Creating protected areas on public lands: is there room for additional conservation?

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Abstract

Establishing protected areas (PAs) has been the most common conservation measure around the world. The Chilean PA system is second in Latin America and seventh worldwide in terms of % of national coverage. Answering the question whether PAs "work" is complicated because their impacts are not directly measurable. Most evaluations rely on indirect estimates based on comparisons between protected and unprotected areas, and such methods can be biased when protection is not randomly assigned. This present research estimates, using matching methods, the causal impact of Chilean PAs as measured by deforestation avoided. Using conventional approaches, results indicate 17% greater deforestation without protection. Correcting for selection bias, matching results show only a 5% avoided deforestation. These results indicate how conventional methods tend to overestimate protection impacts and illustrate how improvements to select appropriate unprotected lands to compare with PSA outcomes can be made. Using only public lands to construct counterfactual scenarios leads to estimates of no additional conservation benefits. A potential explanation, in the Chilean context, is that public lands similar to PAs are already well managed, so converting these lands to PAs provides few additional benefits. These results raise important questions, as to the relative costs of different public land management strategies, and whether there are any particular types of public lands where conversion to PAs would have greater impact. These results also suggest that conversion of private land to PAs may offer greater additional conservation benefits, although costlier for governments and society as a whole. Our analysis indicates that the Chilean government would do well strategically to commit to keep natural forests on public lands alongside the PA network.

JEL Codes: Q58, Q57, Q56, Q01

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1. Introduction

Changes in land use are among the most important human alterations of the Earth´s land surface (Turner et al., 1990; Lambin et al., 1999). As a response to the past consequences and the perceived potential future impacts of large-scale land use changes, private actors and governments have significantly increased the number of protected areas (PAs) to conserve natural landscapes [3,4]. In the context of less developed countries, not only has the public demand for land for conservation increased, as revealed by government policies, but also the overall demand for land for agricultural production, urban and suburban expansion, and other activities (Robalino, 2007). Despite the expansion in PAs in less developed countries (including Chile), not much is known both about the policy process determining the establishment of PAs, and about how successful such areas have been in contributing to their conservation objectives [6]. To inform decision makers regarding any new investments in land conservation, a better understanding is needed regarding where previous PAs have been placed and how effective have been these past conservation investments.

In most countries, governments have not randomly distributed PAs geographically [4], in part due to historical patterns of state land ownership. In-situ biodiversity conservation, for example, has traditionally relied on PAs, and historically such areas often consisted of already public lands [7]. Regardless of the scientific and public-choice factors underlying the establishment of PAs, if their resulting distribution is biased to favor areas of lower conservation threats, then most previously used methods will tend to overestimate the effectiveness of protection for reducing harmful land use and land cover changes (LULCC) [8,9]. This present paper addresses these selection effects.

In terms of effectiveness of PAs, the question of the impact of PAs on LULCC is complicated, because avoided changes to land are not directly measurable. Daniela Miteva et al. [6] summarize the studies that use rigorous empirical designs to quantify the impacts of PAs, finding that these studies have focused predominantly on the effectiveness of PAs in preventing deforestation, most often measured as a binary outcome at the 30x30 meter pixel level [6]. Most of these studies apply empirical designs where PAs are compared with observationally similar unprotected lands (after removing non-comparable areas, such as indigenous reserves or private PAs), but without distinguishing between private and government lands as comparable control areas. This empirical strategy, however, ignores that traditional PA systems are usually based on converted, long-held government lands, which perhaps have different land use regimes relative to private lands. An important question for the PA decision process is, What are the effects of establishing PAs in comparison with the counterfactual scenario obtained from government land without PAs?

