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Evidence from the Peruvian Amazon

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Abstract

Protected areas are a cornerstone of forest conservation in developing countries. Yet we know little about their effects on forest cover change or the socioeconomic status of local communities, and even less about the relationship between these effects. This paper assesses whether "win-win" scenarios are possible—that is, whether protected areas can both stem forest cover change and alleviate poverty. We examine protected areas in the Peruvian Amazon using high-resolution satellite images and household-level survey data for the early 2000s. To control for protected areas' nonrandom siting, we rely on quasi-experimental (matching) methods. We find that the average protected area reduces forest cover change. We do not find a robust negative effect on local communities. Protected areas that allow sustainable extractive activities are more effective in reducing forest cover change but less effective in delivering win-win outcomes.

Key Words: conservation, deforestation, protected areas, poverty, land use, land conservation

JEL Classification Numbers: Q56, Q23, Q24, R14, R52

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1. Introduction

Protected areas are a cornerstone of forest conservation policy in developing countries (UNEP 2010; Millennium Ecosystem Assessment 2005). Today, approximately 13 percent of the land area of developing countries is protected (IUCN and UNEP-WCMC 2011). Policymakers' chief aim in establishing protected areas is typically to conserve forests and the ecological benefits they provide, including carbon sequestration, biodiversity habitat, and hydrological services. The hope is that these goals can be achieved without imposing significant costs on local communities. However, the direction and magnitude of protected areas' effects both on local communities and on the environment are uncertain.

In theory, protected areas could impose economic costs on local communities by limiting their ability to use forests for agriculture, logging, and hunting. But they also could provide economic benefits by spurring tourism, attracting infrastructure investments, and ensuring the continued provision of valuable forest ecosystem services (Robalino 2007; Ferraro and Hanauer 2012; Ferraro 2008).[1]

In principle, protected areas stem forest clearing and degradation within their borders by restricting land-use change and extractive activities. Yet these restrictions may not be enforced

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[1] The Millennium Ecosystem Assessment divides the contribution of protected areas to poverty reduction in four categories: (a) provisioning services: provision of natural products such as food, fresh water, fuelwood, and herbal medicines that have direct use-value to rural communities; (b) regulating services: benefits from ecosystem services such as climate regulation, watershed protection, coastal protection, water purification, carbon sequestration, and pollination; (c) cultural services: benefits from religious values, tourism, education, and cultural heritage; and (d) supporting services: benefits from soil formation, nutrient cycling, and primary production (IUCN 2004).

because of insufficient human, financial, and political resources, uncertainty about land tenure, and conflicts with local communities (Balmford et al. 2003; Bruner et al. 2004; Naughton-Treves et al. 2005). When regulatory control is particularly weak, protected areas can even exacerbate forest cover change by creating de facto open-access regimes (Blackman et al. 2014a; Wittemyer et al. 2008; Liu et al. 2001).

Hence, empirical research is needed to measure the net effects of protected areas on both forest cover change and socioeconomic outcomes. Unfortunately, however, accurately measuring these effects is challenging because protected areas are not randomly located. Rather, policymakers tend to establish them in remote regions with relatively low deforestation pressure and high levels of poverty (Sachs et al. 2009; Andam et al. 2010; Ferraro et al. 2011). As a result, the most common strategy for measuring protected environmental and socioeconomic effects—simply comparing outcomes of interest (e.g., deforestation rates and poverty rates) inside protected area boundaries with outcomes outside—may generate biased results (Blackman 2013; Joppa and Pfaff 2010). Such analyses tend to conflate the environmental and socioeconomic effects of restrictions on land-use change and extractive activity with the effects of the preexisting characteristics of the land on which they are established.

Recently, scholars have begun to use quasi-experimental program evaluation techniques, such as matching and instrumental variables, to control for protected areas' nonrandom siting, along with remote sensing data to measure forest cover change (Blackman 2013). The thin but quickly growing body of evidence using such approaches suggests that on average, even after controlling for nonrandom siting, protected areas are in fact effective in reducing deforestation, although substantially less effective than indicated by a simple inside-outside comparison. For example, using a global sample, Joppa and Pfaff (2010) find that protected areas stem deforestation in three quarters of the 147 countries in their sample, but typically by less than half the amount that an inside-outside comparison would suggest. Nelson and Chomitz (2011) find that in Latin America and the Caribbean as a whole, strictly protected areas that prohibit all extractive activity reduce fire incidence (a proxy for tropical deforestation) by 3 to 4 percentage points, multiuse protection reduces it by 5 to 6 percentage points, and protected areas in indigenous areas reduce it by 16 to 17 percentage points. Andam et al. (2008) find that protected areas in Costa Rica reduce deforestation by 10 percentage points. And in northern Thailand, Sims (2010) finds that protected areas cut deforestation by 7 to 19 percentage points.

An emerging literature also examines protected areas' effects on local communities, controlling for their preexisting characteristics. Andam et al. (2010) find that protected areas reduce poverty by 1.3 percentage points in Costa Rica and by 7.9 percentage points in Thailand. Robalino and Villalobos (2010) find that nonagricultural wages earned close to parks in Costa

Rica are higher only for people living near tourist entrances. Canavire and Hanauer (2013) find mixed results for Bolivia, depending on the socioeconomic indicator. And Robalino et al. (2012) find that protected areas in Mexico lead to higher levels of economic marginality in both the short and the long run.[2]

In this paper we assess the environmental and socioeconomic effects of protected areas in the Peruvian Amazon. We use high-resolution 2000–2005 remote sensing data to measure forest cover change, including both deforestation and forest degradation, and contemporaneous household survey data to measure socioeconomic outcomes. We use quasi-experimental (matching) techniques to control for protected areas' nonrandom siting. For Peru, considered a megadiverse country because of its species richness, accurately measuring protected areas' environmental and socioeconomic effects is particularly important: half the population lives in poverty, and protected areas account for 27 percent of the total land surface in the Amazon region.[3]

Our study makes several contributions. To our knowledge, it provides the first rigorous evidence—obtained by controlling for protected areas' nonrandom siting—for the Amazon on the effects of protected areas on both forest cover change and local communities.[4] We bring to bear particularly rich data. We compare the effectiveness for both outcomes within the same time frame, thus minimizing potential for bias due to mismatched temporal data. We use detailed household-level data as measured by the Peruvian government, comparing expenditures with a predefined poverty line (rather than a proxy poverty index). Finally, our remote sensing data capture forest degradation, which is the dominant type of forest cover change in the Peruvian Amazon, as well as deforestation.

As discussed below, we use Mahalanobis matching to control for nonrandom siting. In assessing the effects of protected areas on forest cover change, we compare outcomes on plots of land inside protected areas with observationally similar matched plots outside. To measure

[2] Andam et al. (2010) and Canavire and Hanauer (2013) use a poverty index that includes variables at the individual level (adult men, average age of education, average members per bedroom) and variables at the household level (dwelling without bathroom, dwelling using fuelwood for cooking, dwelling with dirt floors, dwelling without electricity, and dwelling without water access). Robalino and Villalobos (2010) evaluate the effects on local wages, and Sims (2010) focuses on poverty headcount ratios.

[3] Indigenous territories and reserves for tribes in isolation account for an additional 15 percent of the Amazon land area (14 percent and 1 percent, respectively). See Oliveira et al. (2007) for further details.

[4] Blackman et al. (2012) examines the effect on 2000-2005 forest cover change of the titling of native communities in the Peruvian Amazon.

socioeconomic effects, we compare outcomes in households located just outside protected areas (few people live inside) with observationally similar households not adjacent to protected areas.[5] We find that the establishment of protected areas reduces deforestation and disturbance. We do not find a robust negative effect on local communities. Older protected areas, which allow sustainable extractive activities, are more effective in reducing forest cover change but less effective in delivering win-win outcomes.

