar in varied locations. The distribution of deforestation from this expansion depended in part upon variations in precipitation, temperature and soil that greatly influenced which crops could grow where.

Over the last two decades, deforestation has slowed. This is due in part to falling commodity prices. Falling beef prices encouraged abandonment of cleared land in the Guanacaste Peninsula (Sanchez 2000) where cattle are the dominant product. The slowing is also due in part to a rise in the returns to forest. The rise in ecotourism since the early 1990s played a major role. Starting in 1997, public payments to owners of forested land were made in return for multiple environmental services provided by forest. 'Sustainable forestry' and 'shade coffee' have also contributed to the increase in returns from forested land. This is in part due to price premia from timber and coffee labeling.

2.2.2 Protected Areas Network

Starting in the 1960s, Costa Rica created a system of protected areas (Table 1). Between 1974 and 1978, e.g., the fraction of the country in protected areas expanded from 3% to 12%. Currently it is approximately 25% (Sanchez et al. 2002). Below, we empirically examine impacts of the national parks and biological reserves.

Table 1 -- establishment dates and characteristics of 132 protected areas

Category	Number	Area (ha)	Number Started Per Decade					Nat'l %[1]
			< 60s	***60s***	***70s***	***80s***	***90s***	
National Parks	24	541,576	1	1	11	1	10	10.6
Biological Reserves	9	39,644	-	-	5	2	2	0.8
Wildlife Refuges	39	181,018	-	-	-	9	30	3.5
Forestry Reserves	12	291,513	-	2	6	1	3	5.7
Protection Zones	31	178,677	-	-	10	11	10	3.5
Wetlands	14	50,465	-	-	1	1	12	1.0
Special categories	3	1,650	-	1	1	-	1	< 0.1
Total	132	1,284,543	1	4	34	25	68	25.1

[1]: indicates the percent of the national territory within these types of protected areas

Since 1979, three Forestry Laws (1979, 1986 and 1996) were passed and agency structures have also changed. Prior to 1995, three agencies (Forestry, National Parks, and Wildlife) were responsible for conservation. SINAC (National System of Conservation Areas) was created in 1995, consolidating agencies and the park system. SINAC placed all existing areas into 11 Conservation Areas which form the protected area structure.[9]

[9] In national parks and biological reserves, no land-cover change should occur. In forest reserves and wildlife refuges, some land-cover change is permitted. Government still owes private land owners for some of the currently protected areas that formerly were private lands (Segnini 2000) --

New protected areas have been proposed, including areas in the Mesoamerican Biological Corridor (Powell et al. 2000). It has been suggested that the set of protected areas should cover the range of ecological conditions present in Costa Rica. How to do that using the minimal area of new protection has been actively considered (Garcia 1997).

3. Data & Matching

3.1 Data

3.1.1 Forest

We obtained spatial data on forest in 1986 and 1997 from University of Alberta (Sanchez-Azofeifa et al. 2003). The data were derived from Landsat satellite images that have a 28m resolution and distinguish forest from non-forest and mangroves. They allow us to estimate annual deforestation at a national level and to see which of the pixels, exactly, were deforested between 1986 and 1997. It is worth noting that we use pixels, not parcels, since we do not observe the legal boundaries of private land holdings.

3.1.2 Protected Areas

We obtained spatial data on all of the protected areas during this period from the Instituto Teconológico de Costa Rica. There are eleven types of protection distinguished in the data and the categories are believed to correspond to actual intensity of protection. Our analyses focus upon the national parks and biological reserves. These are the most protected categories, with rules against any form of land-use change. Sanchez et al. 2003 show that deforestation in those areas has been essentially zero while there is significant deforestation in categories other than national parks and biological reserves.

We analyze the effect on deforestation of the protected areas created before 1986, i.e. before the deforestation that we examine. Most of the protected areas, in fact, were created by then. We do not examine the effect on deforestation of the parks created after 1986 but before 1997 since we could not separate the clearing that occurred before they became parks from the clearing that occurred afterwards. For parks created after 1998, which again is not a large area, we leave them in the set of unprotected locations from which we draw the matched

a 1994 Supreme Court ruling upheld the need for compensation (Busch et al. 2000). Yet the national parks and biological reserves are not in fact cleared (Sanchez et al. 2003) and our analyses assume they will remain so while protected. Future work could examine the impacts of the other categories of reserves, which may not be very large.

unprotected comparison set, since not only was there not legal protection during our deforestation period but also they might be good controls.

3.1.3 Other Factors in Land Use

Additional maps from the Ministry of Transport and Instituto Tecnologico show the locations of rivers, cities, national parks, schools, sawmills, national and local roads and slopes. These factors can be used as controls in our tests of the impact of protection. The cities to which we measure fixed distances (in km) are San Jose, Limon and Caldera. We also measure distances (km) to the closest local and the closest national road (as of 1985), closest mill (1999) and closest school (2000), plus the 1986 distance to the forest frontier.

