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LETTER

Avoided Deforestation Linked to Environmental Registration of Properties in the Brazilian Amazon

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Abstract

We quantified the avoided deforestation impacts of environmental land registration in Brazil's Amazonian states of Mato Grosso and Pará between 2005 and 2014. We find that the program reduced deforestation on registered lands. The magnitude of the effect implies that deforestation in the two states would have been 10% higher in the absence of the program. The impacts of registration varied over time, likely due to changing suites of policies linking environmental registration to land use incentives. Our results also reveal that agriculturally suitable lands and those located in regions undergoing the most land-use change were more likely to be registered than those in less suitable, less dynamic regions. We conclude that environmental registration is an important first step in implementing avoided deforestation policies targeting private landholders.

Introduction

Forest conservation has the potential to provide as much as 40% of the emission reductions needed to mitigate climate change (Baccini *et al.* 2012; Harris *et al.* 2012). Brazil houses nearly 13% of the world's remaining forests (Food and Agriculture Organization 2016), and although its deforestation rate has slowed in recent years, it remains the second highest contributor to global forest loss (Food and Agriculture Organization 2016). Efforts by private and public sector actors have turned Brazil's Amazon into a laboratory for deforestation policy, especially for conservation on private properties (Siqueira *et al.* 2015; Richards & VanWey 2015).

A variety of interventions have aimed to control deforestation on private lands in the Brazilian Amazon, including improved satellite monitoring (Shimabukuro *et al.* 2007; Assunção *et al.* 2014), increased enforcement of the Forest Code (Arima *et al.* 2014; Nepstad *et al.* 2014), credit restrictions for areas involved in excessive deforestation (Conselho Monetário Nacional 2008; Assunção *et al.* 2013), and private sector zero-deforestation agreements (Gibbs H. K. *et al.* 2015a; Gibbs H. *et al.* 2015b). Maps of private properties, which facilitate land-use monitoring, link responsibility to a specific producer, and open the path to secure tenure, have the potential to strengthen forest governance efforts (Rajão *et al.* 2012). Brazil has made substantial progress mapping properties for environmental registration, first with a handful of state-level systems in the Amazon, and more recently with a national "SiCAR" system (Sistema Nacional de Cadastro Ambiental Rural, SiCAR 2016). This article assesses changes in deforestation behavior associated with environmental registration in the Amazon states of Mato Grosso and Pará, which had the most developed state-level systems that preceded the SiCAR, and also the highest deforestation rates among states in the Amazon (INPE 2015).

The goals of registration programs were similar in the two states: to inform officials and property owners about the degree of Forest Code compliance on each property and to qualify properties for rural activity licenses. Pará's Rural Environmental Registry (CAR by its Portuguese acronym) was introduced in 2004 for rural properties involved in economic enterprises, and then redesigned in 2008, when it became obligatory for all properties (State of Pará 2006, 2008). Mato Grosso began offering the LAU (Licença Ambiental Única) for properties compliant with the Forest Code as a prerequisite for certain operational licenses, including those for legal deforestation. In 2009, Mato Grosso introduced the CAR as a voluntary program and a first step toward LAU. Both state governments heavily promoted registration. In Mato Grosso, the MT Legal program protected registrants from fines due to old illegal deforestation as they pursued Forest Code compliance, and in Pará municipal governments received incentives to promote enrollment (State of Pará 2016). In addition, multiple nongovernmental organizations launched campaigns to promote registration, sometimes with support from producers' unions and municipal governments (Brannstrom *et al.* 2012). Many of these programs were still focused on promoting registration during the study period and had not yet used the CAR to sanction noncompliant deforestation, with the exception of the zero-deforestation cattle agreements (Gibbs H. K. *et al.* 2015a). Table S1 presents a timeline of policy actions.

CAR implementation varied between the states. The most important difference was the ease of registration. Pará offered registrants a provisional CAR based on self-declared, unverified information about property location and extent of forest set-asides (SIMLAM 2008). Mato Grosso, on the other hand, issued a CAR only after an application review process and the signing of legally binding plan to achieve full Forest Code compliance (State of Mato Grosso 2008). Brazil's national SiCAR process parallels that of Pará.