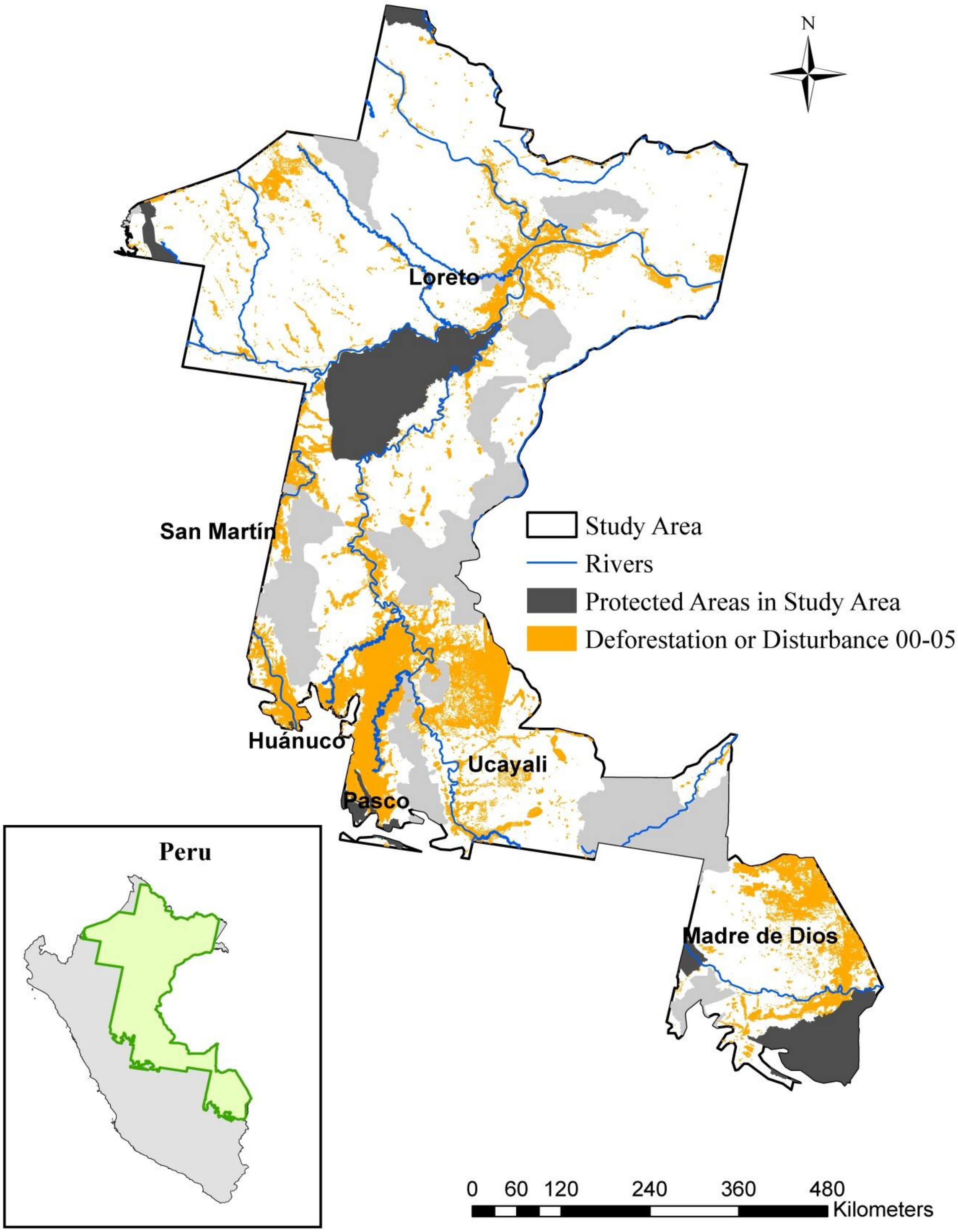
The remainder of the paper is organized as follows. The next section provides background information on the Peruvian Amazon, its protected areas, and local socioeconomic characteristics. Section 3 describes the method of analysis, and Section 4, the data. Section 5 discusses our main results. The last section presents the conclusions and their policy implications.

2. Background

Peru, which is host to 84 of the planet's 117 life zones, is one of the world's 17 megadiverse countries. Comprising 66 million hectares, the Peruvian Amazon accounts for 60 percent of Peru's land mass and 90 percent of its forests (Galarza and La Serna 2005). It represents the second-largest forest in South America, after Brazil. Figure 1 shows the study area, which represents nearly 80 percent of the Peruvian Amazon.

[5] The number of households inside protected areas is very limited (only 54 households across six years); thus we do not include this category in the analysis.

Figure 1. Study Area



2.1. Forest Cover Change

Forest cover change in the Peruvian Amazon is a serious concern. Using the same 2000–2006 remote sensing data that we employ, Oliveira et al. (2007) estimate 63,200 hectares of forest disturbance and 64,500 hectares of deforestation per year, highly concentrated in the regions of Ucayali and Madre de Dios. Agriculture and illegal logging, much of it conducted by migrants from the western regions, are often blamed for this forest damage (Alvarez and Naughton-Treves 2003; Galarza and La Serna 2005). Sears and Pinedo-Vasquez (2011) describe at length the organization of legal and illegal logging in the Peruvian Amazon, enabled by the emphasis of forest authorities and national police on monitoring the movement of logs rather than the process of extraction. A lack of state funds prevents forest authorities from improving their monitoring capability (Rios-Trigoso 2003; World Bank 2006). Illegal and artisanal mining are considered other important causes of deforestation, especially in Madre de Dios (Swenson et al. 2011).

2.2. Protected Areas

Protected areas are the main instruments for biodiversity conservation in Peru. The legal definition of a natural protected area in Peruvian legislation echoes the International Union for Conservation of Nature (IUCN) 1994 definition and emphasizes biological diversity conservation (Solano 2010).

As of 2012, Peru had 111 national protected areas and 70 regional or private protected areas. National protected areas are established in perpetuity and cannot be transferred to private agents. Private protected areas can be formally recognized by the government on a voluntary basis, on the owners' application.[6] Protected areas, both national and private, account for approximately 17 percent of total land surface. Seven percent of the total protected area land is classified as "strictly protected" (e.g., national parks, national sanctuaries, and historical sanctuaries); the remaining 93 percent is "nonstrictly protected" and found in community-based reserves, native communities, and other classifications that permit sustainable use of natural resources.

Peru's first protected area was created in 1961. However, the Natural Protected Area Act (Law Nº 26834) was enacted only in 1997 and did not become effective until 2001 (Supreme

[6] According to Solano (2010), legally speaking, the national protected areas system includes only national-level protected areas; regional and private protected areas are referred to as complementary. However, functionally and politically, all levels are seen as part of the system.

Decree Nº 038-2001-AG). The act defines the different types of protection, their characteristics, and the institutional structure to manage, control, and regulate the protected areas.

Until 2008, the Ministry of Agriculture managed the protected areas system through various government branches and at different administrative levels. In 2008, its responsibilities were transferred to the newly created National Service for Natural Protected Areas (Sistema Nacional de Áreas Naturales Protegidas, SINANPE), a specialized technical agency of the newly created Ministry of the Environment (Solano 2010).

Our study area includes 29 national and regional protected areas, shown in Figure 1. Areas with dark shading are included in the statistical analysis; the others are excluded.[7]

2.3. Socioeconomic Conditions

Peru's rapid and sustained economic growth has substantially reduced poverty, particularly since 2000. The percentage of inhabitants living in poverty fell from 55 to 45 percent over our study period, 2001 to 2006 (and continued falling, to 31 percent in 2010).[8] Peruvians living in extreme poverty—those unable to purchase the most basic basket of necessities—fell from 24 to 16 percent over the study period (and to 10 percent in 2010).[9] However, economic prosperity has not reached the people living in the Amazon. The percentage of this area's population living in poverty exceeded 50 percent during our study period. Furthermore, the disparity between rural and urban populations remains unchanged: the percentage of poor people in rural areas is double that in urban areas, and the percentage of extremely poor people is five times greater.

Poverty indicators are highly correlated with access to infrastructure. For instance, 95 percent of people in the Peruvian Amazon have no electricity. Further, more than 70 percent of the people living in the rural Amazon cannot meet one or more basic needs, as defined by the Peruvian government, such as access to clean water, quality of housing, lack of crowding, education of head of household, or access to schooling (INEI 2011).

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[7] Appendix 1 shows the year of establishment of the protected areas. This variable allows us to identify the protected areas that are considered treated (dark shading in Figure 1) during our period of study. Light gray areas in Figure 1 are protected areas excluded from the analysis. See section 4.2 for more detail.

[8] The poverty rate is estimated using the cost of basic needs method, which includes (i) a specified bundle of foods typically consumed by the poor, at local prices, and (ii) consumption of nonfood goods.

[9] The extreme poverty rate is estimated using only the bundle of foods typically consumed by the poor, at local prices. Consumption of nonfood goods is excluded.

Departments in the northern Amazon (Amazonas, Loreto, San Martin, Ucayali) are especially poor. They also are home to a large number of protected areas. Madre de Dios department, in the southern Amazon, had the lowest poverty rate—about half of that for the Amazon as a whole during our study period.