This paper corrects these problems with selection bias and the proper choice of the controls in evaluating the impacts of PAs, presenting causal estimates of their effectiveness in Chile. The paper demonstrates that evaluations can be substantially improved by controlling for biases along dimensions that are observable. We address two main research questions: What is the impact of Chilean PAs on avoided deforestation between 1986 and 2011? And, how do estimates of the impacts of PAs vary when using only public land as matched control units? This research effort constitutes the first impact evaluation of one of the oldest PAs systems in Latin America, which protects one of the few remaining extensive temperate rainforests in the world.

2. PAs, LULCC and the Chilean system of PAs

PAs are, and will remain, the cornerstone of global conservation efforts (Hansen and Defries, 2007). An increasing human population and standard of living, and demand for multiple ecosystem services, will intensify competition for land inside and outside PAs. In the context of PAs and avoided deforestation, protection effectiveness will depend on the conservation opportunity costs of keeping land in forest. Robalino (2007) and Pfaff et al. (2009), presents a framework for considering PAs' impacts on LULCC where protection effectiveness depend on rents determined by opportunity costs. Therefore, if we consider PAs impact on avoided deforestation, PAs may remain forested due to the protection itself (i.e. *de jure* protection) or because the landscape characteristics of the protected lands discourage LULCC (i.e. *de facto* protection). In the latter case, protection may have no impact at all. The primary question PAs administrators should ask is whether the conservation scheme has a sufficiently large "additionality" which is the difference in conservation between the with-PAs scenario and the without-PAs baseline [12].

At the end the impact of PAs is an empirical question that requires rigorous empirical evidence to be answered. This is the research challenge that this paper will address in the context of one of the oldest PA network in the Latin American and The Caribbean region.

For the Chilean case, in the middle of the nineteenth century, the rapid deforestation of south-central Chile, caused by land settlement and consequent agriculture and livestock activities, increased awareness about conservation (Pauchard and Villarroel, 2002). Decree Law 18362 of 1984 created the national public system of PAs (*Sistema Nacional de Áreas Silvestres Protegidas del Estado*, SNASPE). The purpose of the law was to organize the scattered PAs around a unified conservation system with the common purpose of protecting Chilean natural resources. With the creation of SNASPE, the government tried to promote the definition and legalization of PAs boundaries and the assignment of specific management objectives for each unit in the system, so it can be considered as the true beginning of PAs in Chile (Pauchard and Villarroel, 2002).

Considering the different land uses represented in the Chilean system of PAs, almost 30% corresponds to forest. Chile has the largest temperate forest area in South America and more than half of the total area of temperate forests in the southern hemisphere [14]. This Chilean temperate forest has been classified as a biodiversity hotspot for conservation (Myers, et al., 2000) and has also been included among the most threatened eco-regions in the world in the Global 200 initiative launched by WWF and the World Bank [16]. Most of the Chilean forests (including native and exotic forests) are distributed along the Coastal and the Andean Range of Chile from 35° to 56° totaling an area equal to 15.6 million ha [17].

In general for the case of Chile, the main driving force behind LULCC is the replacement of native forests by forest plantations and agricultural crops, a factor that contributes to soil loss, forest clearing, and the consequent loss of biodiversity (Lara et al., 2009). In previous qualitative evaluations of SNASPE (see Armesto, et al., 1992; Rozzi, et al., 1994; Neira et al., 2002; Pauchard and Villarroel, 2002; Lara et al., 2009), authors have recognized that SNASPE geographic distribution and ecosystem representation is insufficient to achieve adequate levels of conservation and that the poor conservation status of native forests may be explained by the Chilean forest policies followed since 1974.[2] These policies have not provided economic incentives for the sustainable management and conservation of native forests, in contrast to the use of public funds to support the establishment of forest plantations.

At present, Chile has 14.1 million ha of PAs in its national public system which represents 18.7% of the Chilean territory. The system includes 31 national parks, 48 national reserves, and 15 natural monuments, with the first two categories encompassing 99.9% of the total area, and the system is administered by the Chilean Forest Service (*Corporación Nacional Forestal*, CONAF)[3]. Chilean protected areas rank second in Latin America and seventh worldwide in terms of percentage of national coverage (Cofre and Marquet, 1999).