For spatially varying unobserved factors, we also use the ministry of agriculture's administrative divisions (Central, Heredia, Huetar Norte, Huetar Atlantica, Brunca, Pacifico Central and Chorotega) to generate regional dummies to use as more controls.

We use rain and a fixed vegetation description based on the Holdridge Life Zones, which consider precipitation and temperature as proxies for ecosystems' characteristics. Costa Rica has 12 such Life Zones: humid pre-montane, humid lower-montane, tropical humid, very humid pre-montane, very humid lower montane, very humid montane, tropical dry, pluvial pre-montane, pluvial lower-montane, pluvial montane and paramo.

3.1.4 Units of Analysis

Ten thousand points were randomly drawn across the 51,000 squared kilometers of Costa Rica. These are used as observations. Out of them, 170 were dropped because their location was covered by clouds as satellites recorded images or because, according to data experts, the information taken from the satellite images was inconclusive. We also eliminated locations not in forest in 1986 as we focus upon deforestation. The fraction of land in forest in 1986 was 47.89%, which left us with 4229 observations for the analysis..

3.2 Matching Approach

To calculate protected areas' impacts on deforestation, we need to estimate what would have been the deforestation rate without protection. We then compare the actual deforestation rate in protected areas with this estimated deforestation counterfactual.

If protection were implemented randomly across forests, we would need only the average deforestation rate outside of protected areas for a good estimate of protection's impact on clearing. In expectation, all other factors would cancel out and the difference in the deforestation inside versus outside of protected areas would be due to the protection. However, protection is not randomly distributed. As noted, many rationales could explain why planners base choices on the observable site characteristics that affect deforestation.

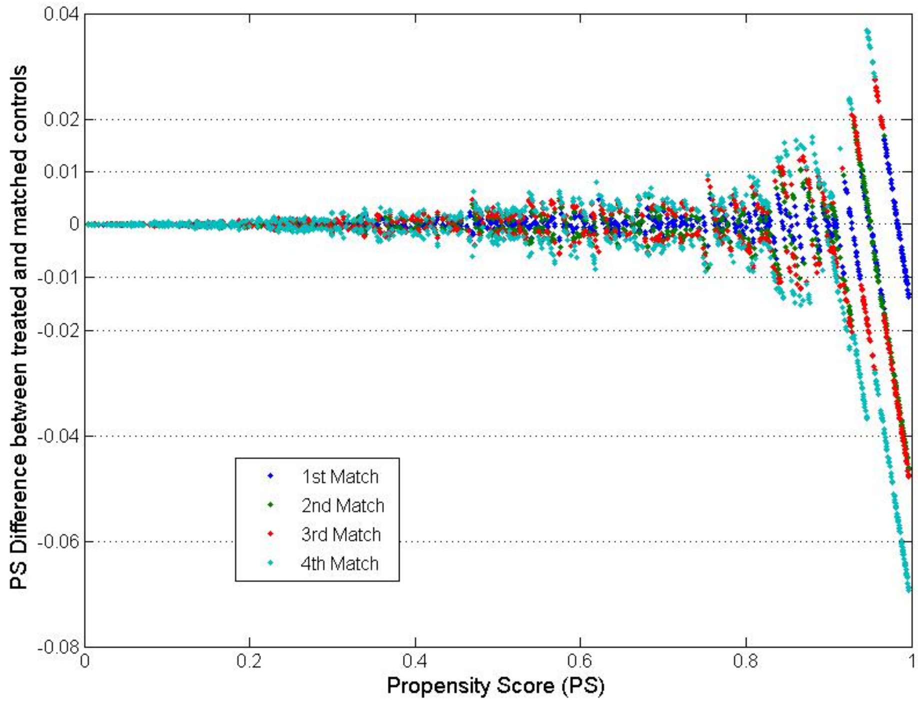
We use matching techniques to avoid bias from the non-random allocation of forest protection. The principle is to compare protected areas, which differ from average locations, with similar unprotected areas in order to better isolate the effect of protection. Thus the control group compared to protected areas is a subset of unprotected locations. Specifically, we try to find the unprotected point(s) most similar to each protected point.

We use the probability of a parcel being in a protected area to define 'similarity'. The estimated probabilities of being protected result from a probit model for protection, with the regressors being all of the observed covariates of the treatment (Rosenbaum and Rubin 1983), many or all of which would be expected to influence rates of deforestation as well. Thus, protected areas' deforestation is compared to deforestation of unprotected parcels that have probabilities of being protected that are similar to the protected points.

Below, we use the four most similar unprotected points for each protected point in order to form a control group for comparison with protected-area deforestation. When the number of matched unprotected control points per protected point rises, the variance of this estimate decreases given more data. However, bias also increases as each additional next-best matched point is a bit less similar to the protected point than the match before.