3. Methods

As discussed above, we use matching methods to control for protected areas' nonrandom siting. The aim is to simulate an experimental design in which, conditional on the covariates, the only systematic difference between treated (protected) and untreated (unprotected) areas is exposure to the treatment (Blundell and Costa-Dias 2009). Matching enables us to construct a counterfactual for the treated units—that is, an estimate of what outcomes would have been on these units absent protection. The counterfactual is the outcome on "matched" control units that are observationally similar to treated units—specifically, similar in terms of confounding variables that affect both selection into the treatment (i.e., policymakers' choices about which land units to target for conservation) and the outcome. A variety of techniques can be used to match treated and control units. We use Mahalanobis covariate matching because it generates the best covariate balance statistics.

3.1. Naïve Estimator

A naïve estimator of the average treatment effect on the treated (ATT)—which in our case corresponds to the simple inside-outside comparison discussed in the introduction—is the difference in average outcomes for the treated units (Y_T) and (unmatched) control units (Y_C).

$$ATT_{Naive} = \overline{Y_T} - \overline{Y_C} \quad [1]$$

3.2. Mahalanobis Covariate Matching

With matched control units, which represent a subset (S) of the total pool of potential controls, the ATT becomes

$$ATT_{Match} = \overline{Y_T} - \overline{Y_{S \in C}} \quad [2]$$

This ATT is unbiased, given two important assumptions. The first (commonly referred to as ignorability or conditional independence) is that potential outcomes are independent of treatment assignment conditional on covariates. The second (called common support) is that the distributions of the treated and untreated groups overlap (Blundell and Costa-Dias 2009; Imbens and Wooldridge 2009).

We use the Mahalanobis metric—a measure of distance in n-dimensional covariate space—to match control observations to treated observations (Rubin 1984). Our primary specification uses the single nearest neighbor to each treated unit to act as the counterfactual.

To ensure robustness, we use postmatching regression bias adjustment, where the average effect is adjusted for any imbalance on covariates (X). Also, we estimate Abadie and Imbens (2006) heteroskedasticity robust standard errors that account for our use of a fixed number of matches. Formally, ATT is now given by

$$ATT_{PostMatch} = \widetilde{Y_T} - \widetilde{Y_{S \in C}} \quad [3]$$

where

$$\widetilde{Y_T} = \overline{Y_T} - \beta(X_i - X_j) \text{ and } \widetilde{Y_{S \in C}} = \overline{Y_{S \in C}} - \gamma(X_i - X_j).$$

This equation implies that the matched outcome is adjusted by the difference in covariates relative to the matched observation. The postmatching regression adjustment should be small in large samples, and it is robust against misspecification of the regression function (Abadie and Imbens 2011; Imbens and Wooldridge 2009).

4. Data

4.1. Unit of Analysis and Sample

The units of analysis for examining the effect of protected areas on the two outcomes of interest, forest cover change and socioeconomic outcomes, are different. For the analysis of forest cover change it is a $30m^2$ "plot" of land. The size is the resolution of the data used to create our forest cover change dependent variable (discussed below). Creating the plot-level data set used in the forest cover change analysis involved three steps. First, we compiled and then geo-referenced geographic information system GIS data on (forest cover) outcomes, treatments (protected areas), and control variables, including climatological, geophysical, socioeconomic, and institutional land characteristics (Table 1). Second, from the billions of $30m^2$ plots in our study area, we selected a sample to be used in the empirical analysis. We performed this step by overlaying a 1-km rectangular grid on the study area (i.e., a grid with lines spaced 1 km apart) and selecting plots where grid lines crossed. Finally, for each of the resulting 337,382 plots, we created a plot-level relational database comprising information from all the layers of the GIS.

The unit of analysis for examining the effect of protected areas on socioeconomic outcomes is the household. The minimum spatial level of analysis for which geo-locator information is available is at the community (i.e., *centro poblado*). Therefore, we built the socioeconomic data set by coding household surveys at the community level and inputting geographic locations, using the information collected during the 2007 Peruvian census. Creating the household-level data set entailed compiling and then geo-referencing GIS data on (socioeconomic) outcomes, treatments (protected areas) and control variables, including climatological, geophysical, socioeconomic, and institutional land characteristics (Table 1). For each of the approximately 42,000 households, we created a household-level relational database comprising information from all the layers of the GIS.

4.2. Treated and Control Units

The definitions of treated and control units for examining the effect of protected areas on the two outcomes are also different. For our analysis of forest cover change, plots are treated if they are located inside the boundaries of a protected area established before 2000. We identified these plots using a map from the National Service for Protected Areas (Servicio Nacional de Áreas Naturales Protegida, SERNANP). Plots outside protected areas and outside areas affected by other natural resource polities (forest concession, mining concession, and native communities) are potential control units.

Only protected areas established before 2000, the first year of our study period, are included in the analysis. This criterion ensures that all treated plots were protected during the entire study period, not just part of it. Of the 29 protected areas in our study area, 10 satisfy this condition, all of them national protected areas (Appendix 1).[10]

For our analysis of socioeconomic outcomes, households located just outside protected areas established before 2000 are considered treated (few people live inside protected areas). We define two distance bands: households within 5 km from the protected area's border, and households within 10 km. Households outside these buffer zones, outside all protected areas, and

[10] The regional and private concession areas are not considered treated because most were established in 2010. Thus, we cannot establish their causal effect.

outside areas affected by other natural resource polities (forest concession, mining concession, and native communities) are potential control units.

Table 1. Variables in Peru Data

Variable	Units	Source	Scale	Years
Outcomes				
Deforestation	0/1	CIW	30 m^2	2000–2005
Disturbance	0/1	CIW	30m^2	2000–2005
Average income (per capita)	Soles	INEI	Household	2001–2006
Average expenditure (per capita)	Soles	INEI	Household	2001–2006
Poverty rate	%	INEI	Household	2001–2006
Extreme poverty rate	%	INEI	Household	2001–2006
Treatments				
Protected areas	0/1	SERNANP	1:1,000,000	2012
Controls				
Geophysical and climatological				
Elevation	Meters	SRTM	90m	2006
Slope	Degrees	SRTM	90m	2006
Aspect (=1 if north, northwest, or northeast)	0/1	SRTM	90m	2006
Average precipitation	Mm	WorldClim	30s	1950–2000
Average maximum temperature	C	WorldClim	30s	1950–2000
Average mean temperature	C	WorldClim	30s	1950–2000
Distance to nearest population center > 10k	km	INEI-MTC	n.a.	2007
Distance to nearest population center	km	INEI-MTC	n.a.	2007
Proportion land suitable for forestry	Proportion	INRENA	1:1,000,000	2000
Socioeconomic				
Water source in house	%	INEI	District	1993
Electric lighting	%	INEI	District	1993
Literacy	%	INEI	District	1993
Primary school education	%	INEI	District	1993
Employment in agriculture or forestry	%	INEI	District	1993

CIW = Carnegie Institution of Washington, Stanford University;
INEI = Instituto Nacional de Estadística e Informática;
INRENA = Instituto Nacional de Recursos Naturales;
MTC = Ministerio de Transportes y Communicaciones;
SERNANP = Servicio Nacional de Areas Naturales Protegidas por el Estado;
SRTM = Shuttle Radar Topography Mission. The 2006 digital elevation model data are available at http://strm.usgs.gov and described in Far et al. (2007);
WorldClim refers to 1950–2000 global climate data, available at www.worldclim.org and described in Hijmans et al. (2005);
n.a. = metadata not available.

4.3. Outcome Variables

Generated from LANDSAT images, our forest cover change data have a resolution of $30m^2$ and cover 79 percent of the Peruvian Amazon from 2000 to 2005. They include estimates of both annual deforestation and forest disturbance (see Oliveira et al. 2007 for a detailed description).[11] We use three forest cover change outcome variables. All are dummies. The first indicates whether a plot was deforested in any year between 2001 and 2005, the second whether it was disturbed during this period, and the last whether it was deforested or disturbed (Table 1, above).

Our socioeconomic data come from the Peruvian National Household Survey, which provides information on household characteristics and expenditure from 2001 to 2006 for all private households and their occupants living in urban and rural areas in all 25 departments of Peru.[12] Our indicators are per capita income and expenditure, poverty rate, and extreme poverty rate. To estimate poverty, expenditures are compared with a predefined (monetary) poverty line. The poverty line definition includes food and nonfood consumption; that for the extreme poverty line includes only food consumption. Because we pooled the 2001–2006 data set, monetary values were deflated temporally and geographically to 2006 prices in metropolitan Lima to make all values comparable (Table 1, above).