In terms of used criteria to establish PAs, the motivations have been diverse and have evolved to reach currently to the use of specific criteria and standards. However, at the beginning of the Chilean history of environmental protection, the criteria did not necessarily reflect conservation objectives, but they reflected motivations to regulate wood extraction and commercialization, to protect public land without productive value (i.e. land with no capacity to sustain agriculture or cattle production), or to conserve landscape beauty (Basic and Arriagada, 2012). As explained in Figure 1, conservation opportunity costs never have been mentioned as a criterion for PAs selection in Chile. Then, expected conservation additionality in the context of Chilean PAs may be questioned. Previous studies of Chilean PAs impact have not analyzed conservation effectiveness on avoided conservation (i.e. what would have been the level of conservation had the PA not established), and there is absolutely no empirical evidence of the impact of the system, an important knowledge gap that this paper aims to fill. Figure 2 shows the study area.

[2] In 1974, the Law of Forest Development (Decree Law N° 701) was established. The main objective of this law was the regulation of forest activities on forest land and degraded soils. This law also aimed to promote forestation by small forest landowners to prevent soil loss, and to protect and restore soils. See http://www.conaf.cl/.

[3] According to the Chilean law, a national park is an area of great extension that includes unique and representative environments and habitats of the national biological diversity, and its main objective is preservation. A national reserve is a smaller area where conservation is necessary due to potential conservation threats. The natural monuments include small areas in places with high archeological, cultural or natural value.

3. Data

The research estimates the causal impact on avoided deforestation of PAs established after the SNASPE creation in 1984.[4] The PAs located in the study area and selected for this study protect 561,920 ha. We use Geographic Information Systems to build a geospatial data set of relevant biophysical and socioeconomic conditions. We first established the forest cover conditions using a mosaic of Landsat Multi-Spectral Scanner satellite images between 1974 and 1976, and from 1986 and 2011 Landsat Thematic Mapper satellite images (Landscape Ecology Laboratory, *Universidad de Concepción,* Chile) (see Figure 3).[5] A random sample of 5,613 and 13,097 points (pixels) was obtained to characterize protected and unprotected land respectively. To determine if a land pixel is considered protected for the analyses, a layer containing all PAs was overlaid with a general map of the study area. This dataset includes approximately one pixel per 1 km^2 of land. The sampling excluded indigenous land and private PAs because they are subject to different legal and land use regimes.

To check the accuracy of the random sampling process, we confirmed that there were no significant differences between our sample of land pixels and the entire land area shown in Figure 2 in terms of important characteristics (i.e. protected status, type of protection, proportion under each land capacity and land suitability classes).

Avoided deforestation was calculated based on the forest cover variable defined as the presence or absence of forest (i.e. a binary variable indicating if a plot is either forested or deforested in each year). As a result, the outcome variable measures the change in forest as the difference between the change in forest cover on protected plots (Y=1 if conserved) and the change in forest cover on matched unprotected plots in the same period (1986-2011). Thus, a positive sign indicates that protection resulted in avoided deforestation. Table 1 shows the differences between protected and unprotected areas in terms of the outcome variable (i.e. conservation probability or avoided deforestation). A simple comparison between protected and unprotected areas show a higher probability of conservation on unprotected land for the period 1975-1986, however for the period 1986-2011, protected land shows a higher conservation probability. These results don´t allow concluding about PAs impacts in terms of avoided deforestation, but they show statistically significant differences in terms of the outcome variable between protected and unprotected areas in the study region.

[4] Until the 1970s, several government agencies were in charge of PAs creation and management. However, unified legislation on PAs was not available until 1984. With the creation of SNASPE, the government tried to promote the definition and legalization of PAs boundaries and the assignment of management objectives for each unit in the system, none of which previously had been clear for a large proportion of PAs [13]. For that reason, the SNASPE creation in 1984 can be considered the true beginning of PAs in Chile.