Choosing a fixed number of the most similar locations for each protected location implies that we do not fix the level of similarity required for inclusion in a control group. The n^{th} most similar location for a protected Point A may be almost identical to Point A while the n^{th} most similar location for Point B may be very different from B. Concretely, Figure 2 shows that the n^{th} most similar location is less similar for protected points with very high probabilities of being protected. Those points have less well matched controls. In section 4 below, we discuss and check the implications of this for impact estimation, including robustness checks in which sufficiently dissimilar control points are not used.

Figure 2 – Areas Most Likely To Be Protected Are Harder To Match



Note: estimated probabilities shown here are generated from analysis in Table 3a (then matched).

Having chosen control points, we can simply calculate their deforestation rate as the counterfactual deforestation estimate of what would have happened in the protected areas had they not been protected. This can be compared to the deforestation in protected areas for an estimate of the impact of protection. However, we can also do this inference within a regression. Thus, for the protected plus the matched unprotected points, we will regress the binary deforestation outcome on a protection dummy and the other covariates expected to affect deforestation rates. The standard errors from such a regression are not correct (even with bootstrapping, as per Abadie and Imbens 2006). Following Hill et al. 2003, we address some of the issues with the standard errors by weighting unprotected observations by the number of times they are included as controls for protected points.

4. Results

4.1 Protection's Average Impact

4.1.1 Regression Without Matching

We start by showing the importance of the non-random distribution of protection. Considering all protected areas at once, Table 2a presents a simple comparison of rates of deforestation inside national parks and biological reserves (labeled 'Protection') and rates outside those protected areas. Deforestation inside those protected areas is around zero, as indicated by the Protection coefficient being about the same magnitude of the constant but of the opposite sign. The table suggests about 9% avoided deforestation during 1986-1997, i.e. without protection 9% of 1986 forest in those areas would have been cleared.

Table 2a – Protected Points versus All Unprotected Points
(all protected areas lowering 1986-97 deforestation rates)

DEPEN. VARIABLE =DEFORESTATION 86-97	OLS	# obs= 4,229	Rsquared= 0.02
INDEP. VARIABLES	Coefficient	t-statistic	t-probability
Protection	**-0.093**	**-9.8**	**0.00**
Constant	0.096	21.0	0.00

However, as noted above, there is good reason to expect that protected areas are on lands that differ on average from unprotected lands. Table 2b presents a first natural approach to taking that into account by controlling for sites' observed characteristics in a regression comparing protected and unprotected sites. This table suggests only about 2% avoided deforestation. Thus, while below we advocate using matching to better control for the impacts of difference in land characteristics, Table 2b suggests that they matter.

Table 2b – Protected Points versus All Unprotected Points with Controls
(all protected areas lowering 1986-97 deforestation rates given other effects)

DEPEN. VARIABLE =DEFORESTATION 86-97	OLS	# obs= 4,229	Rsquared= 0.08
INDEP. VARIABLES	Coefficient	T-statistic	t-probability
Protection	**-0.020**	**-1.67**	**0.10**
Distance to San Jose	0.0006	1.2	0.22
(Distance to San Jose)^2	-6 e-6	-3.1	0.00
Distance to Nat'l Road	-0.002	-1.1	0.27
(Distance to Nat'l Road)^2	7 e-5	1.0	0.32
Distance to Local Road	-0.003	-1.4	0.17
(Distance to Local Road)^2	7 e-6	0.1	0.93
Distance to Wide River	-0.002	-0.7	0.51
(Distance to Wide River)^2	1 e-4	0.5	0.60
Distance to Clearing	-0.035	-5.5	0.00
(Distance to Clearing)^2	0.003	5.1	0.00
Rain	0.019	0.7	0.46
(Rain)^2	-0.003	-0.9	0.37
Elevation	-0.041	-1.8	0.08
(Elevation)^2	0.011	1.4	0.15
Slope	-0.003	-4.1	0.00
[region dummies]	[pretty	weak	overall]
constant	.14	2.6	0.01

4.1.2 Matching For Average Impact

Here we follow Andam et al. 2008 in suggesting that a regression such as in Table 2b faces a considerable challenge to control perfectly for protected lands being different from unprotected lands not only in protection status but also in key land characteristics.[10] Matching lowers the burden of stripping out the impacts of the

---

[10] More generally, this assertion underlies the matching literature: "Unless the regression equation holds in the region in which observations are lacking, covariance will not remove all the bias, and in practice may remove only a small part or it. Secondly, even if the regression is valid in the no man's land, the standard errors of the adjusted means become large, because the standard error formula in a covariance analysis takes account of the fact that extrapolation is being

land differences since it 'compares apples to apples', i.e. compares protected points with the subset of unprotected points with characteristics most similar to the protected points. We use propensity-score matching (Rosenbaum and Rubin 1983) based upon the regression shown in Table 3a.