This article presents estimates of the impact of CAR registration on deforestation. Specifically, we examined the impacts of registration in Mato Grosso and Pará between 2006 and 2013 using randomly drawn points from the forested area of the two states. We developed a rigorous counterfactual by limiting our analysis to only areas that eventually enrolled properties, and exploited variation in the timing of enrollment to identify CAR's effect on forest cover. To assess how representative enrolled areas are of the eligible regions of the state, we measured differences in geographic characteristics between areas that enrolled in CAR during the study period and those that did not. Finally, we compared outcomes between the states, and examined how impacts changed over time as complementary policies evolved.

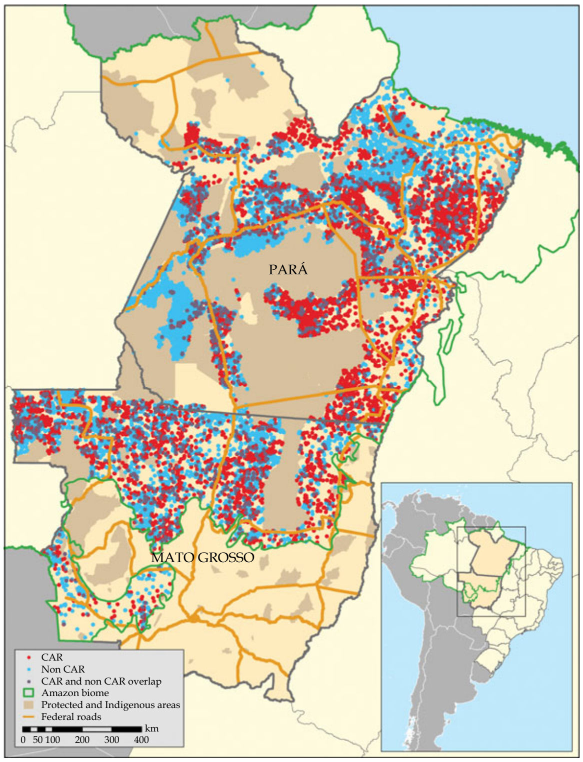

Figure 1 Sample points.
Estimation sample. Excludes points without forest in 2005, as well as points falling in various types of conservation areas, indigenous reserves, and INCRA settlement zones.

Methods

Study area and data

We quantified avoided deforestation from property registration across the state of Pará and the portion of Mato Grosso in the Amazon biome. We divided the study area into four zones and generated 10,000 random points within each for a total of 40,000 random points. The zones were defined as areas of Pará with and without CAR, and areas of Mato Grosso with and without CAR or LAU (Section S2). Areas not eligible for registration in CAR were excluded.

Figure 1 shows the points in the sample that still had forest in 2005 and were eligible for CAR registration. It illustrates that large areas of Pará are ineligible for CAR, that there are remote eligible areas where points tend not to be registered, and that there are many unregistered points clustered near those that are registered.

As points have no area, we assign characteristics of the layers on which they fall to each point. The outcome variable is an indicator for presence of forest cover from 2005 to 2014 measured using Brazil's PRODES forest monitoring data (INPE 2015). A key control variable, potential for agricultural productivity, was extracted from a soy production suitability map (Soares-Filho *et al.* 2014). For the purposes of assessing selection bias, we also examine other geographic point characteristics, including elevation, slope, distance from nearest city and highway, and deforestation risk.

Estimating avoided deforestation on CAR properties

We estimated avoided deforestation between 2005 and 2014 at the point level on areas that registered from 2006 to 2013. Because PRODES measures gross deforestation only, we excluded points where forest was already cleared by 2005. In our models that measured treatment effect, we restricted our sample to points falling inside properties that eventually enrolled during our study period. We used a linear probability model with fixed effects at the point level and time effects for each year (formal model in Section S4). We also included interaction terms between year effects and state, as well as between year effects and land productivity. We also tested whether there was heterogeneity in program impacts across states and time periods.