4.4. Covariates

Covariates were selected to help isolate the causal effect of protected areas on forest cover change and poverty. We control for elevation, slope, precipitation, temperature, aspect, distances to population centers, land suitability, and socioeconomic conditions. Low elevation and low slope tend to be more suitable for agriculture activities, and thus protected areas tend to be located on land that is relatively steep at high elevation (Blackman et al. 2014a; Canavire and Hanauer 2013; Andam et al. 2010; Sims 2010). Further, we control specifically for forestland suitability because protected areas are more likely to be placed in forested lands in the Amazon. Since protected areas tend to be located far from cities (Canavire and Hanauer 2013; Andam et al. 2010; Sims 2010), we also control for Euclidian (linear) distance to major cities and to cities

[11] Oliveira et al. (2007, p. 1233) measure disturbance based on timber extraction: "We adapted a satellite-based forest disturbance detection system, originally designed for industrial-grade timber extraction monitoring in Brazil, to Peru's generally smaller-scale forest disturbance regimes."

[12] The 2000 household survey was excluded from the analysis because it is not strictly comparable to the 2001–2006 household surveys. The sample in 2000 was derived from the 1993 census; the other samples were derived from the 1999 pre-census.

with more than 10,000 people. Being closer to markets could raise profit margins from clearing and hence increase pressure for deforestation (Pfaff et al. 2009).

Finally, we control for an extended set of district-level socioeconomic variables[13] (i.e., percentage of houses with access to water, percentage of houses with access to electricity, percentage of houses with at least one member with primary education, literacy rate, and percentage of houses with employment in the agricultural and forestry sector) and geophysical variables (i.e., temperature and aspect).

4.5. Summary Statistics

Table 2 reports summary statistics for the plot-level variables used in our analysis of forest cover change. First, note that rates of deforestation and disturbance both inside and outside protected areas are quite low, ranging from 0 percent (deforestation inside protected areas) to just 2 percent (deforestation outside). As expected, the rates of deforestation, disturbance, and deforestation plus disturbance inside protected areas are lower than outside (0.0 vs. 1.2 percent, 0.1 vs. 0.8 percent, and 0.1 vs. 2.0 percent, respectively). The difference between rates inside and outside protected areas is the naïve estimator discussed in Section 3 (equation 1). This estimator, which is statistically significant at the 1 percent level, indicates that protected areas reduce deforestation by 1.1 percentage points, disturbance by 0.8 percentage points, and deforestation plus disturbance by 1.8 percentage points.

Turning to the covariates, we see that plots located inside protected areas tend to have higher elevation and slope. We also find small but statistically significant differences in precipitation, temperature, distances to population centers, and land suitability. The statistical significance of these differences, however, stems largely from our large sample size.

Tables 3 and 4 display summary statistics for socioeconomic variables (i.e., expenditure, income, and poverty rates) and covariates of interest by treatment and control group, according to their location: households within a 5-km buffer (Table 3) and households within a 10-km buffer (Table 4) from the protected areas. The number of households within 5 km is 674, increasing to 910 households within 10 km.

[13] Drawn from the 1993 national census.

Table 2. Summary Statistics for Forest Cover Change Analysis (at plot level)

Variable	Inside national protected areas (n = 97,596)		Outside national protected areas (n = 239,786)		Mean difference[2/]	
	Mean	Std. dev.	Mean	Std. dev.		
Outcome						
Deforestation rate (0/1)	0.000	0.018	0.012	0.108	–0.011	***
Disturbance rate (0/1)	0.001	0.030	0.008	0.092	–0.008	***
Deforestation plus disturbance rate (0/1)	0.001	0.035	0.020	0.139	–0.018	***
Geophysical and climatological						
Elevation (meters)	417.86	378.77	248.20	297.09	169.66	***
Slope (degrees)	5.69	7.18	2.94	4.70	2.75	***
Average precipitation (mm) (1950–2000)	191.42	41.94	207.88	45.52	–16.46	***
Average maximum temperature (C) (1950–2000)	30.74	1.31	30.93	1.18	–0.20	***
Average mean temperature (C) (1950–2000)	25.13	1.62	25.69	1.37	–0.56	***
Aspect (=1 if north, northwest, or northeast)	0.27	0.44	0.27	0.44	0.00	
Distance to nearest population center > 10k (km)	138,986	93,880	141,435	91,857	–2,449	***
Distance to nearest population center (km)	147.65	65.95	152.60	55.40	–4.95	***
Proportion land suitable for forestry	0.50	0.31	0.62	0.25	–0.13	***
Socioeconomic (district-level)[1/]						
Water source in house (%)	6.61	10.47	4.58	9.81	2.02	***
Electric lighting (%)	24.82	17.30	24.60	16.05	0.23	***
Literacy (%)	78.52	6.88	74.95	9.24	3.57	***
Primary school education (%)	67.56	10.03	68.49	8.69	–0.93	***
Employment in agriculture or forestry (%)	63.48	21.42	68.05	16.59	–4.56	***

[1/] Socioeconomic variables are at the district level (drawn from the 1993 national census).
[2/] T-test. *** p<0.01, ** p<0.05, * p<0.1.

The mean values for the variables of interest, income and poverty, are practically the same for both buffer zones, indicating that households living close to protected areas (treated) are not very different from those living farther away (the pool of potential control households). Average monthly per capita income of households inside the 5-km and 10-km buffers is S/. 254 Peruvian soles (roughly US$ 75), versus S/. 265 Peruvian soles (equivalent to US$ 78) for households not adjacent to protected areas. These differences are not statistically significant. Even though average income does not vary by much, treated households tend to have a lower poverty rate (54 vs. 64 percent) and also a lower extreme poverty rate (25 vs. 29 percent).

With regard to the covariates, we see that households within the 5-km and 10-km buffers tend to be located in zones with lower slope and considerably lower elevation. Also, these households tend to live in warmer and rainier areas and closer to population centers (not greater than 10,000 people). Differences in socioeconomic indicators are marginal, however, because of our large sample size.

Table 3. Summary Statistics for Socioeconomic Analysis (at Household Level), 5-km Buffer Definition

Variable	Inside 5-km buffer around protected areas (n = 674)		Outside 5-km buffer around protected areas (n = 39,546/41,351)		Mean difference[3/]	
	Mean	Std. dev.	Mean	Std. dev.		
Outcome[1/]						
Average income (per capita)	254.09	317.70	265.71	358.92	–104.83	
Average expenditure (per capita)	230.93	193.38	234.13	201.33	29.60	
Poverty rate	0.54	0.50	0.63	0.48	0.06	***
Extreme poverty rate	0.27	0.44	0.29	0.45	–0.18	
Geophysical and climatological						
Elevation (meters)	442.94	439.50	1,838.44	1,515.98	–1,073.03	***
Slope (degrees)	6.98	8.99	9.64	9.51	–2.53	***
Average precipitation (mm) (1950–2000)	209.32	49.74	68.33	62.68	146.64	***
Average maximum temperature (C) (1950–2000)	305.34	15.63	236.14	55.88	249.46	***
Average mean temperature (C) (1950–2000)	249.04	20.88	170.68	64.65	184.39	***
Aspect (=1 if north, northwest, or northeast)	0.34	0.47	0.36	0.48	–0.15	
Distance to nearest population center > 10k (km)	44,782	41,257	29,855	30,445	14,337	***
Distance to nearest population center (km)	50.63	282.94	60.85	417.74	–367.11	
Proportion land suitable for forestry (%)	0.48	0.50	0.12	0.33	0.15	***
Socioeconomic (district-level)[2/]						
Water source in house (%)	13.68	11.85	23.13	22.80	–9.11	***
Electric lighting (%)	28.91	23.18	31.08	29.08	–0.17	*
Literacy (%)	79.78	7.46	77.38	11.96	67.82	***
Primary school education (%)	63.13	10.71	63.00	14.53	48.60	
Employment in agriculture or forestry (%)	58.70	22.91	61.93	28.07	30.63	***

[1/] Expenditure variables are in Peruvian soles. The average exchange rate from 2001 to 2006 was S/. 3.4 per US dollar.
[2/] Socioeconomic variables are at the district level (drawn from the 1993 national census).
[3/] T-test. *** p<0.01, ** p<0.05, * p<0.1.