Table 3a – Estimating 'Similarity' (probability of protection)
(all protected areas explained by observed land characteristics)

DEP. VARIABLE =PROTECTION	Probit	# obs= 4,229	McFadden Rsq = .38
INDEP. VARIABLES	Coefficient	T-statistic	T-probability
Distance to San Jose	-0.02	-6.7	0.00
(Distance to San Jose)^2	1 e-4	8.1	0.00
Distance to Nat'l Road	0.007	0.5	0.64
(Distance to Nat'l Road)^2	0.002	3.1	0.00
Distance to Local Road	0.15	8.9	0.00
(Distance to Local Road)^2	-0.005	-7.5	0.00
Distance to Wide River	0.08	3.9	0.00
(Distance to Wide River)^2	-0.005	-3.1	0.00
Distance to Clearing	0.40	10	0.00
(Distance to Clearing)^2	-0.03	-5.8	0.00
Rain	0.48	2.6	0.01
(Rain)^2	-0.05	-2.3	0.02
Elevation	-0.13	-0.9	0.39
(Elevation)^2	0.15	3.0	0.00
Slope	0.01	3.3	0.00
[region dummies]	[all < 0	versus	region 6]
constant	-2.2	-5.9	.00

Specifically, for each point in our sample we generate from the results in Table3a an estimate of the probability of being within a protected area. The probability index is a form of summary of similarity. As seen in the table, certain kinds of land characteristics make protection more likely. The predicted

employed. Consequently the adjusted differences may become insignificant merely because the adjusted comparisons are of low precision. When the groups differ widely in x, these differences imply that the interpretation of an adjusted analysis is speculative rather than soundly based." (Cochran, in Rubin 1984).

probability is a convenient single index that aggregates the implications of differences between points along a number of dimensions.

Table 3b shows that using a location's probability of being protected to define the 'similarity' between points actually does produce a subset of the unprotected areas which has average land characteristics more similar to the set of protected points. While average matched characteristics are not identical to treated characteristics, for every characteristic they are more similar than all unprotected to the protected points (and often much more).

Table 3b – More 'Similar' (per Table 3a) Points Are In Fact More Similar (comparing average land characteristics between protected and control groups)

CHARACTERISTICS	Protected Points	All Unprotected Points	Matched Unprotected Points
Deforestation	*0.0021*	*0.0960*	*0.0193*
Distance to San Jose	101	90	98
(Distance to San Jose)^2	12527	10374	11997
Distance to Nat'l Road	14.9	6.4	13.4
(Distance to Nat'l Road)^2	314	73	252
Distance to Local Road	10.6	4.6	9.9
(Distance to Local Road)^2	153	46	127
Distance to Wide River	3.9	3.2	4.0
(Distance to Wide River)^2	23	16	23
Distance to Clearing	3.2	0.7	2.8
(Distance to Clearing)^2	18	2	12
Rain	4.04	3.78	4.08
(Rain)^2	17.3	15.3	17.5
Elevation	1.3	0.6	1.4
(Elevation)^2	2.6	0.9	2.8
Slope	14.2	8.6	15.1

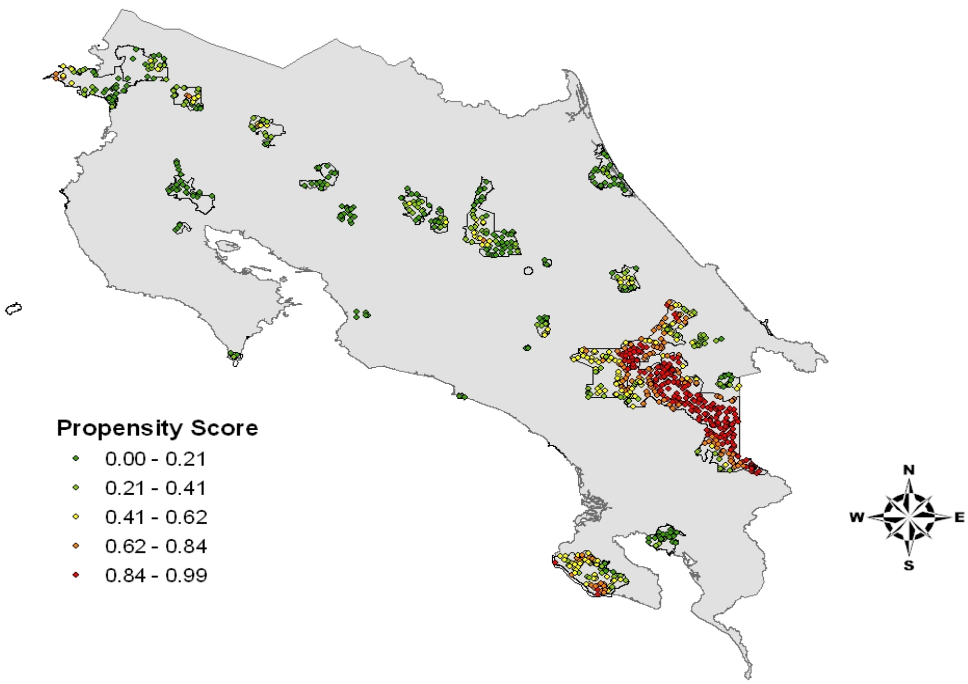
Given this sample of control or matched unprotected points, now we can compare the deforestation in the protected points to that in the matched unprotected points. Table 4 presents regression coefficients for Protection (suppressing results for other variables), i.e. our matching estimates of the average impact of protection. The first estimate, for the full set of protected and matched unprotected points, is lower than the result in Table 2b yet it confirms that the estimate of 9% greatly overstated an impact of more like 1-2%.