[5] Landsat Multispectral Scanner (MSS) images consist of four spectral bands with 60 meter spatial resolution and Landsat Thematic Mapper (TM) images consist of seven spectral bands with a spatial resolution of 30-meter pixels. The MSS pixels were resampled to make them comparable to TM pixels.

Table 1. Description and summary statistics for avoided deforestation

Variable Description	Mean Protected land	Mean Unprotected land	t-stat	Norm Diff[b]
Deforestation between 1975-1986 [a]	0.757 (0.430)	0.827 (0.378)	2.589	-0.172
Deforestation between 1986-2011 [a]	0.892 (0.310)	0.723 (0.447)	-15.899	0.544

[a] These outcomes show the difference between the change in forest cover on protected plots (Y = 1 if non-deforested) and the change in forest cover on matched unprotected plots in the same period. Thus, a positive sign indicates that protection resulted in higher probability of conservation or avoided deforestation.

[b] Normalized difference = $\frac{\bar{X}_T - \bar{X}_C}{\sqrt{S_T^2 + S_C^2/2}}$ where T = PSA and C = non-PSA [24]

We also wish to control for differences among protected and unprotected areas across characteristics that affect both deforestation and protection decisions. Therefore, the forest cover data was combined with spatially explicit data on covariates believed to affect both PA location and LULCC. The biophysical, geographical and socioeconomic characterization of Chilean PAs is oriented to reveal the drivers of LULCC and conservation status in Chile when compared with non-protected areas. In the scientific literature, the main drivers of PAs establishment are related with land use (Andam et al., 2008; Pfaff et al., 2009), soil characteristics (Pfaff, 1999; Carmona and Nahuelhual, 2012) and transportation costs (Chomitz and Gray, 1996; Pfaff, 1999; Pfaff et al., 2007; Andam et al., 2008; Carmona and Nahuelhual, 2012). Other drivers may include ecological characteristics like slope and distance to rivers (Pfaff et al., 2007; Andam et al., 2008; Carmona and Nahuelhual, 2012). We also draw on previous impact evaluation of PAs (Andam et al., 2008; Pfaff et al., 2009; Ferraro and Hanauer, 2010; Sims, 2010). For the purpose of this paper, variables describing terrain, climate, and remoteness were used to compare protected land with unprotected land as shown in Table 2 and Table 3 presents the summary statistics for this confounders used in our analysis.

Table 2. Definitions of variables and data sources for drivers of PAs establishment

Variable	Definition	Data source
Socioeconomic drivers of PAs establishment		
Distance to river	Euclidean linear distance to the closest river	Ministry of the Interior (2002), scale: 1:20.000
Distance to closest city	Euclidean linear distance to the border of the real urban sprawl	Ministry of the Interior (2002), scale: 1:20.000
Distance to road	Euclidean linear distance to the closest national highway	Adapted from the Ministry of Public Works (2012)
Biophysical drivers of PAs establishment		
Altitude	Mean value of sampled pints using a GIS layer with terrain elevation using meters at the seal level (MASL) as measurement unit with a spatial resolution of 30 and 90 mts.	Terrain Elevation Model (TEM) years 2008 and 2001, International Centre for Tropical Agriculture (CIAT).
Slope	Mean value of sampled points using a GIS layer with terrain elevation using an angle of inclination to the horizontal (degrees) as measurement unit with a spatial resolution of 30 and 90 mts.	Terrain Elevation Model (TEM) years 2008 and 2001, International Centre for Tropical Agriculture (CIAT).
Precipitation	Annual precipitation (mm)	Universidad de La Frontera , Temuco, Chile (2004), scale: 1:250.000
High soil erodibility	Proportion of sampled points with very high and high soil erodibility.	National Commission of the Environment, scale: 1:250.000
Medium soil erodibility	Proportion of sampled points with very moderate soil erodibility.	National Commission of the Environment, scale: 1:250.000
Low soil erodibility	Proportion of sampled points with very low and very low soil erodibility.	National Commission of the Environment, scale: 1:250.000
High productivity land	Proportion of sampled points with land use capacity I, II and III where land is suitable for agricultural production. Class II & III may require special land and crop management	Natural Resources Information (1996), scale: 1:20.000.
Medium productivity land	Proportion of sampled points with land use capacity IV and V; moderately suitable for agricultural production	Natural Resources Information (1996), scale: 1:20.000
Low productivity land	Proportion of sample points with land use capacity VI, VII and VIII; strong limiting factors on agricultural production.	Natural Resources Information (1996), scale: 1:20.000.