Table 4. Summary Statistics for Socioeconomic Analysis (at Household Level), 10-km Buffer Definition

Variable	Inside 10-km buffer around protected areas (n = 910)		Outside 10-km buffer around protected areas (n = 36,624/36,959)		Mean difference[3/]	
	Mean	Std. dev.	Mean	Std. dev.		
Outcome[1/]						
Average income (per capita)	253.75	294.61	262.42	354.55	–100.80	
Average expenditure (per capita)	230.83	182.03	231.36	199.03	31.80	
Poverty rate	0.55	0.50	0.64	0.48	0.07	***
Extreme poverty rate	0.25	0.43	0.29	0.46	–0.21	***
Geophysical and climatological						
Elevation (meters)	515.37	533.77	1,893.14	1,511.07	–995.70	***
Slope (degrees)	7.33	8.63	10.03	9.63	–2.31	***
Average precipitation (mm) (1950–2000)	203.35	49.60	66.95	60.22	143.14	***
Average maximum temperature (C) (1950–2000)	302.72	18.40	234.67	55.99	246.73	***
Average mean temperature (C) (1950–2000)	245.72	24.10	168.50	64.62	181.10	***
Aspect (=1 if north, northwest, or northeast)	0.34	0.47	0.37	0.48	–0.14	*
Distance to nearest population center > 10k (km)	45,432	40,443	30,495	30,320	15,112	***
Distance to nearest population center (km)	59.09	403.41	62.32	428.64	–369.55	
Proportion land suitable for forestry (%)	0.49	0.50	0.11	0.32	0.17	***
Socioeconomic (district-level)[2/]						
Water source in house (%)	13.12	11.70	22.74	22.67	–9.54	***
Electric lighting (%)	29.32	21.82	30.32	28.93	0.40	
Literacy (%)	80.33	6.85	77.03	12.02	68.30	***
Primary school education (%)	62.58	10.62	63.41	14.42	48.16	*
Employment in agriculture or forestry (%)	59.04	21.39	62.79	27.58	31.46	***

[1/] Expenditure variables are in Peruvian soles. The average exchange rate from 2001 to 2006 was S/. 3.4 per dollar.
[2/] Socioeconomic variables are at the district level (drawn from the 1993 national census).
[3/] T-test. *** p<0.01, ** p<0.05, * p<0.1.

5. Results

For our estimates to be interpreted as causal, the only observable difference between the treated units and the controls should be the conservation policy assignment. For each covariate, then, we use three statistics to evaluate the extent to which that is true: (a) the difference in means; (b) the standardized mean difference (the difference in means for treated and control units divided by the pooled standard deviation); and (c) the variance ratio between treated and control units, which should be equal to one if there is perfect balance (Sekhon 2011). Although no clear threshold for acceptable standardized mean difference exists, Rosenbaum and Rubin (1985) suggest that a standardized difference greater than 20 (of 100) should be considered large.

5.1. Effects on Forest Cover Change

Balance statistics for deforestation and disturbance after matching are encouraging (Appendix 2). Matching reduces the standardized mean difference to less than 5 units (of 100) for all covariates used in the analysis. The average standardized difference before matching is 13 units; after matching it is 0.43 units. Matching also greatly improves the variance ratio. After matching, 9 of 15 covariates deviate from 1 by just 0.02 units. Thus, overall, the balance statistics indicate that we can interpret our estimated treatment effects as causal.

Table 5 presents ATT estimates for deforestation, disturbance, and deforestation plus disturbance for both our estimators: matching without bias adjustment, and matching with bias adjustment. The magnitude of the ATTs does not vary much across the two estimators. However, levels of significance occasionally differ. We focus the discussion on the estimator with bias adjustment, since it is more conservative.

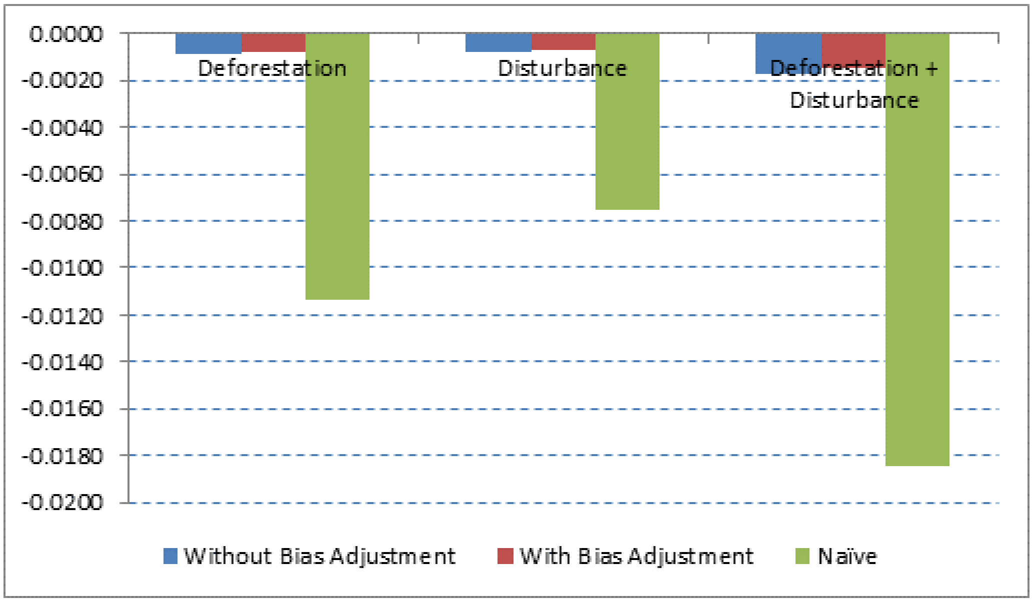
Table 5. Forest Cover Change: Average Treatment Effect on Treated

	Deforestation	Disturbance	Deforestation + disturbance
		Without bias adjustment	
Estimate	–0.0009 ***	–0.0008 ***	–0.0017 ***
Standard error	0.0002	0.0002	0.0003
T-stat	–4.1240	–3.3584	–5.2596
		With bias adjustment	
Estimate	–0.0008 **	–0.0007	–0.0015 **
Standard error[1/]	0.0003	0.0006	0.0007
T-stat	–2.4297	–1.1667	–2.1650

[1/] Abadie-Imbens (2006) standard errors.
***, **, and * indicate significance at the 0.01, 0.05, and 0.1 levels, respectively.

Our results suggest that protected areas reduce deforestation plus disturbance by 0.15 percentage points over a six-year period, or by 0.03 percent per year. Deforestation alone falls by 0.08 percentage points, or 0.01 percentage points per year. Results for disturbance are not statistically significant. These estimates are much smaller than the naïve estimators. The naïve deforestation estimate is 1.1 percentage points and the disturbance naïve estimate, 0.8 percentage points (Table 2 and Figure 2). In both cases the naïve estimates overstate the effectiveness of protected areas on deforestation and disturbance by an order of magnitude of 10.

Figure 2. Forest Cover Change: Naïve Effects and ATT



The estimated effect of protected areas is economically meaningful. If the average deforestation rate in the unprotected portions of the study area is a good representation of Peruvian deforestation rate (about 0.19 percent), then we can say that protected areas has reduced deforestation by 8 percent within the six-year period (≈0.15/0.19).

To assess whether the effect of protected areas on forest cover change is mediated by the protected area's characteristics—that is, to test for heterogeneous treatment effects—we categorize our sample of protected areas by vintage (established before vs. after 1990) and by type of protection (strictly protected areas, such as national parks, vs. nonstrictly protected areas, such as reserved area and protected forests).

We use a 1990 cutoff because in Peru that year, major fiscal, monetary, industrial, and social policies were implemented to reduce hyperinflation, budget deficits, and poverty and to increase productivity and economic growth (for further detail, refer to Abusada et al. 2000). In our sample of 10 protected areas, 6 were established before 1990 (3 of which were established before 1973). By law, every protected area must have a five-year master management plan. We hypothesize that older protected areas have had more time to identify challenges and constraints and to develop solutions. Empirical evidence suggests that in at least some countries, older protected areas prevent more deforestation than newer ones (Ferraro and Hanauer 2011; Ferraro et al. 2011).

It is not clear whether strict or mixed-use protection avoids more forest cover change. Although by definition, strict protection prohibits all extractive activity, its effectiveness depends on the willingness and ability of a formal regulatory authority to monitor and enforce land cover change restrictions. But such regulators are in short supply in developing countries (Bruner et al. 2004). In principle, mixed-use protection can sidestep this constraint because it relies more on local organizations to enforce land-use restrictions. Although the evidence is quite mixed, at least some studies indicate that mixed-use protected areas (or multiple-use parks) can be more effective at reducing deforestation (Blackman 2014; Nelson and Chomitz 2011; Pfaff et al. 2013; Ferraro et al. 2013).[14]

Our results suggest that protected areas established before 1990 and nonstrictly protected areas are more effective in reducing deforestation (Table 6). Protected areas established before 1990 cut deforestation by 0.13 percentage points (twice the ATT for the pooled sample), did not have a statistically significant effect on disturbance, and reduced and deforestation plus disturbance by 0.20 percentage points (Table 6). Results for protected areas established after 1990 are not statistically significant.

