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Governance, Location and Avoided Deforestation from Protected Areas: Greater Restrictions Can Have Lower Impact, Due to Differences in Location

ALEXANDER PFAFF
Duke University, Durham, USA

JUAN ROBALINO
CATIE, Turrialba, Costa Rica

EIRIVELTHON LIMA
Inter-American Development Bank, Washington, USA

CATALINA SANDOVAL
CATIE, Turrialba, Costa Rica

and

LUIS DIEGO HERRERA *
Duke University, Durham, USA

Summary. — For Acre, in the Brazilian Amazon, we find that protection types with differences in governance, including different constraints on local economic development, also differ in their locations. Taking this into account, we estimate the deforestation impacts of these protection types that feature different levels of restrictions. To avoid bias, we compare these protected locations with unprotected locations that are similar in their characteristics relevant for deforestation. We find that sustainable use protection, whose governance permits some local deforestation, is found on sites with high clearing threat. That allows more avoided deforestation than from integral protection, which bans clearing but seems feasible only further from deforestation threats. Based on our results, it seems that the political economy involved in siting such restrictions on production is likely to affect the ability of protected areas to reduce emissions from deforestation and degradation.

Key words — deforestation, protected areas, livelihoods, REDD, Brazil, Acre

1. INTRODUCTION

Loss of standing forest generates a major component of emissions in developing countries, particularly in the tropics, e.g., Brazil and Indonesia, where recent deforestation has been occurring. As a result, the desire for reductions in emissions from deforestation and degradation (REDD), alongside longstanding concerns about species and other forest services (such as water quality), motivates consideration of various new policies—or shifts in policy—that could conserve forest. Yet, forest protection has tradeoffs. It is a challenge to conserve forest and improve livelihoods. As is clear in World Bank studies of development options (World Bank, 2008, 2010a, 2010b), the sectors that drive losses of forest also play major roles within forested countries' economies. Such conservation-development tradeoffs call for efficiency and creativity within policy, based upon solid evidence.

Any such policy deliberation should involve consideration of candidate policies' impacts upon deforestation, economic aggregates, and distribution (Corbera, Kosoy, & Martinez-Tuna, 2007; Scharlemann *et al.*, 2010, e.g., discuss the choice of policy instruments for REDD). We provide evidence that protected areas that differ in governance also differ in location and, thus, in deforestation impact (others make claims about the local *economic* impact of such interventions; see, e.g., Section 2[1]).

Protected areas generally have been assumed to lower deforestation, yet solid evidence is limited, despite many past

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evaluations (Joppa & Pfaff, 2010a[2]). A policy counterfactual, i.e., a claim about what would have occurred without protection, is required for evaluation. Often, this has not been based upon the characteristics of the protected areas' locations (although lately, the set of conservation evaluations that include more careful counterfactuals has been growing[3]). Our focus is variation in locations. We show that protected-area types which differ in governance also differ in their locations, which, in turn, influence their forest impacts—and thus REDD.[4]

For our study of Acre, in the Brazilian Amazon, local terms for the governance of protection evoke a variety of goals. The less-restrictive governance categories we study are sustainable use (IUCN V–VI[5]), which brings to mind local needs, and indigenous lands (no IUCN bin), which refers to un-empowered peoples. Those two categories can be compared to integral governance (IUCN's I–IV), which is more restrictive, officially not permitting any production and clearing.[6] Acre State clearly sees tradeoffs in improving both forests and livelihoods (e.g., Sills, Pattanayak, Ferraro, & Alger, 2006). Our evidence suggests that local political economy, within various informed deliberate processes (not observed by us, and consistent with Alston *et al.*, 1999), implied that governance differences led to differences across protection types in locations, clearing threats and, thus, forest impacts.

Building upon prior work,[7] we examine deforestation during 2000–04 and 2004–08, in order to estimate the impact on deforestation rates of each of the categories of protected area: sustainable use, indigenous and integral. The impact of a policy is just a difference—between what occurred and a counterfactual scenario, without a policy, that we stress cannot be observed. To estimate such counterfactuals, i.e., what would have happened to the forest in protected areas if not protected, we use clearing of similar unprotected land (supported by theory in Hyde, 2012).

The characteristics of a protected location are critical to include in impact evaluation. Estimating the counterfactual without them, yields errors.[8] A counterfactual based upon clearing for all unprotected land tends to overestimate protected areas' impacts, as it ignores protection's low-threat locations (globally, protection is biased toward lower threats (Joppa & Pfaff, 2009)). That same approach underestimates impact for situations in which conservation targeted threats, as was suggested by Pfaff and Sanchez-Azofeifa (2004) concerning locations for protected areas and as was done for payments in some cases in Costa Rica and Mexico (which were evaluated in Arriagada, Ferraro, Sills, Pattanayak, & Cordero, 2012 and Alix-Garcia, Shapiro, & Sims, 2012, using counterfactuals based on characteristics).

For Acre, we find that protection's locations are, on average, biased toward lower threats. Our matching (apples-to-apples) impact estimate, based on unprotected land similar to protected land, suggests that a great deal of protected forest would have remained standing without policy. This approach lowers impact estimates by over half (from ∼2% avoided deforestation to ∼1%).

We also analyze subsets of protected areas that differ in terms of some key characteristics such as distances to roads and cities—influential in deforestation and the location of protection. For all governance types and for each type, protected areas closer to roads or cities avoided more deforestation than the distant protected areas. Those farther than average from roads and cities effectively did not block clearing, while those closer blocked over twice the average clearing.[9] Time periods also provide subsets that differ in deforestation and in protection's implementation.

Building upon all of that, our focus is the variation in impact by protection's governance. Protection types differ in location—perhaps as governance affects tradeoffs that affect locations. Sustainable use protection targets areas with people, while integral protection seems to target an absence of local stakeholders. Thus, sustainable use protection occurs closer to clearing threats. Due to such locations, sustainable use areas have more impact despite permitting more clearing. Thus, the governance type oriented toward local livelihoods has avoided more deforestation. That is not because forest outcomes necessarily are ordered in this way, for any given location.[10] Rather, it seems that sustainable use protection simply is more feasible in high-threat locations, which is important for decisions about how to allocate the global resources in support of REDD.

The paper proceeds as follows. Section 2 provides background on protection in Acre. Section 3 provides relevant frameworks. Section 4 describes data and our matching approach. Section 5 presents all of our results, while Section 6 concludes with summary and discussion.

2. ACRE'S PROTECTED AREAS

(a) *Multiple investments in protection*

In the Brazilian Amazon, protection includes: (i) developing a legal framework for forest conservation and management, (ii) establishing areas, (iii) regularizing tenure, (iv) developing and implementing management plans, (v) investing in technologies to monitor, (vi) building enforcement capacity, and (vii) supporting sustainable economic activities using natural resources.[11] The range of forms of support is considerable, from basic infrastructure provision including secondary roads through direct support for producers' organizations, such as subsidies or targeted government programs that guarantee the purchase of some local production. Importantly for us, such support goes more to sustainable use areas than to integral protection.[12]

Over the past twelve years, Acre State has invested significant resources in a system of protected areas. To finance this, the state has worked with the Inter-American Development Bank (IDB), World Bank (WB), Banco Nacional de Desenvolvimento Economico e Social (BNDES), Caixa Economica Federal (CEF), and the federal government. In these joint efforts, the government has spent nearly US$500 million on multi-sector projects, each with at least one component on capacity to sustainably manage and protect natural resources, to set up a system of protected areas and to develop and implement a plan to support sustainable economic activities.[13]

Basic investments in Acre included the legal framework for protected areas (Lei Estadual n° 1.426/2001) and the State Economic and Ecological Zoning (Lei Estadual n° 1.904/2007), the main tools used to choose where to create protection and to prioritize investments in land tenure, sustainable business development services, and other social services. Acre is one of the first Amazon states with a wall-to-wall fine-scale (detect forest loss of 2 hectares) monitoring system. This investment was followed up by investments in capacity building for the main government agencies which manage and monitor the protected areas. These actions were linked, eventually, to the creation of nearly 1 million hectares of protected areas during 2004–05 (WWF 2009).