Table 3. Covariate Balance

Variable	Sample[a]	Mean Value Protected Area	Mean Value Unprotected Area[b]	Diff Mean Value	Avg. Raw eQQ Diff[c]	Mean eCDF Diff[d]	Norm diff[e]
Distance to river (km)	Unmatched	2.54	2.25	0.29	0.29	0.03	0.13
	Matched	2.14	2.10	0.04	0.06	0.01	0.02
Distance to closest city (km)	Unmatched	37.63	22.88	14.75	14.83	0.22	0.81
	Matched	30.06	29.52	0.54	0.89	0.02	0.03
Distance to road (km)	Unmatched	32.48	40.39	-7.91	8.33	0.09	-0.34
	Matched	33.39	34.15	-0.76	1.28	0.02	-0.04
Altitude (masl)	Unmatched	645.93	528.70	117.23	117.88	0.07	0.29
	Matched	670.60	657.65	12.95	14.111	0.01	0.03
Slope (°)	Unmatched	19.54	15.16	4.38	4.37	0.09	0.37
	Matched	18.56	18.45	0.11	0.47	0.01	0.01
Precipitation (mm)	Unmatched	2190.00	1942.10	247.90	253.97	0.22	0.86
	Matched	2147.10	2141.30	-0.20	22.07	0.02	0.02
Temperature (°C)	Unmatched	3.88	-10.91	14.79	21.39	0.14	0.05
	Matched	4.06	4.32	-0.26	0.27	0.05	-0.18
High soil erodibility[f]	Unmatched	0.92	0.46	0.45	0.45	0.23	1.13
	Matched	0.91	0.91	0.00	0.00	0.00	0.00
Low soil erodibility[f]	Unmatched	0.08	0.43	-0.35	0.35	0.17	-0.87
	Matched	0.09	0.09	0.00	0.00	0.00	0.00

[a] N treated = 1978; N available controls = 23181.
[b] Weighted means for matched controls.
[c] Mean (for categorical covariate) or median (for continuous covariate) difference in the empirical quantile-quantile plot of treatment and control groups on the scale in which the covariate is measured.
[d] Mean eCDF = mean differences in empirical cumulative distribution function.
[e] Normalized difference = $\frac{\bar{X}_T - \bar{X}_C}{\sqrt{S_T^2 + S_C^2/2}}$ where T = PSA and C = non-PSA [24].
[f] According to FAO, the erodibility of a soil as a material with a greater or lesser degree of coherence is defined by its resistance to two energy sources: the impact of raindrops on the soil surface, and the shearing action of runoff between clods in grooves or rills (see http://www.fao.org/docrep/t1765e/t1765e0f.htm, accessed on June 3, 2013).

4. Empirical strategy

We want to estimate the difference between the expected potential change in forest cover on protected land and the counterfactual expected potential change in forest cover (i.e. what would have happened had the PA not been created) on unprotected areas. To ensure an appropriate causal analysis, we used four strategies: (i) compare means, (ii) conduct statistical matching, (c) adjust for remaining bias post-matching, and (d) test for unobservables that may bias causal estimates.