With regard to protection type, mixed-use protected areas reduced deforestation by 0.10 percentage points (slightly more than the ATT for the pooled sample) and deforestation plus disturbance by 0.22 percentage points. In the case of strictly protected areas, deforestation is not statistically significant, but disturbance is. Strictly protected areas actually *increase* disturbance by 0.07 percentage points and deforestation plus disturbance by 0.10 percentage points.

[14] Using data from Bolivia, Costa Rica, Indonesia, and Thailand (along with consistent definitions of park types), Ferraro et al. (2013) find that although effects vary across and even within countries, in general, strict protection outperforms less strict protection, albeit only slightly in many cases.

Table 6. Heterogeneous Effects on Forest Cover Change

	Deforestation	Disturbance	Deforestation + disturbance
A.1. PAs established before 1990			
Without bias adjustment			
Estimate	–0.0009***	–0.0007**	–0.0015***
Standard error	0.0003	0.0003	0.0004
T-stat	–2.9411	–2.1011	–3.5449
With bias adjustment			
Estimate	–0.0013**	–0.0007	–0.0020***
Standard error[1/]	0.0004	0.0006	0.0008
T-stat	–3.2032	–1.1027	–2.6170
A.2. PAs established after 1990			
Without bias adjustment			
Estimate	–0.0005**	–0.0008**	–0.0013***
Standard error	0.0003	0.0003	0.0004
T-stat	–2.1109	–2.2365	–3.0544
With bias adjustment			
Estimate	–0.0002	–0.0009	–0.0011
Standard error[1/]	0.0012	0.0010	0.0016
T-stat	–0.1973	–0.8576	–0.7123
B.1. PAs strictly protected (national parks)			
Without bias adjustment			
Estimate	–0.0004	0.0005**	0.0002
Standard error	0.0003	0.0003	0.0004
T-stat	–1.4143	2.1217	0.5000
With bias adjustment			
Estimate	0.0003	0.0007***	0.0010***
Standard error[1/]	0.0003	0.0003	0.0004
T-stat	1.0767	2.6982	2.6629
B.2. PAs non-strictly protected			
Without bias adjustment			
Estimate	–0.0010***	–0.0013***	–0.0023***
Standard error	0.0003	0.0003	0.0004
T-stat	–3.4752	–4.0977	–5.3737
With bias adjustment			
Estimate	–0.0010**	–0.0012	–0.0022**
Standard error[1/]	0.0004	0.0008	0.0009
T-stat	–2.5363	–1.5775	–2.5440

[1/] Abadie-Imbens (2006) standard errors.
***, **, and * indicate significance at the 0.01, 0.05, and 0.1 levels, respectively.

5.2. Effects on Local Communities

We next evaluate the effects of protected areas on socioeconomic indicators for nearby households. First we review the balance for covariates results[15] (Appendix 3). In all cases, standardized means are less than 20 units (of hundreds) satisfying the Rosenbaum and Rubin (1985) criterion. Under both buffer definitions, of the 14 covariates, seven had a standardized mean difference of less than 5 units after matching. The average standardized difference before matching was 57 for the 5-km buffer and 77 units for the 10-km buffer; after matching, it fell to 2 and 3 units, respectively. Likewise, there is substantial improvement in the variance ratio between treated and control units.

Table 7 shows the estimated treatment effect on the treated for four socioeconomic indicators: total expenditure per capita (in Peruvian soles), total income per capita (in Peruvian soles), poverty rate, and extreme poverty rate.[16]

For households living in a 5-km buffer, protected areas exacerbate extreme poverty. However, protected areas do not have a statistically significant effect on the other three socioeconomic indicators. For households living within a 10-km buffer, the effect of protected areas on extreme poverty vanishes. The effect on expenditure is positive and weakly significant. Hence, there is some indication, but certainly not a strong one, that protected areas may have adverse socioeconomic effects on local communities.

Figure 3 summarizes our results and compares them with the naïve estimator. As in the case of protected areas' effects on forest cover change, naïve estimates overestimate the effects across all definitions because of selection bias.

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[15] The poverty analysis includes an additional covariate in the matching procedure: a dummy for the Amazon. Because some households live very close to protected areas but are in the Andes, not in the Amazon, we added this dummy variable to increase the number of potential controls, therefore increasing efficiency. Results do not change qualitatively when the sample is restricted to the Amazon.

[16] The average exchange rate from 2001 to 2006 was 3.4 Peruvian soles per US dollar.

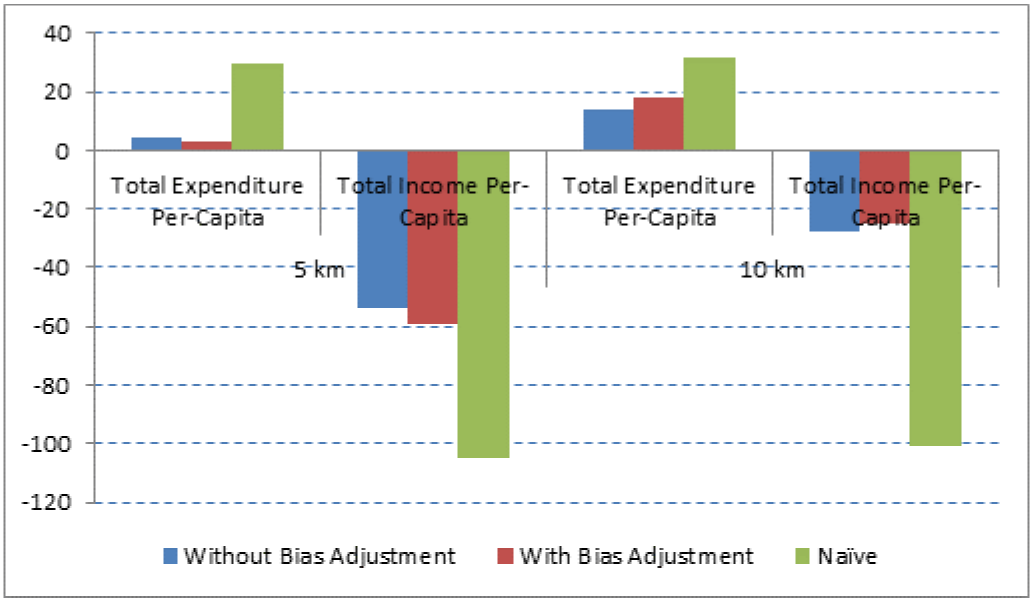
Table 7. Socioeconomic Indicators: Average Treatment Effect on Treated

	Total expenditure per capita	Total income per capita	Poverty rate	Extreme poverty rate
	Inside national protected areas (5-km buffer)			
	Without bias adjustment			
Estimate	4.6919	–53.3750 **	0.0133	0.0715 ***
Standard error	9.2121	24.8940	0.0257	0.0216
T-stat	0.6105	0.0320	0.6056	0.0009
	With bias adjustment			
Estimate	2.6822	–59.2300	0.0272	0.0845 **
Standard error[1/]	12.6290	47.2560	0.0409	0.0365
T-stat	0.8318	0.2101	0.5064	0.0207
	Inside national protected areas (10-km buffer)			
	Without bias adjustment			
Estimate	13.8580 *	–27.4230	–0.0095	0.0151
Standard error	7.5500	19.0640	0.0216	0.0192
T-stat	0.0664	0.1503	0.6617	0.4320
	With bias adjustment			
Estimate	18.2290 *	–25.1030	–0.0242	0.0075
Standard error[1/]	10.6640	35.8280	0.0356	0.0328
T-stat	0.0874	0.4835	0.4959	0.8197