Table 4 – Protected Versus Matched Unprotected Points
(all protected areas lowering 1986-97 deforestation rates)

DEP. VARIABLE =DEFORESTATION	*OLS*		
1. FULL SAMPLE (obs=4,790)	coefficient	t-statistic	t-probability
Protection	**-0.013**	-2.0	0.05
2. DROP Pscore > 0.75 (obs=3,192)	coefficient	t-statistic	t-probability
Protection	**-0.026**	-4.1	0.00
3. DROP |Pdiff| > .01 (obs=4,245)	coefficient	t-statistic	t-probability
Protection	**-0.022**	-4.4	0.00

However, Figures 2 and 3 convey additional detail about the quality of the match. Table 3b demonstrates that matching greatly improves the similarity of the groups compared but that on many dimensions they are not identical. Figure 2 shows that it is the protected points which are very likely to be protected, e.g. have all of the qualities that tend to lead to protection, which are harder to match. They simply do not have perfect analogs in the set of unprotected points. Figure 3 shows those are focused in particular protected areas.

Figure 3 – Protected Areas Differ In Predicted Probability Of Protection



Note: estimated probabilities shown here are generated from analysis in Table 3a.

Table 4's second and third estimates are robustness checks based on these figures. The second one is the Protection coefficient from a regression like the first one but dropping the 321 protected points with probabilities of being protected above 0.75 (along with their matched controls so the number of observations drops more). The third one is the result from a regression like the first one but dropping the unprotected control points for which the difference in probability between the protected point and the matched unprotected point is above 0.01 (these points are easily seen in Figure 2, noting that 32 protected points are also dropped because all their matches were poor). These estimates are just above 2%[11], suggesting a robust conclusion that the average impact of parks is more like 2% than 9%.

[11] One might presume these are better estimates. However, the protected points dropped here are those with the worst characteristics for agriculture. For those, we estimate close to no impact of parks on forest. The lower rows of Table 4, then, use higher quality matches but for an unrepresentative subset of all the protected areas which, in particular, drops protected areas for which we would expect a lower estimate.

To this point, we are just confirming Andam et al. 2008's average-impact results for the time period 1986-1997, which we study here. Again, the corrected impact estimate is less than a third of the estimate from a simple comparison, not addressing differences in land. We also are communicating the matching approach that we'll use for all estimates below in making our core point that *the actual forest impacts of parks vary greatly over space*.

4.2 Protection's Impact Varies

Table 5 summarizes the results of six regressions in a manner similar to Table 4c, i.e. suppressing the table almost completely relative to Table 4a to focus on 'Protection'. These six are three pairings of high-versus-low pressure subsets for land characteristics and each result below is the result for 'Protection' using the matching estimation method. Recall from Tables 4 that 2% is our current best estimate of the average impact of parks.

Table 5 – Matching Impact Estimates Across Location Subsets
(subsets of protected areas lowering 1986-97 fraction deforested)

DEP. VARIABLE = DEFORESTATION	*LOWER PRESSURE*	*HIGHER PRESSURE*
DISTANCE TO SAN JOSE	*over 85 km*	*under 85 km*
Protection	**-0.001** (0.21)	**-0.042** (0.00)
DISTANCE TO NATIONAL ROADS	*over 7.53 km*	*under 7.53 km*
Protection	**-0.003** (0.76)	**-0.050** (0.00)
SLOPE	*over 7.12 degrees*	*under 7.12 degrees*
Protection	**-0.011** (0.47)	**-0.142** (0.00)

Note: as in Table 4 we present coefficients and t-probabilities, but formatted for easiest comparison of high and low pressure and again suppressing results for all of the non-park variables..

4.2.1 Capital City

A natural comparison involves proximity to the largest city and market in Costa Rica, the capital city San Jose. From prior research (see Pfaff and Robalino et al. 2007b, Geist and Lambin 2002 and others) and basic intuition, being closer to markets should raise the profit from clearing and increase the pressure for deforestation. Table 5 shows that the protected areas 'far' from San Jose (> 85km) have almost no impacts at all. In contrast, those 'close' to San Jose (<= 85km, that being the median distance) seem to have avoided over 4% deforestation during 1986-1997. This is clearly policy relevant, with one subset having double the average impact and the other essentially no impact.