Following Andam et al. (2008) and given that protection is influenced by observable characteristics that also affect deforestation, we used matching methods to estimate avoided deforestation. Matching methods are being increasingly applied in the impact evaluation literature as one way to establish cause–effect relationships with nonexperimental data [31]. Matching works by comparing conservation outcomes on protected and unprotected forest plots that were ‘‘very similar’’ in terms of the observed baseline characteristics. The goal of matching is to make the characteristics distributions of protected and unprotected plots similar (called covariate balancing). Matching can be viewed as a way to make the protected and unprotected covariate distributions look similar by reweighting the sample observations (e.g., unprotected plots that are poor matches receive a weight of zero). Thus, matching mimics random assignment through the ex post construction of a control group [9].

We used a simple difference-in-differences (DID) estimator (called the Before-After-Control-Impact estimator in the ecology literature), which can control for time-invariant unobservable characteristics. When estimating the causal impact of PAs with the simple DID estimator, the key identification assumption is that the expected trend in forest cover of the unprotected land is equal to the expected trend in forest cover of the PAs in the absence of the program. To make this assumption more plausible, we first characterized all control unprotected land in our sample based on PAs selection criteria and then selected land based on these criteria and the rule that protected and unprotected areas should be forested at the baseline making treated and control areas more similar at baseline (a form of “pre-matching”). Deforestation trends before the SNASPE creation was also compared between protected and unprotected land using the 1974-1976 classified satellite images described in the previous section.

Based on an assessment of covariate balance quality across a variety of matching methods [32,33], we chose one-to-one, nearest-neighbor covariate matching with replacement using a generalized version of the Mahalanobis distance metric and genetic matching algorithm that maximizes covariate balance. Matching was done in R. Bootstrapped standard errors are invalid with non-smooth, nearest-neighbor matching with replacement [34], and thus we use Abadie and Imbens’ (2006) variance formula to conduct a t-test of the mean difference-in-differences.

Matching estimators of PAs impacts may still be biased due to discrepancies between the covariates of the matched protected pixels and their unprotected matches. We reduce this bias by using regression methods for the matched data. The use of a postmatching bias-correction procedure asymptotically removes the conditional bias in finite samples [35], although this use of regression is different from its use in the full sample. Here the covariate distributions are likely to be similar in the matched sample, and so regression is not used to extrapolate out of sample. This strategy of post-matching regression adjustment typically generates treatment effects estimates that are more accurate and more robust to misspecification than parametric regression alone [32,36].

5. Results

We estimated the effect of protection on deforestation between 1986 and 2011 using comparable forest-cover data for both years. For that purpose, we took land that was forested in 1986 and compared deforestation in protected and unprotected forests. Table 4 presents the DID matching estimates of avoided deforestation as a proportion of forest conserved. Estimates based on matching methods are compared with estimates based on more conventional methods used in the conservation-science literature. In the second column are estimates for PAs established after SNASPE creation (1984).[6] The first row presents the avoided deforestation estimates generated by conventional methods used in the conservation-science literature where deforestation on protected plots is compared with deforestation on unprotected areas, without controlling for other covariates. It implies that 16.9% of protected plots would have been deforested by 2011 in the absence of protection.

Nevertheless, as seen in Table 3, the protected and unprotected control areas differ on key covariates that could affect protection status and changes in forest cover. In terms of the covariates associated with protection status and deforestation, Table 3 shows that there are statistically significant differences between protected and unprotected land across all the socioeconomic and biophysical drivers associated with protection status. In general, PAs are farther from cities and road networks, and are located on steeper and higher land. Similarly, PAs also tend to be placed on land less suitable for agriculture and on soil with higher erodibility. As a consequence, most of the PAs in Figure 2 would have remained conserved because the landscape characteristics of the protected lands discourage LULCC. Thus one might worry that, despite our pre-matching effort and the similar baseline forest cover before protection, the mean avoided deforestation change in forest cover among protected land from 1986 to 2011 in the absence of protection may not be well represented by the mean change in forest cover among the control unprotected land during the same period. In fact, the avoided deforestation estimates from the matching approaches are much smaller. Covariate matching estimates, with and without calipers, imply that only 4.7% and 4.8% of