Our approach identified the effect of registration by comparing properties that registered earlier to those that register later, rather than comparing areas that register with areas that do not. This method is preferable to matching because it is only possible to match on observable characteristics, while our approach accounted for both observable and unobservable factors that condition registration. The assumption behind this specification was that points that registered later constituted a valid counterfactual for earlier registrants. Just as with a comparison between unenrolled properties, there may have been reasons why landowners chose to register land early or late. While this assumption is in principle untestable, we found evidence for its plausibility in summary statistics, and in a test of whether deforestation time trends for early registrants were similar to those of later registrants in the years prior to the program.

In examining the characteristics of different cohorts (Section S3, Figure S1, and Table S4), we observed that earlier registrants came from larger properties, and that in Pará the earliest cohorts had slightly lower baseline forest cover than later ones. Given the variation used to identify effects, this could have resulted in an overestimate of impacts. However, we conducted a robustness check by dropping this group of properties and no found difference in impact (Section S8, Table S8). Furthermore, we found that there were not differences in pre-2005 deforestation trends between early and later registrants (Section S5, Table S5). This suggests that the later registrants provided a reasonable control group. In contrast, we also found pre-program time trends of never versus ever-registered properties to be quite different (Section S5, Table S5, column (1)), suggesting that a comparison with non-registered points would yield biased estimates of impact.

Results

More productive land enrolled in the CAR

The entire sample of points (Table 1) included all those that might possibly have registered for CAR in both states. On average, points on properties enrolled in CAR by 2013 were 5.2 percentage points less likely to be forested in 2005 relative to points on properties that did not enroll. Points on enrolled properties were located 10 km farther from the nearest highway, and were nearly twice as likely to be suitable for large-scale agriculture. Points registered in CAR were from municipalities with 27% higher deforestation rates prior to 2005. Deforestation risk was higher for registered than for non-registered points, and registered points were more likely to be in pasture or crop land by 2012. Overall, this suggests that registered areas tended to be in more suitable, actively used areas, with a longer history of agricultural use. This implies that using non-CAR land as a counterfactual for CAR registrants would understate the impact of enrolling in the program, since land with higher deforestation potential was more likely to register.

In Mato Grosso, registered areas were more likely to be forested in 2005 than unregistered areas, while in Pará the relationship was reversed. Registered points in Mato Grosso also tended to be in more forested municipalities (in 2001), while the opposite was true in Pará. Although registered land in both states had higher scores for agricultural suitability and deforestation risk than unregistered land, in Mato Grosso the registered land was actually more likely to be forested in 2012. Thus, the bias toward registration of land more actively being brought into production was stronger in Pará, where there is a more pronounced forest-agriculture frontier.

Deforestation in Mato Grosso and Pará reduced by 10% following property registration

Enrollment in CAR reduced deforestation on average by 0.5 percentage points (Table 2, column (3)). This effect gives the average difference in the probability of forest cover before versus after registration. The time trend of

Table 1 Summary statistics by CAR enrollment

	(1) CAR by 2014	(2) Never CAR	(3) Diff	(4) CAR/MT	(5) Non-CAR/MT	(6) CAR/Pará	(7) Non-CAR/Pará
Proportion forested points, 2005	0.530	0.582	−0.087	0.568	0.517	0.508	0.640
Municipal defor 2001–2004	0.019	0.015	0.158	0.022	0.022	0.017	0.010
% municipality forested, 2001	0.487	0.480	0.011	0.506	0.457	0.478	0.495
Normalized defor risk	−0.097	−0.218	0.115	0.223	0.489	−0.280	−0.696
Kilometers to nearest highway	83.272	73.675	0.109	98.056	89.134	74.037	63.988
Kilometers to nearest city	49.474	47.661	0.038	51.086	50.835	48.249	45.788
Agriculturally apt (0/1)	0.275	0.190	0.148	0.499	0.409	0.147	0.045
Slope in degrees	9.854	9.495	0.034	7.068	8.101	11.413	10.328
Elevation in m	205.180	172.888	0.191	284.187	270.729	159.696	107.417
Point in INCRA settlement	0.146	0.148	0.012	0.018	0.125	0.220	0.156
Point in indigenous territory	0.008	0.033	−0.127	0.014	0.042	0.005	0.027
Point in conservation area	0.060	0.120	−0.156	0.000	0.000	0.093	0.205
Pasture, 2012	0.275	0.194	0.153	0.241	0.288	0.294	0.121
Secondary vegetation, 2012	0.087	0.076	0.030	0.055	0.060	0.105	0.084
Forest, 2012	0.458	0.443	0.013	0.455	0.372	0.457	0.494
Crop, 2012	0.035	0.017	0.077	0.085	0.042	0.007	0.001
Observations	13,721	16,263	29,984	4,358	5,644	9,995	9,987