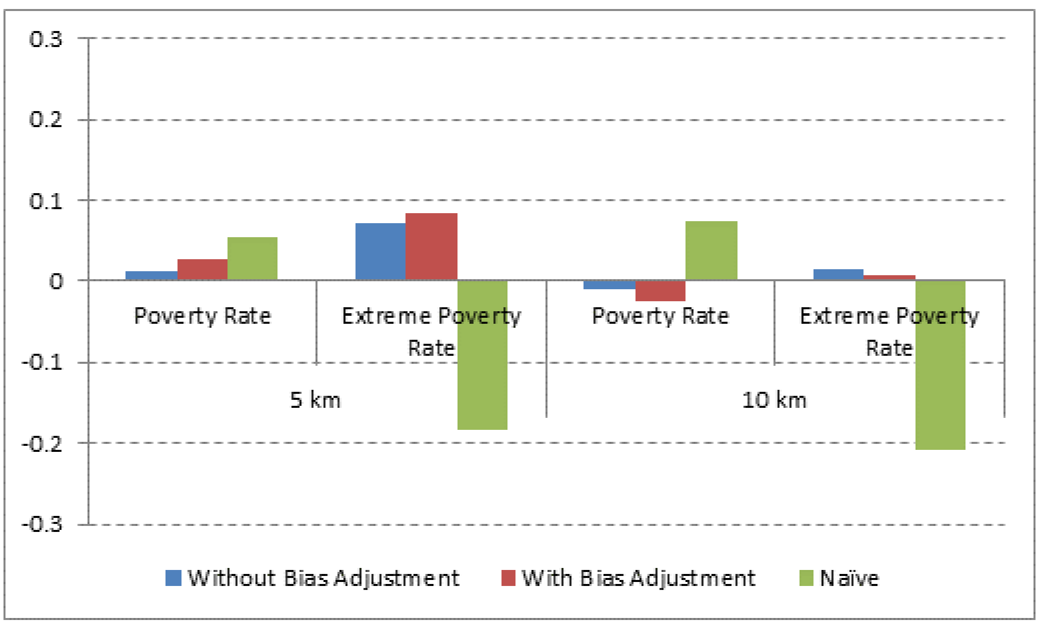
[1/] Abadie-Imbens (2006) standard errors.
***, **, and * indicate significance at the 0.01, 0.05, and 0.1 levels, respectively.

Figure 3. Socioeconomic: Naïve Effects and ATT

Panel A: Total Expenditure and Income



Panel B: Poverty and Extreme Poverty



Our results on local community effects differ from those in the recent empirical literature (Andam et al. 2010; Sims 2010; Robalino and Villalobos 2010). These studies find strong evidence that protected areas have socioeconomic benefits for local communities. By contrast, our results do not indicate that households in close proximity to protected areas are better off. One potential explanation could involve the type of economic activity that protected areas create. Others studies examine Costa Rica and Thailand, where ecotourism, and in particular ecotourism associated with protected areas, is common. In our case, of the 10 protected areas selected, only 4—Bahuaja Sonene, Manu, Tampobata and Pacaya-Samiria—are known to have ecotourism potential. However, this potential is not yet well developed, primarily because the areas are difficult to reach. For instance, traveling to Pacaya-Samiria, one of the oldest protected areas in our sample, from Lima, Peru's capital city and port of entry for international tourists, would entail flying to Iquitos (~90 minutes), driving to Nauta (~60 minutes), and taking a boat ride (~120 minutes) to the protected area. This limited access is reflected in the number of visitors. Tampobata, one of the most visited protected areas in the Amazon had a monthly average of only 1,039 visitors between 1999 and 2007.

Finally, to assess whether the effect of protected areas on local communities is mediated by the protected area's characteristics, we again categorize our sample of protected areas by vintage (established before or after 1990) and by type of protection (strictly protected areas vs. nonstrictly protected areas). We find that older protected areas exacerbate extreme poverty for households living in a 5-km buffer zone (Table 8). This result comports with our earlier finding that older protected areas are most effective in stemming deforestation and disturbance. Presumably, the restrictions that helped reduce forest cover change had adverse socioeconomic effects. We find no strong evidence of heterogeneity treatment effects for households in the 10-km buffer zone (Table 9).

Table 8. Heterogeneous Effects on Socioeconomic Indicators: 5-km Buffer Around Protected Areas

	Total expenditure per capita	Total income per capita	Poverty rate	Extreme poverty rate
	A.1. PAs established before 1990			
	Without bias adjustment			
Estimate	–3.2633	–9.0039	0.0331	0.0915***
Standard error	9.4994	15.0900	0.0306	0.0279
T-stat	–0.3435	–0.5967	1.0800	3.2856
	With bias adjustment			
Estimate	–13.1020	–23.3720	0.0595	0.1119**
Standard error[1/]	12.8160	21.8030	0.0450	0.0480
T-stat	–1.0223	–1.0720	1.3232	2.3324
	A.2. PAs established after 1990			
	Without bias adjustment			
Estimate	29.6310	–192.4800**	–0.0489	0.0086
Standard error	23.6450	90.5630	0.0450	0.0172
T-stat	1.2532	–2.1253	–1.0857	0.4985
	With bias adjustment			
Estimate	90.8140***	27.2140	–0.0939	0.0078
Standard error[1/]	34.2070	183.4200	0.0950	0.0162
T-stat	2.6548	0.1484	–0.9890	0.4827
	B.1. PAs strictly protected (national parks)			
	Without bias adjustment			
Estimate	31.1920	6.2666	–0.0641	0.0812**
Standard error	18.9730	29.1460	0.0456	0.0377
T-stat	1.6440	0.2150	–1.4050	2.1552
	With bias adjustment			
Estimate	39.3860*	13.9770	–0.0829	0.0687
Standard error[1/]	22.3680	37.7440	0.0676	0.0553
T-stat	1.7608	0.3703	–1.2262	1.2418
	B.2. PAs non-strictly protected			
	Without bias adjustment			
Estimate	–10.9440	–87.4930***	0.0390	0.0475*
Standard error	10.4310	33.9010	0.0308	0.0265
T-stat	–1.0492	–2.5808	1.2686	1.7936
	With bias adjustment			
Estimate	–17.6320	–109.8700	0.0677	0.0676
Standard error[1/]	15.7690	66.9280	0.0505	0.0476
T-stat	–1.1182	–1.6417	1.3392	1.4212

[1/] Abadie-Imbens (2006) standard errors.

***, **, and * indicate significance at the 0.01, 0.05, and 0.1 levels, respectively.

Table 9. Heterogeneous Effects on Socioeconomic Indicators: 10-km Buffer Around Protected Areas

	Total expenditure per capita	Total income per capita		Poverty rate	Extreme poverty rate
	A.1. PAs established before 1990				
	Without bias adjustment				
Estimate	6.6534	–6.5412		0.0194	0.0199
Standard error	7.6781	12.2570		0.0251	0.0242
T-stat	0.8665	–0.5337		0.7733	0.8223
	With bias adjustment				
Estimate	–0.5468	–17.3730		0.0192	0.0206
Standard error[1/]	10.4400	17.5010		0.0391	0.0422
T-stat	–0.0524	–0.9927		0.4913	0.4879
	A.2. PAs established after 1990				
	Without bias adjustment				
Estimate	21.6170	–132.1900	*	–0.0669	–0.0178
Standard error	21.3330	74.4010		0.0408	0.0176
T-stat	1.0133	–1.7767		–1.6415	–1.0127
	With bias adjustment				
Estimate	71.7300	46.8690		–0.1050	–0.0180
Standard error[1/]	32.1520	149.2200		0.0831	0.0261
T-stat	2.2310	0.3141		–1.2633	–0.6903
	B.1. PAs strictly protected (National Parks)				
	Without bias adjustment				
Estimate	17.4870	6.2673		–0.0012	–0.0137
Standard error	14.5970	21.6340		0.0366	0.0350
T-stat	1.1980	0.2897		–0.0317	–0.3908
	With bias adjustment				
Estimate	–7.3188	–16.9110		0.0810	0.0397
Standard error[1/]	19.6290	27.2810		0.0584	0.0604
T-stat	–0.3729	–0.6199		1.3870	0.6567
	B.2. PAs non-strictly protected				
	Without bias adjustment				
Estimate	–0.0660	–50.6640	*	0.0266	0.0185
Standard error	8.9679	26.3140		0.0265	0.0232
T-stat	–0.0074	–1.9254		1.0054	0.7989
	With bias adjustment				
Estimate	10.7920	–43.4620		0.0115	0.0056
Standard error[1/]	14.0320	51.6860		0.0455	0.0408
T-stat	0.7691	–0.8409		0.2520	0.1381

[1/] Abadie-Imbens (2006) standard errors.

***, **, and * indicate significance at the 0.01, 0.05, and 0.1 levels, respectively.

6. Conclusions

We have assessed the effect of national protected areas on environmental and socioeconomic outcomes in the Peruvian Amazon. We used data on both deforestation and disturbance from high-resolution satellite images and socioeconomic data from the National Household Survey. We used quasi-experimental matching techniques to control for protected areas' nonrandom siting.