[6] Decree Law 18,362 of 1984 created the national public system of protected areas: SNASPE. However, program implementation took time after that date. For the purpose of this study, 1986 data provide the pre-SNASPE information necessary to construct baseline forest cover scenarios for both protected and unprotected areas.

protected plots would have been deforested by 2011 in the absence of protection respectively.[7] These could still be because even after matching, there are statistically significant differences in the observable baseline characteristics of PAs and matched controls. Table 3 shows several metrics of covariate balance before and after matching for the sample. The fifth and sixth columns of Table 3 present two measures of the differences in the covariate distributions between protected and unprotected areas: the difference in means and the average distance between the two empirical quantile functions (values greater than 0 indicate deviations between the groups in some part of the empirical distribution). If matching is effective, these measures should move towards zero (Ho et al., 2007), which is what we observe. However, by using a post-matching bias-correction procedure that asymptotically removes the conditional bias in finite samples, the last row of Table 4 shows that 4.7% of protected plots would have been deforested by 2011 in the absence of protection which is not much different from the estimates with matching without the bias-correction procedure. To put Table 3's estimates into perspective, consider that 561,920 ha of forest were protected between 1984 and 2011. Thus, conventional methods imply 95,526 ha of avoided deforestation. In contrast, the matching methods imply 26,410-26,972 ha of avoided deforestation (see Figure 4).

In some countries, PAs can be assigned without enough financial resources, or without the infrastructure and networking needed to substitute consumable resources and protect the area from development or misuse. Moreover, PAs are biased towards where they can least prevent land conversion. Often it may be financially and politically expedient to protect public land with low financial value avoiding places with conflictive land use alternatives when considering conservation objectives [4]. In the Chilean context, PAs established in the study area came from public land set aside for conservation purposes. Although the SNASPE law includes private land expropriation for conservation objectives, the history of PAs in Chile does not show evidence of this kind of practice. As a result, the current system of public PAs originates almost exclusively from public land. Therefore, counterfactual scenarios obtained from forest cover changes on matched unprotected land may not reflect same results one may obtain if these counterfactual scenarios are constructed using only public land as potential control unprotected areas. Third column of Table 4 presents DID matching estimates using public land never protected and forested in 1986 as control. Neither estimates from conventional conservation science approaches nor from sample selected by matching show significant estimates of PAs impact on avoided deforestation between 1986 and 2011.

[7] To further address concerns about potential bias, we also present estimates based on matching using calipers to improve covariate balance. Calipers define a tolerance level for judging the quality of the matches: if available controls are not good matches for a treated unit (i.e., there is no match within the caliper), the unit is eliminated from the sample. Calipers reduce potential bias, but at the cost of estimating a treatment effect for only a subset of the sample. In our study, we view calipers as a robustness check. We define the caliper as 0.5 standard deviations of each matching covariate.

Table 4: Estimated avoided deforestation as a proportion of forest protected

	Protected after 1986 (control: never protected and forested in 1986)	Protected after 1986 (control: never protected and foreste
Conventional conservation science approach		
Difference in means[a]	0.169***	0.011
[N protected pixels]	[1978]	[1978]
{N available controls}	{23181}	{339}
Sample selected by covariate matching		
Difference in means[b]	0.047** (0.021)	0.023 (0.081)
[N matched controls]	[1978]	[1978]
Sample selected by covariate matching with calipers[c]		
Difference in means[b]	0.048***	-0.008 (0.029)
[N outside calipers]	[714]	[1018]
{N matched controls with calipers}	{1264}	{960}
Marginal effect from multivariate regression[d]	0.047*** (0.013)	-0.004 (0.013)

[a] Statistical significant difference in means evaluated with a Chi-squared test between treated and control sub-samples.