One critical choice by Acre was the large share of sustainable use areas. Today, roughly two-thirds of the protected areas in Acre (combining federal and state) are of the sustainable use protection type (SEMA 2010) highly distinct from integral protection—including investments to develop sustainable businesses for local communities that live inside and around protected areas. Acre State, through several programs and policies, has supported the integration of its extractive communities into supply chains for non-timber forest products and timber. Also, the State has been supporting the development of the forestry sector through forest concessions (state forests are sustainable use protected areas). Last, the State Government has many programs for social protection targeted especially toward families living inside the sustainable-use protected areas.

(b) *Location and management of protection*

For our analyses, the processes determining location and management are very important. According to the Law (n° 4.340/2002), creating an area should be based on both technical studies and public consultations—regardless of the degree of protection. Technical studies cover topics including forest cover, biodiversity, the presence of indigenous and/or traditional communities, land rights, and human pressure. This helps to inform agencies concerning tradeoffs involved in creating protection (and, after creation, involved again in decisions about levels of enforcement). Differences in where sustainable use and integral protection are sited appear quite conscious. For instance, if the prior presence of people living in or more generally using a forest site is seen to dictate sustainable use instead of integral protection, then spatial distributions will differ.

Public consultations are just that: consultations to both receive and provide information. Communities do not possess the power to veto proposed protection, but their feedback is to be taken into account. All of the information gathered should be presented by the environmental agency to the local populations as well as all other interested stakeholders, and in an easy-to-understand fashion. Critical issues include: (i) defining the type of protection to be created (sustainable use *versus* integral); and (ii) the extent and boundaries of protection. If integral locations are located only where there is little local resistance, for example, again, that leads to differences in spatial distribution by protection type, including with respect to clearing pressure.

After all of these studies have been done, and all of these consultations have taken place, a government (federal, state, municipal) decree creates the protection. After that creation occurs, the agency in charge, within five years, should elaborate and approve these management plans.[14] The details of these plans matter—otherwise processes for creating sustainable use and integral protection plans would be exactly the same. Management plans show where and how the natural resources can be used. They also provide a timetable of activities, including the establishment of administrative procedures for management, placement of infrastructure, clarification of tenure, mechanisms for financial sustainability, and monitoring, and law enforcement. All management requirements are in the protected-areas laws, administrative acts, and sector-specific laws. For example, the forest-concessions law and forest code give significant guidance concerning what will be considered "sustainable use economic activities." Looking for a basis for different forest impacts by protection type in these details, the support for smallholder production might suggest that sustainable use areas would avoid less deforestation than integral areas. On the other hand, poorly capitalized households in sites with sustainable use restrictions may not deforest as much as other actors in the same locations, thus those areas could prevent substantial deforestation.

3. PROTECTION'S IMPACTS: CONCEPTUAL FRAMEWORKS

(a) *Importance of location (i.e., land characteristics)*

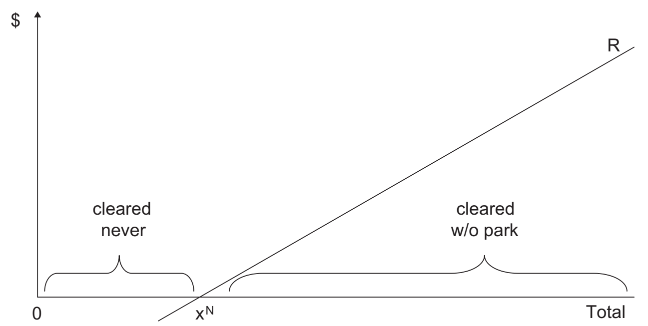
Figure 1 presents a simple but useful framework for considering protected areas' impacts by providing an important perspective on the expected variation in land use without protection. Land is ordered by the rent that it provides, lower to higher as we move to the right (for empirics, we use observed characteristics that affect rents). Where rents are greater than zero, land will be deforested in the absence of protection. Where rents are negative, the land will remain in forest even without protection. Without protection, deforestation will occur only above x^N in Figure 1.

Thus a protected area lowers clearing only above x^N. Its impact thereby depends on what fraction of its land is in that interval. If that is 1, every parcel protected avoided deforestation (here we leave aside any spillover effects, as in Robalino (2007), and in Robalino and Pfaff (2012)). We estimate what fraction of protected land is in that interval which is cleared without protection by examining outcomes for unprotected forested locations similar to the lands in protected areas. If a large fraction of the unprotected locations that are similar to protected lands were deforested, then the protected lands in question will be estimated to have had a large impact on forest cover.

Considering challenges to estimation, if all land above x^N and only that land is protected, it would be impossible to find unprotected land that is like the protected land in all characteristics other than protection. The same is true if all of the land below x^N and only that land is protected. This suggests that when applying matching methods in order to find similar parcels, we must check whether even the most similar land is similar (see Tables 2 and 3 for "balances" after matching).

(b) *Other claims concerning heterogeneous deforestation impacts of protection*

We consider restrictions on resource extraction and how they relate to improvements in forest outcomes. Many indicate that restrictions are important, but yet just establishing them is not enough since compliance needs to be monitored (Ostrom & Nagendra, 2007). The costs of monitoring are, however, significant within the developing countries (Danielsen *et al.*, 2009) and especially when protected areas are large (Banana & Gombya-Ssembajjwe, 2000). Strategies to improve monitoring using local communities who have the appropriate



R = profit from cleared land use minus profit from forested land

Figure 1. *Profitability and private land-use choice.*

incentives might be one form of a solution (Danielsen *et al.*, 2009; Nagendra, Pareet, Sharma, Schweik, & Adhikari, 2007; Ostrom & Nagendra, 2007).

Another important variable said to help explain key outcomes is property rights. These clearly are related to restrictions upon extraction, since property rights define what is allowed. Changes in property-rights regimes in the implementation of protected areas can lead to lower levels of monitoring by local communities and, thus, worse forest outcomes (Somanathan, 1991).

An important element of success is whether local communities are part of the process. When local communities see the creation of a protected area as legitimate, they are more willing to monitor as well as to follow through by sanctioning any illegal activities that are discovered (Ostrom & Nagendra, 2007). It has also been suggested for Uganda, for instance, that when local communities understand what the extraction rules are and when there is enforcement, forests fare better than when enforcement is weak and the locals are not involved (Banana & Gombya-Ssembajjwe, 2000; see also Oestreicher *et al.*, 2009 for one similar result for Panama). Another claim is that conservation that considers enforcement and community participation can address issues related to leakage and to permanence (Oestreicher *et al.*, 2009). Further, for Nepal, regimes with community-based institutions appear to be more effective (Nagendra *et al.*, 2007).