4.2.2 National Roads

Access to and from a parcel of forested land is more generally considered to be a consistently important factor in deforestation (see, for instance, Pfaff 1999, Kaimowitz and Angelson 1998 and many others). Here Table 5 shows the results for the parks on either side of a threshold distance to the nearest national road. Much like parks far from San Jose (though the result is stronger), no impact is found for parks 'far' (> 7.53km) from a national road. In contrast, parks 'close' (<= 7.53km) to national roads avoided a rate of 5% deforestation within their boundaries during 1986-1997 by reducing clearing to zero.

4.2.3 Slope

Considering other factors expected to affect the underlying deforestation process and which might be correlated with non-random location of protected areas, without question slope matters for clearing. For instance, Robalino and Pfaff 2009 find slope's influence to be a dependable enough driver of individual deforestation decisions to use variation in slopes on neighboring lands as instruments for neighboring deforestation, in an effort to test for the impact of neighbors upon one's deforestation decision. In that and other analyses, clearing for agriculture is much less likely when slopes are high.

Table 5 strongly confirms this view. For land under less pressure of deforestation, i.e. 'high' slopes (here that means over 7.12 degrees), roughly a 1% impact is indicated by the 'Protection' coefficient but that is not statistically significantly different from zero. In contrast, on 'low' slopes (<= 7.12 degrees), the impact estimate is a considerable 14%. Summarizing Table 5's implications, targeting new parks clearly can affect park impact.

5. Discussion

In support of conservation planning, we considered whether observable characteristics of forested locations being considered for protection could predict the impact of protection. We found that they could. Avoided deforestation, during 1986 - 1997, was greater within the protected areas closer to the capital city, closer to a national road, and on flatter land. With data on ecoservices and land costs, this insight should help guide future investment.

The underlying point is that deforestation rates vary across the landscape due to a variety of factors. It is the deforestation rate that would have occurred without protection that indicates the impact of a protected area upon the deforestation rate. Thus for a well-protected area, avoided deforestation varies with the threat that was blocked. Put another way, a protected area could be fully forested but its impact could be nothing, should it be located upon lands so poor for agriculture they would not have been cleared in any case.

Along the way, we confirmed that the average impact of parks is much lower than typical estimates would suggest (a point Andam et al. 2008 made already for Costa Rica, which Joppa and Pfaff 2009a's review of the parks literature shows was missing before). Drawing on our main point above (i.e.,that park impact is higher on lands facing real threat), the reason other estimates overstate impact is that parks in Costa Rica are not located on average lands but instead are biased towards lands that face lower-than-average threats. Joppa and Pfaff 2009b show this is not special to Costa Rica but holds around the globe.

We do not comment here on why this bias exists. It could be a focus upon pristine land where favored species can still thrive. Alternatively, this bias could reflect land cost. Land that is better for agricultural production and thus also profits, e.g. land with lower slope and lower cost of transport to market, may have a higher land price. All else equal, for conservation a planner would like to acquire valued habitat at lower cost per hectare.

Our results, though, suggest that a focus on lower cost could yield lower benefit. In the extreme, very low cost land under no agricultural threat might have zero impact. Then, no matter how valued the species on that land, the park itself does not contribute.

Thus, our result does not change the fact that land cost matters, however it may indicate that holding eco-services constant in some cases one might prefer a higher-cost location when the gain in actual impact on deforestation outweighs the cost from the higher price.

Looking forward, the drivers of deforestation we highlight here will continue to be important for future protected area planning. However, land-use dynamics inevitably shift as time passes; e.g., given global marketplaces, external forces shift relevant prices. Put another way, land not currently under high threat could be highly pressured later on. Such evolution of driving forces without question makes any impact prediction uncertain. Nonetheless the core point of this paper will hold, i.e. planners should consider impacts. Even under uncertainty, simply adding "How is the deforestation threat currently distributed across space and is it evolving?" to conservation planners' core list of questions can help greatly not only for siting now but also in stimulating collection of relevant information.

References

Abadie, A. and G. W. Imbens (2006) "Large sample properties of matching estimators for average treatment effects", *Econometrica* 74 (1): 235-267

Andam, K.S., Ferraro, P.J., Pfaff, A., Sanchez-Azofiefa, A., and Robalino, J. (2008) "Measuring the Effectiveness of Protected Area Networks in Reducing Deforestation" *Proceedings of the National Academy of Sciences of the United States of America* 105 (42): 16089-16094.

Bruner, A.G., Gullison, R.E., Rice, R.E., da Fonseca, G.A.B. (2001) Effectiveness of parks in protecting tropical biodiversity. *Science* 291:125-128.

Busch, C.B., Sathaye, JA., and Sanchez-Azofeifa, GA., 2000, Estimating the Greenhouse Gas Benefits of Forestry Projects: A Costa Rican Case Study (LBNL-42289, Berkeley, CA).

Camm, J.D., Norman, S.K., Polasky, S., and Solow, A.R. 2002, Nature Reserve Selection to Maximize Expected Species Coverage, Operations Research 50(6), 946-955.