In line with previous studies, our results suggest that protected areas do reduce deforestation plus disturbance by 0.15 percentage points over a six-year period, or by 0.03 percent per year. These results are 10 times lower than the (usually estimated) naïve estimator. We also find that protected areas established before 1990 and nonstrictly protected areas are more effective in reducing deforestation. The average reduction in deforestation for protected areas established before 1990 is twice more than the total average effect (i.e., including both older and newer protected areas), whereas nonstrictly protected areas are slightly more effective in reducing deforestation than the overall average. Given the park authority's limitations for monitoring and control, this result suggests that giving local communities access to some resource use may be a more effective strategy for conserving forests than strict protection.

Even though we find total and heterogeneous effects on deforestation, we do not find conclusive evidence that protected areas help reduce (or increase) poverty in surrounding communities. Thus we do not find a "win-win" scenario.

A better understanding of why local communities do not benefit from the establishment of protected areas could further the legitimacy and sustainability of protected areas policies. Future studies should focus on understanding the causal channels that will inform policymaking for protected areas and promote not only environmental objectives but also social goals.

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Appendix 1. Protected Areas within Study Area

Protected area	Type	Year of establishment	Included in study?
Allpahuayo Mishana	National reserve	2004	
Alto Purús	National park	2004	
Amarakaeri	Community reserve	2002	
Ampiyacu Apayacu	Regional conservation area	2010	
Bahuaja Sonene	National park	1996	Yes
Comunal Tamshiyacu Tahuayo	Regional conservation area	2009	
Cordillera Azul	National park	2001	
Cordillera Escalera	Regional conservation area	2005	
El Sira	Community reserve	2001	
Güeppí	Reserved area	1997	Yes
Habana Rural Inn	Private conservation area	2010	
Herman Dantas	Private conservation area	2010	
Ichigkat Muja-Cordillera del Cóndor	National park	2007	
Imiria	Regional conservation area	2010	
Manu	National park	1973	Yes
Matsés	National reserve	2009	
Pacaya Samiria	National reserve	1972	Yes
Pucacuro	National reserve	2010	
Purus	Community reserve	2004	
Refugio K'erenda Homet	Private conservation area	2010	
Sagrada Familia	Private conservation area	2006	
San Matias San Carlos	Protected forest	1987	Yes
Santiago Comaina	Reserved area	1999	Yes
Selva Botanica	Private conservation area	2010	
Sierra del Divisor	Reserved area	2006	
Tambopata	National reserve	2000	Yes
Tingo María	National park	1965	Yes
Yanachaga-Chemillén	National park	1986	Yes
Yanesha	Community reserve	1988	Yes

Appendix 2. Forest Cover Change: Balance for Covariate of interest (at Plot Level)

	Mean treatment	Mean control	Mean difference	Std. mean difference	Variance ratio (Tr/Co)
Aspect (=1 if north, northwest, or northeast)					
Before matching	0.29	0.27	0.02	4.23	1.04
After matching	0.29	0.28	0.00	1.09	1.01
Average precipitation (mm) (1950–2000)					
Before matching	209.65	207.88	1.77	4.28	0.83
After matching	209.65	210.35	–0.70	–1.68	0.78
Slope (degrees)					
Before matching	3.44	2.94	0.50	7.89	1.81
After matching	3.44	3.37	0.07	1.11	1.02
Average mean temperature (C) (1950–2000)					
Before matching	25.68	25.69	–0.02	–0.91	1.45
After matching	25.68	25.67	0.01	0.68	1.06
Average maximum temperature (C) (1950–2000)					
Before matching	30.93	30.93	–0.01	–0.52	1.54
After matching	30.93	30.91	0.02	1.51	1.11
Elevation (meters)					
Before matching	263.80	248.20	15.60	5.28	0.99
After matching	263.80	258.46	5.34	1.81	0.97
Proportion land suitable for forestry (percentage)					
Before matching	0.38	0.62	–0.25	–81.89	1.46
After matching	0.38	0.36	0.01	4.41	0.92
Distance to nearest population center (km)					
Before matching	127.52	152.60	–25.08	–35.63	1.62
After matching	127.52	129.31	–1.79	–2.55	1.00
Distance to nearest population center > 10,000 people (km)					
Before matching	98885.00	141435.00	–42550.00	–67.14	0.48
After matching	98885.00	96851.00	2034.00	3.21	1.04
Percentage district water source in house					
Before matching	6.66	4.58	2.08	22.52	0.88
After matching	6.66	6.47	0.19	2.06	1.02
Percentage district yes electric lighting					
Before matching	19.38	24.60	–5.22	–28.33	1.32
After matching	19.38	19.67	–0.28	–1.54	1.01
Literacy rate (percentage)					
Before matching	79.30	74.95	4.35	77.30	0.37
After matching	79.30	79.26	0.04	0.69	0.98
Percentage district primary school education					
Before matching	68.70	68.49	0.21	2.11	1.32
After matching	68.70	68.58	0.12	1.20	1.01
Percentage district employment in agriculture or forestry					
Before matching	65.25	68.05	–2.80	–12.67	1.77
After matching	65.25	65.41	–0.16	–0.75	0.98
Population density (per square km)					
Before matching	1.52	3.35	–1.83	–95.41	0.02
After matching	1.52	1.62	–0.09	–4.79	0.70

Appendix 3. Socioeconomic Effects: Balance for Covariate of Interest (at Household Level)

	5-km buffer around PAs			10-km buffer around PAs		
	Mean eifference	Std. mean diff.	Variance ratio (Tr/Co)	Mean difference	Std. mean diff.	Variance ratio (Tr/Co)
Aspect (=1 if north, northwest, or northeast)						
Before matching	–0.03	–5.61	0.97	–0.03	–5.78	0.97
After matching	0.02	5.02	1.04	0.04	7.42	1.06
Average precipitation (mm) (1950–2000)						
Before matching	143.16	287.79	0.69	137.16	276.52	0.69
After matching	5.11	10.28	1.08	6.53	13.17	1.05
Slope (degrees)						
Before matching	–2.84	–31.61	0.88	–2.72	–31.56	0.80
After matching	1.24	13.83	1.19	0.82	9.47	1.06
Average mean temperature (C) (1950–2000)						
Before matching	79.53	380.86	0.11	77.54	321.71	0.14
After matching	0.10	0.48	1.15	0.91	3.75	0.68
Average maximum temperature (C) (1950–2000)						
Before matching	70.13	448.68	0.08	68.31	371.14	0.11
After matching	0.14	0.86	1.35	1.07	5.79	0.63
Elevation (meters)						
Before matching	–1416.06	–322.20	0.08	–1383.03	–259.11	0.12
After matching	–6.70	–1.52	0.88	–5.76	–1.08	0.76
Proportion land suitable for forestry (percentage)						
Before matching	0.36	72.29	2.46	0.38	75.35	2.49
After matching	0.00	0.00	1.00	0.00	0.00	1.00
Distance to nearest population center (km)						
Before matching	0.88	0.31	0.74	7.90	1.96	1.45
After matching	8.25	2.92	1.21	8.64	2.14	1.25
Distance to nearest population center > 10,000 people (km)						
Before matching	15323.00	37.14	2.26	15487.00	38.29	2.17
After matching	2372.00	5.75	1.25	–118.00	–0.29	1.08
Percentage district water source in house						
Before matching	–9.51	–80.24	0.27	–9.68	–82.67	0.27
After matching	1.69	14.27	0.77	1.86	15.93	0.78
Percentage district yes electric lighting						
Before matching	–2.29	–9.88	0.63	–1.13	–5.17	0.57
After matching	0.61	2.63	1.00	2.51	11.51	0.90
Literacy rate (percentage)						
Before matching	2.38	31.88	0.39	3.27	47.71	0.32
After matching	–0.98	–13.13	1.56	–0.26	–3.83	1.18
Percentage district primary school education						
Before matching	0.22	2.01	0.54	–0.74	–7.01	0.54
After matching	–1.00	–9.32	0.93	–1.56	–14.66	0.97
Percentage district employment in agriculture or forestry						
Before matching	–3.21	–14.01	0.66	–3.74	–17.50	0.60
After matching	–1.07	–4.68	0.92	–2.38	–11.14	0.87
Amazon (=1 if Amazon)						
Before matching	0.75	—	0.00	0.72	426.71	0.16
After matching	0.00	0.00	—	0.00	2.59	0.87