Considering the case when local communities are not involved in the setting of limits, economic and social problems might jeopardize the effectiveness and existence of national parks (Fiallo & Jacobson, 1995). Protected areas with high restrictions might require local people's removal, generating high local costs if there is significant resistance (Brockington & Schmidt-Soltau, 2004). Claims of conflict generated by protected-area creation are common. Evidence of such conflicts has appeared in, for example, Costa Rica (Rodruíguez, 1997), Uganda (Blomley, 2003), Ecuador (Fiallo & Jacobson, 1995), and also Honduras (Pfeffer, Schlelhas, DeGloria, & Gomez, 2005).

Despite all that logic, community-based forest management may not always be effective (Blaikie, 2006). In Zimbabwe, there is evidence that common-property-resource management has been associated with high levels of breakdown in the local institutions (Campbell *et al.*, 2001). One thought is that how property rights were given back to the communities could have caused problems. This process might have led to the benefit of individual interests at the expense of both local livelihoods and wider public interests (Shackleton *et al.*, 2002 (reference in Blaikie, 2006)).

Overall, it is clear that the level of restrictions on extraction by local communities within a protected area could affect the effectiveness of the protected area. The expected sign of such an effect, however, seems to remain ambiguous—depending upon some critical details of a setting. On one hand, high restrictions upon local users might lead to reductions in their monitoring and enforcement since their own motivations could be shifted. High restrictions also could lessen the clarity, going forward, of the effective local property rights and incentives, while also worsening forest outcomes. Further, high restrictions such as Acre's integral protection might affect areas' locations if policy makers, avoiding social conflicts, site protected areas only near to low threat. On the other hand, higher restrictions on local extraction within a protected area also clearly can generate more forest conservation when adequately monitored and enforced in areas with threat.

4. DATA AND MATCHING

(a) *Data*

(i) *Deforestation*

We study deforestation in Acre during 2000–04 and 2004–08. We use PRODES [15] remotely sensed pixel data on land cover in 2000, 2004, and 2008 from INPE (Brazil's *Instituto Nacional de Pesquisas Espaciais*) and calculate the deforestation during these two time periods. For one observation, the data indicate a single class of land cover. Deforestation is the change from the forest land cover to a non-forest land cover. Thus, for each pixel in forest cover in 2000, our deforestation variable is binary, with a value of 1 if the parcel is covered with forest in 2000 but deforested in 2004 and a value of 0 if the parcel is covered with forest in both of these years. For each pixel in forest in 2004, our deforestation variable takes value 1 if the parcel is in forest in 2004 but deforested in 2008 and value 0 if the parcel is covered with forest in both these years.

The original PRODES dataset was downloaded in raster format from INPE's website in Geographic Coordinate System, South American Datum of 1969. The cell resolution of the raster was 0.000808 decimal degrees, which is equivalent to 2.9088 s, or 90 m around the equator once projected. INPE's analysis, since the year 2001, in fact is conducted at a finer scale and then the results are resampled to 90×90 m, in order to create the downloadable data version.

(ii) *Protected areas*

The Brazilian Legal Amazon is a region of 521,742,300 hectares (about 5 million km^2). Acre makes up about 3%. About 44% of the Legal Amazon is protected, with 8% in integral areas, 14% in sustainable use protection, and 22% in indigenous lands. The latter are distinct from federal integral and sustainable use, but we will call them federal given their oversight. For Acre State (see Section 2 above), we have some detail concerning protection, including both the regulations and interventions, by governance type, plus the process for locating protection.

For Acre, State protected area make up less than 1% of our sample, while almost 18% of our sample is in Federal protected areas during our first time period, with almost 26% in the second time period. About 12% of the sample is in indigenous lands—holding relatively steady over these two time periods. For the entire Legal Amazon, most indigenous land was designated during 1990–99, while most federal areas were created during either 1980–89 or 2000–08. For Acre, Figure 2 provides a map of protection. We focus on the areas protected before 2000. We document that areas protected during 2000–04 differ, and we test those separately.

(iii) *Location characteristics*

Many factors that affect the benefits, direct costs, and opportunity costs of clearing forest affect deforestation decisions. Their influence on both deforestation and locations of protection motivates their inclusion. Thus, to correctly infer the impacts of protected areas on deforestation, we need to control for the influences of these location characteristics on rates of deforestation.

Relevant characteristics of any given location which are not features of the land itself are distances to the nearest road in 1985 (a date chosen because it is before most of the protection) as well as distances to the nearest city in 1991 (again, a date chosen to be before protection choice). Another relevant distance is that to the forest's edge. For analyses of 2000–04