[b] Standard errors for matching estimates using Abadie-Imbens standard error formula [35]

[c] Calipers restrict matches to units within 0.5 standard deviations of each covariate.

[d] OLS regression on avoided deforestation, with covariates including all variables used in covariate matching.

*, **, *** Significance at 10%, 5% and 1%, respectively.

6. Discussion and conclusions

Conservation practitioners and policymakers need credible information on how PAs policies affect ecosystems. The primary question PAs administrators should ask is whether the conservation scheme has a sufficiently large “additionality” which is the difference in conservation between the with-PAs scenario and the without-PAs baseline [12]. However, the potential level of additionality that a PAs network can provide also depends on where protection is being placed. Most previous evaluations on PAs effectiveness have relied on indirect estimates based on comparisons between protected and unprotected areas. However, such methods could easily be biased when protection is not randomly assigned but rather is determined by characteristics that also affect LULCC (e.g., land productivity, accessibility). Our results confirmed that conventional science approaches claim land cover impacts for protection that are actually due to PA network’s landscape characteristics.

In the Chilean case, the state of conservation of its natural resources is a topic of growing concern among the general public as well as national and international conservation organizations. Previous analysis of Chilean PAs have focused only on ecosystem representation, coverage of biodiversity hot-spots, budgets, and boundary issues. However, conservation additionality of PAs has not been mentioned in any previous study. For this case, we show the selection bias when assigning protection, which might be yielding few additional conservation benefits to one of the oldest systems of PAs in Latin America. Chilean PAs are farther from cities and road networks, and are located on steeper and higher land. They tend to be placed on land less suitable for agriculture and on soil with higher erodibility.

In terms of methodological lessons, results show the importance of the comparison group (i.e. selection of appropriate unprotected land to be used as controls to match PAs). In that sense, finding causal impacts of PAs in terms of forest conservation may well depend on the selection of the appropriate control group. Our analysis illustrates how substantial improvements can be made to estimates of PAs impact. However, in estimating forest conservation effectiveness, the selection of appropriate unprotected land in order to compare with outcome observed in PAs is very important. By using public land as potential unprotected controls to construct counterfactual conservation scenarios, results show no difference between the conservation outcome obtained with PAs and the conservation outcome that would have happened had the PAs not established. In the Chilean context, regulatory regimes are similar between PAs and public land similar to protected land, then public lands similar to PAs are well managed and converting these lands to PAs does not necessarily provide additional conservation benefits. In that sense, results suggest that other public lands similar to PAs are just as well protected. These results raise important questions, such as relative costs of different types of public land management, and whether there are any particular types of public lands where creating PAs would have greater impact. These results also suggest that conversion of private land to PAs may offer more avenues in terms of additional conservation benefits when compared with the conservation scenario including only public lands as potential candidates to create new PAs, however at a more expensive cost for government and society as a whole.

These results are consistent with previous studies that show that logging concessions maintain forest cover as efficiently as PAs (see Gaveau et al., 2013), and then combining PAs with public lands may sustain larger forest landscapes than is possible via PAs alone. A growing number of studies also suggest that selectively logged forests (i.e. a forest management plan similar to management of public lands) might be valuable for biodiversity conservation, and well-managed public land might present a realistic and cost effective strategy for forest protection in addition to PAs. If forest in PAs are approximately as well protected as they are in PAs, as our analysis shows, the Chilean government would do well strategically to commit to keep natural forest on public lands alongside the PA network. However, inclusion of private land into the system of PAs may offer a higher level of additional conservation benefits. Therefore promotion of incentives to include private PAs could be very important, especially considering that the expropriation of private land for conservation purposes is less feasible given the financial constraints of a system with very limited resources to invest in conservation.[8]

[8] A new Biodiversity and Protected Areas Law is currently under discussion in the Chilean congress. One of the new objectives of this law refers to the inclusion of a private network of PAs into a new integrated national system of PAs.

7. Bibliography

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