Chomitz, K., Brenes, E. and Constantino, L. 1998. "Financing Environmental Services: The Costa Rican Experience" 10, Central America Country Management Unit, Latin American and the Caribbean Region, The World Bank

Church, RL., Storms, DM., and Davis, FW., 1996. Reserve Selection as a Maximal Covering Location Problem, Biological Conservation 76, 105-112.

Cocks, K.D. and I.A Baird, 1989, Using Mathematical Programming to Address the Multiple Reserve Selection Problem: An Example from the Eyre Peninsula, South Australia, Biological Conservation 49, 113-130.

Csuti, B., Polasky, S., Williams, P.H., Pressey, R.L., Camm, J.D., Kershaw, M., Kiester, A.R., Downs, B., Hamilton, R., Huso, M. and Stahr, K., 1997, A Comparison of Reserve Selection Algorithms Using Data on Terrestrial Vertebrates in Oregon, Biological Conservation 80, 83-97.

Fearnside, P.M., Ferraz, J. 1995. A conservation GAP analysis of Brazil Amazonian vegetation. Conservation Biology 9:1134-1147.

Ferraro, P. 2001. "Global habitat protection: limitations of development interventions and a role for conservation performance payments" *Conservation Biology* 15(4):990-1000.

Garcia, R., 1997. Biologia de la conservacion y areas silvestres protegidas: situacion actual y perspectives en Costa Rica (Instituto Nacional de Biodiversidad (INBio) Press

Geist, H. J. and E. F. Lambin 2002. "Proximate Causes and Underlying Driving Forces of Tropical Deforestation." BioScience **52**(2): 143-150.

Gehlbach, F.R., 1975. Investigation, evaluation, and priority ranking of natural areas, Biological Conservation 8, 79-88.

Harrison, S., 1991. Population growth, land use and deforestation in Costa Rica, 1950-1984, Interciencia 16(2), 83-93.

Hill, J., Waldfogel, J., and Brooks-Gunn, J., 2003. "Sustained Effects of High Participation in an Early Intervention for Low-Birth-Weight Premature Infants" *Developmental Psychology*, 39(4): 730--44.

Hunter, M.L., and Yonzon, P., 1993. Altitudinal distributions of birds, mammals, peoples, forests, and parks in Nepal. *Conservation Biology* 7:420-423.

James, A., Gaston, K. and Balmford, A., 1999. "Balancing the earth's accounts". *Nature* 401: 323–324.

James, A., Gaston, K.J. and Balmford, A., 2001. "Can we afford to conserve biodiversity?" *BioScience* 51: 43–52.

Joppa, L., and Pfaff., A., 2009a. "Re-assessing the forest impact of protection: the challenge of non-random location and corrective methods". *Ecological Economics Reviews* (In Press).

Joppa, L.N. & Pfaff, A., 2009b. "High & Far: how the world's protected areas have avoided threat". Duke University Nicholas School of the Environment Working Paper.

Kaimowitz, D. and Angelsen, A., 1998. Economic Models of Tropical Deforestation: A Review. Bogor, Indonesia, CIFOR.

Kirkpatrick, J.B., 1983. An Iterative Method for Establishing Priorities for the Selection of Nature Reserves: An Example from Tasmania. *Biological Conservation* 25, 127-134.

Miranda, M., Porras, I. T. and Moreno, M. L., 2003. *The social impacts of payments for environmental services in Costa Rica: a quantitative field survey and analysis of the Virilla watershed*. London: IIED Environmental Economics Program.

Oldfield T.E.E., Smith, R., Harrop, S.R., and Leader-Williams, N., 2004. "A gap analysis of terrestrial protected areas in England and its implications for conservation policy". *Biological Conservation* 120:303-309.

Oliveira, P.J.C., Asner, G., Knapp, D., Almeyda, A., Galvan-Gildemeister, R., Keene, S., Raybin, R., and Smith, R. 2007. "Land-use allocation protects the Peruvian Amazon." *Science* 317:1233-1236.

Pagiola, S., 2002. "Paying for Water Services in Central America: learning from Costa Rica" in S. Pagiola, J. Bishop and N. Landell-Mills, eds., *Selling forest environmental services : market-based mechanisms for conservation and development*. London Sterling, VA: Earthscan

Pearce, D. 2005. "Paradoxes in Biodiversity Conservation". *World Economics* 6(3): 57-69

Pfaff A., 1999. "What Drives Deforestation in the Brazilian Amazon? Evidence from Satellite and Socioeconomic Data", J. of Environmental Economics and Management 37(1):26-43.