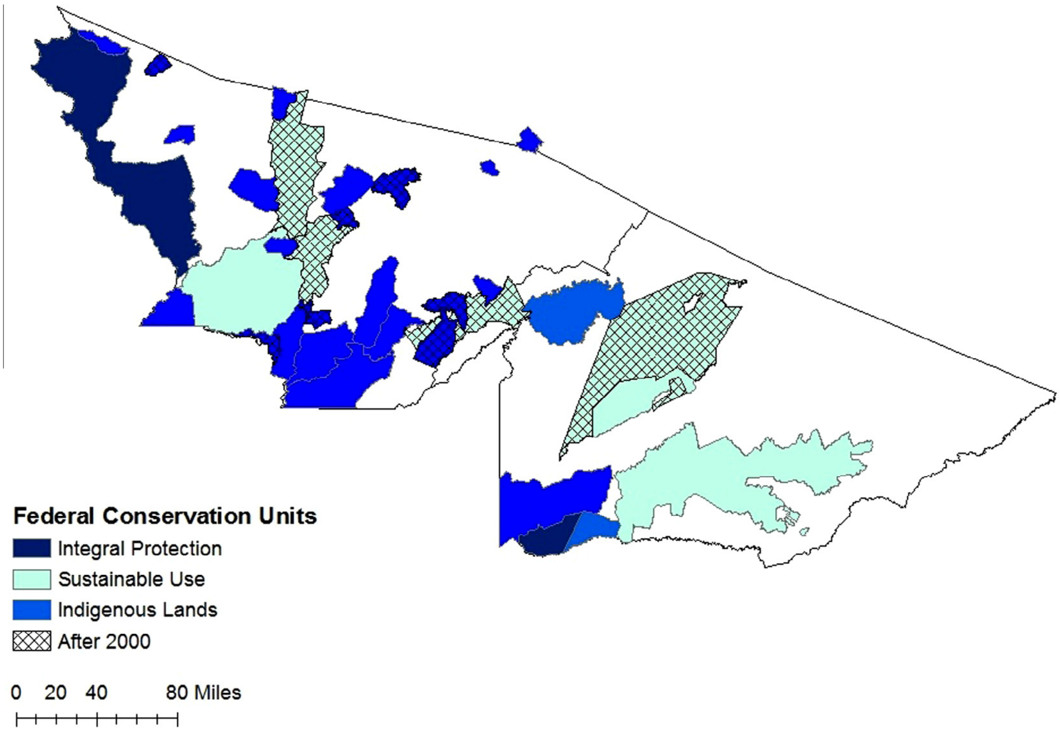


Figure 2. *Acre's protected areas.*

Table 1. *Unprotected and protected forested lands' characteristics*

In 2000	# Hectares	# Obs.	2000–04 Deforest (%)	Distance to road (m)	Distance to city (m)	Distance to edge (m)	Soil fertility (1–9)	Rain index (mm)	Slope index (% flat)
Unprotected land	11,309,897	13,428	2.95	60,742	54,113	5,324	4.17	2,016	22
Land protected before 2000	3,948,203	5,504	0.33	102,868	54,315	5,351	4.47	1,934	10
Federal conservation units	2,551,064	3,327	0.36	87,541	52,748	3,913	4.53	1,928	10
Sustainable-use protection	1,629,145	2,581	0.39	83,281	52,756	3,425	4.62	1,851	10
Integral protection	921,919	746	0.27	102,279	52,720	5,603	4.21	2,193	10
Indigenous land	1,339,538	2,084	0.29	130,988	56,761	7,776	4.44	1,937	07
In 2004	# Hectares	# Obs.	2004–08 Deforest (%)	Distance to road (m)	Distance to city (m)	Distance to edge (m)	Soil fertility (1–9)	Rain index (mm)	Slope index (% flat)
Unprotected land	9,931,282	12,287	2.15	62,092	53,560	5,137	4.15	2,025	23
Land protected before 2000	3,948,203	5,486	0.42	103,027	54,370	4,924	4.47	1,934	10
Federal conservation units	2,551,064	3,315	0.57	87,738	52,827	3,760	4.53	1,928	10
Sustainable-use protection	1,629,145	2,571	0.70	83,519	52,873	3,254	4.62	1,852	11
Integral protection	921,919	744	0.13	102,317	52,670	5,511	4.21	2,193	10
Indigenous land	1,339,538	2,078	0.14	131,088	56,778	6,930	4.44	1,937	07
Land protected 2000–04	1,378,615	2,284	0.13	95,844	65,076	8,242	4.19	2,052	10
Federal conservation units	1,085,472	1,798	0.17	89,306	66,658	8,776	4.19	2,098	10
Sustainable-use protection	1,085,472	1,798	0.17	89,306	66,658	8,776	4.19	2,098	10
Integral protection	—	0	—	—	—	—	—	—	—
Indigenous land	293,143	486	0.00	120,029	59,227	6,264	4.19	1,880	09

deforestation, we use distance to forest edge in 2000, while for 2004–08 deforestation, we use 2004 distances—in both cases employing the same datasets for deforestation that we have just discussed above. The digital road maps were from the Department of Geography at Michigan State University, based on paper maps by DNER (Departamento Nacional de Estradas de Rodagem), an agency in the Transport Ministry in Brazil, while 1991 city information is from the demographic census. We also use maps of relevant biophysical conditions. We employ an index of soil quality, a continuous measure of rainfall (Laurance *et al.*, 2002) and binary indicators of land slope (e.g., whether "steeply sloped" land or "rolling hills") from the Diagnostico product of IBGE (*Instituto Brasileiro de Geografia e Estatistica*). Table 1 provides descriptive statistics (more below).

(iv) *Units of analysis*

Of our 800,000 randomly selected pixels for the Brazilian Amazon (i.e., not every pixel), there are 25,286 in Acre. If our data do not clearly indicate that there is forest cover in

2000 for our first time period (or respectively 2004 for our second time period), then we drop the observation (that occurs for the categories No Data, Non Forest, Water, Clouds, and Residual). This leaves 21,308 forest pixels for 2000, and 21,046 for 2004, the clearing of which we analyze.

We consider a pixel as protected for our first time period only if it is protected in 2000. For our second period, we use the same areas and, separately, analyze new 2000–04 protection. Pixels in protected areas that were created after the time period in question simply are included within the potential controls for that time period, as they were not protected during that period. Pixels within areas created during the time period in question are not included within the analysis because we cannot tell how much of the deforestation occurred before and after the area creation. That leaves 18,948 and 20,072 total observations for our two time periods, respectively, of which 13,439 and 12,297 are in our two control groups, while 5,509 and 7,775 are labeled as protected.

(b) *Empirical strategy—matching*

(i) *Matching basics*

If protection in the Brazilian Amazon and in Acre had been implemented randomly, then its deforestation impact would be easy to estimate. We would only need to look at the difference between the deforestation rate inside and outside of the protected areas. The deforestation rate outside would be an unbiased estimate of what would have been the deforestation rate inside the boundaries of protection had there been no protection, since the other factors would cancel out.

However, neither protection in general nor any protection type seems to be distributed as if location were random. We know from above that sites were not literally chosen at random, and in addition Table 1 conveys that protected lands differ dependably from the unprotected lands. Also, protection types differ from each other, in characteristics that we think affect deforestation. For better inference on protection's impact using observed characteristics we want to address these differences in characteristics, for improved estimated counterfactuals.

To remove the influences of these differences in order to isolate the impact of protection, we apply "matching" methods. The principle is to find improved control groups by "matching" each protected point to the most similar unprotected point(s), for "apples-to-apples" comparisons. Thus, protection will be compared not to all unprotected land, but only to the most similar land. We apply both propensity-score matching and covariate matching, including "exact" matching which forces very high similarity for key variables (e.g., roads), then similarity for all variables.

To define "similarity" in applying propensity-score matching, one uses the probability of a pixel being protected. Thus, the protected pixels are compared to pixels that are not protected but that have similar enough site characteristics to yield a similar probability of being protected. The protection probabilities are generated by a probit model that uses factors that may affect protection and deforestation to explain where protection occurred (Rosenbaum & Rubin, 1983). That means more weight is given to variables which are important determinants of protection.

For covariate matching, "similarity" is defined without any reference to actual protection. Instead, the differences between pixels' characteristics vectors are used directly to match pixels. Those differences generate the similarity index, specifically the multivariate distance between two pixels (Abadie & Imbens, 2006). Thus for a given protected pixel, the distance in the space of all of the factors that may affect deforestation is measured to each of the unprotected pixels.

With similarity defined, we choose how many untreated observations we should compare to each treated observation. There is a tradeoff. As the number of matches increases, the variance of the estimate of protection's impact will decrease, because it will be based on more data. However, the bias will increase, as we have gone beyond the most similar unprotected pixel to ever more dissimilar pixels. To address the latter, for propensity-score matching, we often limit the distance between

Table 2. *Matching improves 2000–04 balance protected minus unprotected, by protection type (for Table 4, row 5; each column is its own analysis)*

	All parks	Sustainable	Integral	Indigenous
Distance to road 1985 (m)				
Pre-matching difference	42,125***	22,539***	1,812***	70,246***
Post-matching difference	8,384***	4,683	6,983***	13,965**
Distance to city 1991 (m)				
Pre-matching difference	202	−1,357**	−1,393	2,648***
Post-matching difference	7	−62	1,486	−462
Distance to forest edge (m)				
Pre-matching difference	26	−1,899***	279	2,452***
Post-matching difference	68	61	−28	111
Soil fertility index (1–9)				
Pre-matching difference	0.30***	0.45	0.05	0.27***
Post-matching difference	0.00	0.00	0.00	0.00
Rain index (mm)				
Pre-matching difference	−82	−164***	178***	−78***
Post-matching difference	−6	−4	−10	−7
Slope (fraction flatter slopes)				
Pre-matching difference	−0.12	−0.12***	−0.12***	−0.16***
Post-matching difference	0.00	0.00	0.00	0.00

Notes: These differences are simple differences in means, showing both scale and sign of difference.
* Significance at 10%.
** Significance at 5%.
*** Significance at 1%.

Table 3. *Matching improves 2004–08 balance protected minus unprotected, by protection type (for Table 5, row 5; each column is its own analysis)*

	All parks	Sustainable	Integral	Indigenous
Distance to road 1985 (m)				
Pre-matching difference	40,935***	21,427***	40,225***	68,996***
Post-matching difference	8,360*	4,792	6,007*	14,065***
Distance to city 1991 (m)				
Pre-matching difference	810*	−687	−890	3,218***
Post-matching difference	289	412	2,016	−349
Distance to forest edge (m)				
Pre-matching difference	−213*	−1,884***	374	1,793***
Post-matching difference	124	48	433	118
Soil fertility index (1–9)				
Pre-matching difference	0.32***	0.47***	0.06	0.29
Post-matching difference	0.00	0.00	0.00	0.00
Rain index (mm)				
Pre-matching difference	−91***	−174***	168***	−88***
Post-matching difference	−7	−5	−8	−8
Slope (fraction flatter slope)				
Pre-matching difference	−0.12***	−0.12***	−0.12***	−0.16***
Post-matching difference	0.00	0.00	0.00	0.00

Notes: These differences are simple differences in means, showing both scale and sign of difference.
* Significance at 10%.
** Significance at 5%.
*** Significance at 1%.

the score of the protected and unprotected observations (using a "caliper"). This allows more matched control observations, for efficiency, while limiting the potential bias. However, to check robustness, also we test different numbers of matches per treated observation.

We also directly check whether the selected unprotected points are, in fact, similar. Tables 2 and 3, for our two time periods respectively, examine the "balance" from matching, i.e., whether the average value of the covariates is distinguishable between protected and matched observations. Ideally it should not be. A significant reduction in differences between groups indicates the potential for this "apples-to-apples" exercise to reduce biases in estimation.

(ii) *Covariates, errors, unobservables, and underlying processes*

Given the balance in covariate averages, matched unprotected deforestation can estimate the counterfactual deforestation for protection. Then, policy impact is simply that counterfactual, minus observed deforestation with protection. However, still there will be differences between these two groups, in terms of location characteristics that are relevant for rates of deforestation. Thus, our preferred matching estimates involve first the matching process and then regressions, which we refer to as "bias adjustment" since this addresses remaining characteristics differences.

Regressions raise issues of regression errors. Natural concerns include spatial correlation, leading neighboring outcomes to be similar, and spatial interactions, if clearing in one site will directly affect its neighbors (Robalino & Pfaff, 2012 for Costa Rica). Given such possibilities, we test for spatial autocorrelation in the errors from regressions after matching (but find none).[16]

The issue of unobservables also immediately raises a question about biases in estimation. While we control for observable characteristics, we do not observe all factors. For instance, we do not know whether the locations considered for protection were populated. We suspect that the factors we do observe, however, such as road and city distances, correlate with unobservables. Thus given our observables, we are not sure of the sign of residual biases. As a robustness check, we computed Rosenbaum bounds to estimate how sensitive our results are to unobservables.

Our time periods, 2000–04 and 2004–08, are analyzed separately from each other. As a general matter, this allows estimated effects of factors other than protection to vary by period, to best eliminate influences in testing protection. For the Brazilian Amazon, also we believe that the underlying processes of clearing shifted over time, including with public actions after 2004. Finally, we cannot study changes over time in integral areas, as none were created in 2000–04.

5. RESULTS

(a) *Where did protection occur?*

(i) *All unprotected* ***versus*** *protected, including by protection type*

Table 1 shows that protected lands' characteristics differ from those of unprotected lands. The two upper rows provide averages for these groups, showing that the protected areas created before 2000 are farther from roads than unprotected lands, as well as less often on gentle slopes. The two groups are not very different in their distances to cities or to forest edges, or in rainfall. The protected lands are deforested less than are the unprotected lands. Of course, given the other differences between the groups, we cannot be sure any difference in clearing is due to protection.

Table 1's second main section refers to the period 2004–08, as noted in the 3rd column. For its upper portion, i.e., the same pre-2000 protected areas considered in the first main section, notable changes are in deforestation: rates fall for Unprotected and for integral and indigenous protection, relative to the 2000–04 rates; for sustainable use protection, however, deforestation rises. Also, in the bottom portion of this section we can see that the land protected during 2000–04 is different from the land protected before 2000. The clearest difference is distance to forest edge. For newly created protection, the distance to forest edge is on the order of twice as large as for pre-2000 protection.

Looking at different types of protected areas, which officially are essentially all federal[17] but feature distinct types of governance, we also see location differences across protection types. Looking across the types within the set of pre-2000 protected areas, the distances to cities, slopes, and rain do not differ much, but distances to roads and forest edges do. Within the newly created protected areas, we cannot compare across these types, as no integral protection was created.

(ii) *Matched unprotected versus protected, including by protection type*

Tables 2 and 3 show that among unprotected lands, there are points sufficiently similar to the protected lands that the matched, or most similar, unprotected lands are not significantly different in most characteristics. It was not easy, though, to find a balance for all characteristics: the unprotected lands similar to protected land on one dimension often differed on another one. Thus an important basis for selecting across estimates is achievement of greatest balance, though some differences will remain even for the best balances, motivating post-matching regressions.

Table 2 shows that significant differences are eliminated for all the other characteristics, when using the most similar unprotected land, yet protected lands still have greater road distance. Specifically, the table shows residual differences, on average, for integral and indigenous areas. In of itself, that is a clear statement—repeated in Table 3—of rather distinct locations by type. We note that these residual differences in distance to road would bias impact estimates upward, if anything, for integral and indigenous areas, but our impact estimates for those types are zero.

(b) *Average protection's forest impacts (combining all protection types)*

(i) *All parks, pre-2000 protection, all observations*

Table 4's 1st column (starting in the upper matrix then in sub-columns in lower matrices) considers all of the pre-2000 protection together—the aggregate of all three types of protection. Its first row conveys that the deforestation rate within park boundaries is about 2.7% lower than the deforestation rate on all unprotected land in Acre. That is a non-trivial effect for 2000–04, and the analogous cell in Table 5 finds a difference of almost 1.8% in the rates for 2004–08.

However, that value may reflect different locations for protected *versus* unprotected land. The other five cells, in that first column of Table 4's upper matrix, suggest that this is the case. Controlling for the differences in the land characteristics seen earlier, using OLS or matching of two types (both "bias adjusted", using regressions for just the points selected by the matching), reduces the estimated deforestation impact of protection to 1% or less for the 2000–04 period. Table 5 makes the same point for 2004–08 deforestation, in fact finding no significant impact using covariate matching given the corrections for locations plus lower clearing in this period.

(ii) *All parks, new 2000–04 protection, all observations*

Such improved estimates of impacts may vary across older *versus* newer protection since, of course, the choices driving the spatial distribution of protection can vary across time periods. Table 6 considers the impacts on 2004–08 deforestation of the new protected areas that were created during 2000–04. Sticking with the combined effect of all protection, i.e., 1st column, the first row conveys that the clearing on protected land is 2% lower than on unprotected land. Again, though, controlling for differences in land characteristics lowers the estimates of impact. For these new protected areas, in fact, all forms of corrected impact estimates are insignificant. The protection-

Table 4. *Pre-2000 protection's impacts on 2000–04 deforestation*

Protection pre-2000	All parks	Sustainable use	Integral	Indigenous
Compare means (full sample)	−2.66%***	−2.55%***	−2.80%***	−2.70%***
OLS regression (full sample)[a]	−1.22%***	−2.65%***	0.45%	−0.33%
P.S. match, caliper 1%, $n = 1$, bias adjusted[a]	−1.08%***	−4.21%***	−0.95%**	−0.38%
P.S. match, caliper 1%, $n = 4$, bias adjusted[a]	−1.14%***	−3.50%***	−0.74%**	−0.26%*
Covariate matching, $n = 1$, bias adjusted[a]	−0.46%	−1.01%*	−1.05%	0.27%
Covariate matching, $n = 4$, bias adjusted[a]	−0.54%**	−1.25%**	0.63%	0.23%
# Treated obs.	*5,504*	*2,581*	*746*	*2,084*