Pfaff, A. and Sánchez, G.A., 2004. "Deforestation pressure and biological reserve planning: a conceptual approach and an illustrative application for Costa Rica." *Resource and Energy Economics* 26 (2): 237-254

Pfaff, A., Robalino, J., and Sánchez, G.A. 2007a. "Evaluating the Impacts of Payments for Environmental Services". Presentation at NBER Summer Institute, July. (http://www.pubpol.duke.edu/research/papers/SAN08-05.pdf)

Pfaff, A., Robalino, J., Walker, R., Aldrich, S., Caldas, M., Reis, E., Perz, S., Bohrer, C. Arima, E., Laurance, W. and Kirby, K., 2007b. "Road investments, spatial spillovers, and deforestation in the Brazilian Amazon." Journal of Regional Science 47:109-123.

Polasky S., Camm, J.D., Solow, A.R., Csuti, B., White, D. and Ding, R. 2000. "Choosing reserve networks with incomplete species information". *Biological Conservation* 94, 1-10.

Polasky, S., Camm, J.D., and Garber-Yeats, B., 2001. Selecting Biological Reserves Cost-Effectively: An Application to Terrestrial Vertebrate Conservation in Oregon, Land Economics 77(1), 68-78.

Powell, G.V.N, Barborak, J., Rodriguez, S.M., 2000. "Assessing representativeness of protected natural areas in Costa Rica for conserving biodiversity: a preliminary GAP analysis". Biological Conservation 93:35-41.

Ramesh, B.R., Menon, S. and Bawa, K.S., 1997. "A vegetation based approach to biodiversity GAP analysis in the Agastyamalai region, Western Ghats, India". Ambio 26:529-536.

Robalino, J., 2007. "Land Conservation Policies and Income Distribution: who bears the burden of our environmental efforts?" *Environment and Development Economics* 12(4):521-533.

Robalino, J., and Pfaff, A. 2009 "Contagious Development: Neighbors' Interactions in Deforestation" mimeo CATIE

Robalino, J., A. Pfaff, A. Sanchez, F. Alpizar, C. Leon, and C.M. Rodriguez (2008). "Deforestation Impacts of Environmental Services Payments: Costa Rica's PSA Program 2000-2005". Presentation at BioEcon conference 10th, September. (http://www.rff.org/RFF/Documents/EfD-DP-08-24.pdf)

Rosenbaum, P. R. and Rubin, D. B., 1983. "The Central Role of the Propensity Score in Observational Studies for Causal Effects". *Biometrika* 70(1): 41-55

Rosero-Bixby, Luis, & Palloni, A., 1998. "Poblacion y deforestacion en Costa Rica, in: Conservacion del Bosque en Costa Rica." Academia Nacional de Ciencias, San Jose, Costa Rica 131-150.

Rubin, D. (1984). "William G. Cochran's Contributions to the Design, Analysis, and Evaluation of Observational Studies." in Rubin, D. (Ed.) *Matched Sampling for Causal Effects* 2006 Cambridge University Press 7-29

Sader, S. and Joyce, A., 1988. "Deforestation Rates and Trends in Costa Rica, 1940 to 1983." *Biotropica* 20, 11-19.

Saetersdal, M., J.M. Line and H.J.B. Birks, 1993, How to Maximize Biological Diversity in Nature Reserve Selection: vascular plants and breeding birds in deciduous woodlands, western Norway, Biological Conservation 66, 131-138.

Sanchez, G.A. (2000). Land use and cover change in Costa Rica. In: Hall, C. (Ed.), Quantifying Sustainable Development. Academic Press, New York, pp. 477–505.

Sanchez, G. A., Harriss, R.C., and Skole, D., 2001. "Deforestation in Costa Rica: a quantitative analysis using remote sensing imagery". *Biotropica* 33**:**378–384.

Sanchez, G. A., Rivard, B., Calvo, J. C., and Moorthy, I., 2002. "Dynamics of tropical deforestation around national parks: remote sensing of forest change on the Osa Peninsula of Costa Rica". *Mountain Research and Development* 22**:**352–358.

Sanchez, G. A. Daily, G. C., Pfaff, A. S. P. and Busch, C., 2003. Integrity and isolation of Costa Rica's national parks and biological reserves: examining the dynamics of land-cover change, *Biological Conservation* 109 (1): 123-135

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

Segnini, G., 2000, Gran deuda por conservacion, La Nacion, February 10th.

Sierra, R, and E. Russman (2006) "On the efficiency of the environmental service payments: A forest conservation assessment in the Osa Peninsula, Costa Rica" *Ecological Economics* 59: 131-141

Solorzano, R., de Camino, R., Woodward, R., Tosi, J., Watson, V., Vasquez, A., Villalobos, C., Jimenez, J., Repetto, R., & Cruz, W., 1991, Accounts Overdue (World Resources Institute, Washington, D.C.).

Stern, MS *et al.* (2001) Parks and factors in their success. *Science* 293:1045-1047.

Tubbs, C.R. and J.W. Blackwood, 1971, Ecological evaluation of land for planning purposes, Biological Conservation 3, 169-172.

Williams, G., 1980, An index for the ranking of wildfowl habitats, as applied to eleven sites in West Surrey, England, Biological Conservation 18, 93-99.