	HighDist	LowDist	HighDist	LowDist	HighDist	LowDist	HighDist	LowDist
Split by distance to road[b]								
Covariate matching, $n = 1$, bias adjusted[a]	−0.04%	−2.12%*	−0.23%	−2.58%*	−0.61%	—	0.30%	−0.90%
Covariate matching, $n = 4$, bias adjusted[a]	0.06%	−2.63%***	−0.22%	−3.56%***	−0.44%	—	0.26%	−0.76%
# Treated obs.	*4,033*	*1,471*	*1,310*	*1,271*	*746*	—	*1,977*	*107*
Split by distance to city[c]								
Covariate matching, $n = 1$, bias adjusted[a]	−0.13%	−0.89%	−0.18%	−1.84%*	−0.99%	0.82%	0.24%	0.36%
Covariate matching, $n = 4$, bias adjusted[a]	−0.08%	−1.12%***	−0.21%	−2.48%***	0.01%	−1.11%**	0.20%	0.39%
# Treated obs.	*2,985*	*2,519*	*1,213*	*1,368*	*432*	*314*	*1,256*	*828*

* Significance at 10%
** Significance at 5%.
*** Significance at 1%.
[a] We use distance to cities, distance to roads, distance to forest edge, soil fertility index, rain index, and slope as control variables in these regressions.
[b] Cutoff value was 10.99.
[c] Cutoff value was 10.82.

Table 5. *Pre-2000 protection's impacts on 2004–08 deforestation*

Protection pre-2000	All parks		Sustainable use		Integral		Indigenous	
Compare means (full sample)	−1.78%***		−1.47%***		−2.07%***		−2.02%***	
OLS regression (full sample)[a]	−0.93%***		−1.71%***		−0.16%		−0.20%	
P.S. match, caliper 1%, $n = 1$, bias adjusted[a]	−0.51%***		−2.08%***		−0.21%		−0.25%	
P.S. match, caliper 1%, $n = 4$, bias adjusted[a]	−0.42%***		−1.74%***		−0.32%		−0.39%**	
Covariate matching, $n = 1$, bias adjusted[a]	−0.03%		−0.15%		−0.02%		0.14%	
Covariate matching, $n = 4$, bias adjusted[a]	−0.17%		−0.37%		0.02%		0.10%	
# Treated obs.	*5,486*		*2,571*		*744*		*2,078*	
	HighDist	LowDist	HighDist	LowDist	HighDist	LowDist	HighDist	LowDist
Split by distance to road[b]								
Covariate matching, $n = 1$, bias adjusted[a]	0.07%	−0.03%	−0.06%	0.53%	−0.04%	—	0.15%	([4])
Covariate matching, $n = 4$, bias adjusted[a]	0.03%	−0.36%	−0.13%	−0.18%	−0.08%	—	0.12%	−0.41%
# Treated obs.	*3,912*	*1,574*	*1,208*	*1,363*	*741*	—	*1,963*	*115*
Split by distance to city[c]								
Covariate matching, $n = 1$, bias adjusted[a]	0.06%	−0.43%	−0.11%	−0.90%**	([d])	−0.06%	0.15%	0.13%
Covariate matching, $n = 4$, bias adjusted[a]	0.05%	−0.50%	−0.07%	−0.89%	([d])	0.12%	0.15%	0.03%
# Treated obs.	*2,916*	*2,570*	*1,181*	*1,390*	*422*	*322*	*1,231*	*847*

* Significance at 10%.
** Significance at 5%.
*** Significance at 1%.
[a] We use distance to cities, distance to roads, distance to forest edge, soil fertility index, rain index, and slope as control variables in these regressions.
[b] Cutoff value was 11.07.
[c] Cutoff value was 10.83.
[d] Neither treated nor matched control observations were deforested in these comparison samples.

Table 6. *New (2000–04) protection's impacts on 2004–08 deforestation*

New protection 2000–04	All parks		Sustainable use		Integral		Indigenous	
Compare means (full sample)	−2.02%***		−1.99%***		—		−2.15%***	
OLS regression (full sample)[a]	0.21%		0.61%*		—		−1.17%**	
P.S. match, caliper 1%, $n = 1$, bias adjusted[a]	−0.08%		−0.22%		—		−0.50%*	
P.S. match, caliper 1%, $n = 4$, bias adjusted[a]	−0.14%		0.02%		—		−0.70%***	
Covariate matching, $n = 1$, bias adjusted[a]	−0.09%		−0.09%		—		−0.22%	
Covariate matching, $n = 4$, bias adjusted[a]	−0.11%		−0.08%		—		−0.32%	
# Treated obs.	*2,284*		*1,798*		—		*486*	
	HighDist	LowDist	HighDist	LowDist	HighDist	LowDist	HighDist	LowDist
Split by distance to road[b]								
Covariate matching, $n = 1$, bias adjusted[a]	0.12%	0.03%	0.21%	0.27%	—	—	([d])	([d])
Covariate matching, $n = 4$, bias adjusted[a]	0.09%	0.08%	0.21%	0.29%	—	—	−0.10%	−0.42%
# Treated obs.	*1,755*	*529*	*1,402*	*396*	—	—	*353*	*133*
Split by distance to city[c]								
Covariate matching, $n = 1$, bias adjusted[a]	−0.27%	0.04%	−0.29%	0.25%	—	—	([d])	−1.15%
Covariate matching, $n = 4$, bias adjusted[a]	−0.25%	−0.16%	−0.27%	0.19%	—	—	−0.16%	−0.53%
# Treated obs.	*1,660*	*624*	*1,302*	*496*	—	—	*358*	*128*

* Significance at 10%.
** Significance at 5%.
*** Significance at 1%.
[a] We use distance to cities, distance to roads, distance to forest edge, soil fertility index, rain index, and slope as control variables in these regressions.
[b] Cutoff value was 11.07.
[c] Cutoff value was 10.83.
[d] Neither treated nor matched control observations were deforested in these comparison samples.

location decisions during 2000–04 clearly differ from those made before 2000.

(iii) *All parks, pre-2000 protection by threat proximity*

Following Table 4's first column to the lower matrices where the sample has been split provides our analyses of the effects on protection's forest impact of two location characteristics. The upper of these additional matrices presents results for subgroups delineated by road distance, with sub-columns of "all parks" (1st) for above- and below-median distances to the nearest road. Below that, in the lower matrix, there are sub-columns delineated by distance to the nearest city (note: in these split-sample tables, we present only the matching estimators with best balances).

For those protected areas that are located farther than the average from the nearest road, the impact estimates are lower than for all parks taken together. The coefficients are about one-tenth as big as the analogous impact estimate using the full sample of all observations. Further, both of the coefficients effectively are zero, in the sense of being statistically insignificant. In strong contrast to this, the estimated impact is higher for the points with lower distances to roads. Each bias-adjusted-covariate-matching estimate is about four times as big as for all observations, noting that a lower degree of significance for $n = 1$ *versus* $n = 4$ could result from fewer data points. At the very least, it is clear that distance to roads powerfully affects protection's forest impact, although for the 2004–08 time period featuring lower deforestation, even for the subset with lower distances to roads the larger estimated impacts are not significant for either the pre-2000 protected areas (Table 5) or the protected areas newly created during 2000–04 (Table 6).

The lower matrix takes the same approach to exploring effects of the distances to cities. Again, the impact estimate for the higher-distance points is well below the impact for all points, while lower-distance areas have higher impact. The message from these threat-proximity subsets is that proximity of protection to drivers of clearing pressure affects protection's forest impact.

(c) *Average forest impacts by protection type*

(i) *Sustainable use versus integral versus indigenous, pre-2000 protection, all observations*

The last columns of Table 4 for 2000–04 impacts and Tables 5 and 6 for 2004–08 separately examine the three types of protection. Differences across these types in the clearing within protected areas can be seen in the top row, where the impact estimate is computed as average clearing within the protected areas, minus average clearing within the unprotected areas. Thus, differences in the top-row estimates reflect differences in the clearing in protected areas. They confirm, from Table 1, that deforestation in protected areas is lowest for integral areas and next lowest for indigenous lands and, finally, that it is highest for the sustainable use protection.

Despite that, in Table 4 sustainable use is the only type with robust significant impact. Put another way, while more clearing is taking place within the borders of sustainable use areas, on net only sustainable use protection produces lower deforestation than on unprotected lands. That can hold only if deforestation on the unprotected lands being compared with protected lands varies by protection type—precisely the case if matching selects the similar unprotected lands. Clearing prevented by sustainable use areas is higher, since their locations feature higher threat.

For 2004–08 impact, Table 5 confirms these points. Its top row shows that clearing in protected areas again is highest for sustainable use. Further, the difference across types grew. Given lower deforestation overall during 2004–08, it is even more clear that the integral and indigenous protection types did not significantly lower deforestation relative to unprotected land. However, it appears that how sustainable use protection was implemented perhaps had shifted (recalling Table 1). While the 2nd–4th rows show sustainable use as having significant impact for this time period, given changed deforestation and implementation rows 5 and 6 show no impact. Table 6 finds the same for newly created protection, which is not a surprise given its locations.

(ii) *Sustainable use versus integral versus indigenous, pre-2000 protection, threat-proximity subsets*

That the sustainable use areas have both most internal clearing and the greatest impact on forest seems unintuitive—but the solution is that sustainable use is located closer to clearing pressure. The results for the subsamples in the lower matrices of Table 3 show the importance of pressure in two ways: first, sustainable use subsets farther from threats have significantly lower impacts; second, sustainable use subsets closer to pressure have greater impacts than the type as a whole.

Following Table 4's sustainable use column to the middle matrix where the samples are split by road distance, the protected points further from roads do not produce significant impact. Those closer, however, have impacts at least twice as high as the average for this governance. Table 4's lowest matrix for sustainable use shows that distances to a city also matter this way. For Table 5, again focusing on estimates with the best balance when considering these subsets, just as for all parks, the lack of average 2004–08 impact for this governance yields no effects.

These lower matrices' splits of integral and indigenous protection also are illuminating. Uniformly, for each protection type, impact estimates from this best-balanced form of controls produce insignificant impacts for the subsets of locations farther from threat. In contrast, even for these types, the impact estimates are higher closer to threat, and one such estimate is significant.

Strikingly, there are no integral points at all that are "close" to the nearest road, meaning closer than the overall average distance to roads. This sharply conveys differences across types in their spatial distributions of protection. Along these lines, and returning to our central focus, within the subsets of protection that are closer to threat than average, where the real impacts lie, in Tables 4 and 5 clearly it is sustainable use areas that have the highest deforestation impact.

(iii) *Robustness checks*

Robustness was the reason to have several approaches included in Tables 4–6. There does not exist any single-best definition of "similarity," nor is there any single truth about how best to control for the differences across groups in the characteristics of their locations. When looking across all these estimates, we emphasized the value of achieving good balances.

Recall that, for matching, our goal was to compare protected lands with the unprotected lands that are the most similar. Yet, such matching can make use of only the observable location characteristics. Characteristics that are not observed could bias estimates of protection's impact. For a sense of how strong a bias in the unobservables that may affect treatment would have to be in order for our estimates to be nullified, we compute "Rosenbaum bounds" for sustainable use. They indicate how much effect the unobservable characteristics would have to have upon the chance of land being protected—controlling for observables—in order for deforestation impacts that we estimate to be consistent with protection's true deforestation impact being insignificant.

For the propensity-score-matching result for 2000–04 deforestation, for the sustainable use protection type (Table 4, $n = 4$, for example), we find that this gamma parameter concerning potential influence of unobservables would have to be between 3.5 and 4. We would need such a parameter value for the estimated impact we provide to, in fact, not be significant at a 5% level. Putting it another way, in order for our estimate of the impact not to indicate any actual impact, two points with the same observable characteristics would have to differ by a factor of almost four in the likelihood of being protected, due solely to the differences in terms of unobservables. That is quite large. For our impact estimate not to imply significance at a 10% level, of course any such influence would have to be even greater, in that case a gamma value between 4 and 4.5.

6. DISCUSSION

We found that, on average, protection in Acre tends toward lower clearing pressure, limiting deforestation impact. Yet sustainable use protected areas face relatively higher threat. Thus, though that less restrictive form of governance permits some deforestation, still its partial blockage of higher clearing threats on average avoided more deforestation than strict protection. Such results are highly relevant for the allocation of any global resources in support of REDD.

Acre's indigenous lands, which also permit livelihoods, did not have a significant impact, in contrast with other Brazilian Amazon findings (Nepstad *et al.*, 2006; Pfaff, Robalino, & Herrera, 2011a, 2011b). We suspect that siting processes for indigenous lands differ somewhat from siting of other forms of governance, implying a different correlation with threat for Acre than for the entire Amazon, such that our results for indigenous land may not have broad implication for its role(s) in REDD.

We also observed changes over time in protection's siting and in how the sustainable use protection was implemented, in addition to shifts over time in background deforestation process. Future work could extend such findings over space and time. Other locations with governance differences in protection could be studied, in particular if siting processes are directly observed. Studying locations featuring new protection within more than one governance type also can add insight, especially if protection types' spatial distributions overlap, facilitating cleaner comparisons. Spatially disaggregated socioeconomic data that were not available here also can extend learning.

Focusing more on temporal shifts *per se*, the dynamics of development have implications for impacts of conservation policies such as protected areas. Locations now facing lower threats could, in the future, face higher threats as development patterns unfold on the evolving frontier. Stone (1998) for instance, documents the evolution of the timber industry in Pará, another state in the Brazilian Amazon. Such shifts over time can greatly shift a policy's impact, consistent with results on protected areas' shifting impacts in Panama within Haruna, Pfaff, van den Ende, and Joppa (submitted for publication). Policies could even shift those development dynamics, as noted within Pfaff and Robalino (2012).

Acre's significant investments in sustainable use protected areas provide a nice case for considering whether REDD funds should ever go to support existing networks of protected areas. Existing protection certainly could be defined as "within the no-REDD baseline," implying that forest is considered protected already and is expected to remain standing without REDD funds. On the other hand, Acre's investments in support of local livelihoods within protected areas may suggest that protection is not politically sustainable or dependable as economic conditions shift. Thus, in principle, REDD support for existing networks of protected areas could have impacts.

More generally, for REDD or other efforts to produce additional conservation of forest, i.e., more than would happen without policy, our results emphasize the importance of baselines. In particular, the baseline clearing rate that can be blocked by a policy varies greatly across space and it should be considered as an important determinant of potential for avoided deforestation. Of course there are tradeoffs, for instance land with higher baseline clearing may be more costly. However, baseline threat is critical and our results emphasize that differences in the threats faced can invert the expected ranking of protection types, in terms of the deforestation that is blocked.

Finally, we emphasize that local economic costs and, related, local political feasibility are natural reasons to expect differences by the type of protection in location, and thus threats faced. Local costs make it politically unfeasible to protect land without some flexibility for production. Our results show flexibility can be more effective in reducing deforestation if higher-threat areas can be protected. More generally, stakeholders' well-being is critical for effective local strategy.

NOTES

1. We note, to emphasize the contrast, that in our case these are not primarily benefits of tourism. See, e.g., Ferraro and Hanauer (2011), Ferraro, Hanauer, and Sims (2011), Sims (2010), and Robalino , Pfaff, Sanchez-Azofeifa, and Villalobos, (2012) for rigorous evidence of protection benefits in Costa Rica and in Thailand.

2. Joppa and Pfaff (2010a) review a rich evaluation literature—see a review by Naughton-Treves, Holland, and Brandon (2005) as well, plus two more recent such reviews by Nagendra (2008) and by Campbell *et al.* (2008). As do we, they emphasize the hurdles for solid inference about protection's impacts upon forests. Protected areas' impacts have been evaluated frequently but the methods used have varied a lot. Some evaluations do not compare but only observe that forest is standing (see Fuller *et al.*, 2004). These lack a comparison to what would have happened had a protected area not been protected. Others compare outcomes within protected-area boundaries to outcomes in all unprotected areas (see DeFries, Hansen, Newton, & Hansen, 2005; Gaveau, Wandono, & Setiabudi, 2007; Messina, Walsh, Mena, & Delamater, 2006; Sánchez-Azofeifa, Quesada-Mateo, Gonzalez-Quesada, Dayanandan, & Bawa, 1999). Many compare protection's outcomes to those in the areas immediately surrounding protection (Bruner, Gullison, Rice, & da Fonseca, 2001; Curran *et al.*, 2004; Kinnaird, Sanderson, O'Brien, Wibisono, & Woolmer, 2003; Liu *et al.*, 2001; Sader, Hayes, Coan, & Soza, 2001; Vin~a *et al.*, 2007). These have not tried to control explicitly for differences in characteristics.

3. Just a few examples, highlighting some work that also discusses heterogeneity in the impacts of protection over space, are Cropper, Puri, and Griffiths (2001), Sims (2010), and Ferrao *et al.* (2011). Such heterogeneity in impact is not surprising in light of longstanding theory about variation in land use across a landscape, such as nicely laid out in Hyde's (2012) perspectives upon forestry.

4. Nelson and Chomitz (2011) is particularly relevant in terms of its focus on types of protection. Our local and deforestation focus is complementary to the focus in that work on the entire globe and fire as an outcome. Alston, Libecap, and Mueller (1999) discuss the relationships of governance and location on the Amazon frontier.

5. For categorizing protection types, IUCN provides a globally applicable strictness ranking by translating local descriptions into their comparable categories, from highest (I) to lowest (VI).

6. The web site http://www.planalto.gov.br/ccivil_03/Leis/L9985.htm provides the law creating the national system of PAs. It defines sustainable-use and integral-protection PAs in chapter III. The specific regulations are partially hyperlinked within the law. For instance, sustainable forest management is regulated by forest code (http://www.planalto.gov.br/ccivil_03/Leis/L4771.htm) and by decree (http://www.planalto.gov.br/ccivil_03/_Ato2004-2006/2006/Decreto/D5975.htm).

7. Andam, Ferraro, Pfaff, Sanchez, and Robalino (2008) apply the same method to average impacts of protection in Costa Rica, while Joppa and Pfaff (2010b) demonstrate that such corrections are important around the globe. Pfaff, Robalino, Sanchez-Azofeifa, Andam, and Ferraro (2009) demonstrate the significant heterogeneity of such improved estimates across space, along easily observable dimensions relevant for the baseline threat of deforestation. Pfaff *et al.* (2011a) apply the approach taken within Pfaff *et al.* (2009) to the Brazilian Amazon. Delgado and Pfaff, 2008 provide an application to a well-known case within Acre, close to the Interoceanic Highway, the Chico Mendes extractive reserve—which has had impact.

8. That is because of the non-random distribution of protection along dimensions relevant for the rate of deforestation. For analyses of the distributions of existing protection (some with views on remaining gaps), see for instance Oldfield, Smith, Harrop, and Leader-Williams (2004), Fearnside and Ferraz (1995), Powell, Barborak, and Rodriguez (2000), Hunter and Yonzon (1993), Ramesh, Menon, and Bawa (1997) and, for the globe, Joppa and Pfaff (2009).

9. This confirms the findings from earlier such comparisons, e.g., Pfaff *et al.* (2009) for Costa Rica.

10. It is possible that this could be the ordering, e.g., if having local occupants is a critical part of enforcement of protection, or if local stakeholders alert agencies concerning illegal intrusions.

11. Silva (2005) lays out the Brazilian protected-areas program, noting that it is in agreement with the Convention on Biological Diversity's (CBD) Program of Work on Protected Areas (PWPA).

12. Stepping back to the source or legal framework, the Law No. 9.985/2000, which establishes the system of protected areas in Brazil, addresses two major issues. First, it divides protected areas into two categories: (1) strictly protected, with biodiversity conservation as the principal objective (equivalent to IUCN categories I, II, and III); and (2) sustainable use, allowing for varying forms and degrees of natural resources use, with biodiversity protection as a secondary objective (equivalent to IUCN IV, V, and VI). Second, the law requires the development of management plan for the protected areas. The management plans are very important because they set limits and best practices for the sustainable use of natural resources that are compatible with the goals of the protected area. In addition, there are regulations aimed at specific economic activities, which apply for economic activities inside and outside protected areas. For instance, selective logging could be done in the national forests and extractive reserves. In both cases, logging must follow the forest code and its regulations (Law No. 4.771/1965).

13. Past investments of the multilateral development banks (MDBs) in Acre mostly have been multi-sector operations, a common strategy to reduce transaction costs. Nearly all the MDB operations have a component on environmental and natural resource management but it is not easy to get the exact number for all financial resources allocated to the protected areas system and associated sustainable development activities. The authors estimate that perhaps 15–20% of that US$500 million figure went into protected areas, environmental management, and sustainable development.

14. Such a process suggests that people considering private decisions concerning any potentially protected areas may get considerable signals over time about the possible arrival of protection. Such information could well affect those private decisions, such as whether to acquire any of the land, since if protection arrives while longstanding ownership cannot be documented, then land invasion will be assumed. Such a process could imply that new protected areas can have impact before actually being officially created. For our purposes, at the least it suggests it is reasonable to assume that the areas created by 1999 (or 2003) can affect 2000–04 (2004–08) outcomes.

15. PRODES (http://www.obt.inpe.br/prodes/) is a project for satellite monitoring of the Amazon.

16. For each of the two time periods analyzed, we consider autocorrelation at different distances, from 5 to 20 km. For none of these distances or time periods did we find any significant tests.

17. Indigenous lands are labeled "federal" here—in the sense that they are overseen by the federal government (although indigenous peoples have considerable autonomy within them). They are, on the other hand, clearly distinct from the other federal areas—integral and sustainable use.

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