Statistics weighted to account for sampling design. Column (3) lists the normalized differences in means across the CAR and non-CAR properties. These can be interpreted as the differences in means relative to the standard deviations in the data. A normalized difference of 0.10 indicates that the two means are 0.10 standard deviations apart.

Table 2 CAR registration increases the probability of conserving forest

	Dependent variable: Forested at end of year						
	Sample of points that eventually registered				Sample of all points		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Change in probability of forest after CAR registration	0.008***	0.005*	0.005***	0.004	0.003*	0.003**	0.006***
	(0.002)	(0.003)	(0.002)	(0.003)	(0.002)	(0.002)	(0.002)
Additional CAR effect on forest in Pará		0.005		0.002			−0.004
		(0.004)		(0.004)			(0.003)
Forest cover trend	−0.004***	−0.003***	−0.002***	−0.002***		−0.002***	−0.002***
	(0.001)	(0.000)	(0.000)	(0.001)		(0.000)	(0.000)
Additional trend in Pará		−0.003***		−0.004***			−0.002***
		(0.001)		(0.001)			(0.001)
Time effects	yes	yes	yes	yes	no	yes	yes
Time × Pará	no	no	yes	yes	no	yes	yes
Time × soy apt	no	no	yes	yes	no	yes	yes
Observations	58977	58977	58977	58977	126275	126275	126275
Adjusted R^2	0.016	0.017	0.019	0.019	0.000	0.015	0.015

Unit of observation is the point. Standard errors are in parentheses and are clustered at the municipal level. $^{*}P < 0.10$, $^{**}P < 0.05$, $^{***}P < 0.01$. Observations weighted to reflect sample design. Columns (1)–(4) only include points that registered for the CAR between 2006 and 2013, inclusive. Columns (5)–(7) also include points that did not register in these years, but were in land that would have been eligible for the program.

deforestation in the sample properties before they are enrolled in CAR is −0.0024 (0.2% per year). This implies that the impact of enrollment in the CAR is, on average, equivalent to about 2 years of average deforestation. In other words, with each additional year, a point is 0.24% less likely to be forested, but if it is enrolled in CAR, it is 0.50% more likely to be forested on average. For example, across the whole region, land registered for 4 years would have lost approximately 0.8% of its forest due to background trends, but because it is registered, it only loses 0.3%. This finding is robust to dropping pre-2010 registrants (Table S8, column (1)), changing the starting year of estimation (Table S8, column (2)), and to an event study specification (Table S7).

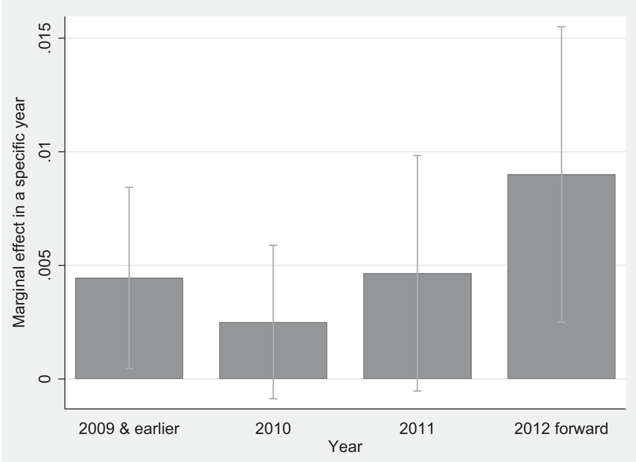

Figure 2 Effect of CAR in different years.
Estimated impacts from Section S6, Table S6, column (6). Bars show the sum of coefficients and 95% confidence intervals for baseline plus all years up to year of effect. For example, the first bar shows the baseline effect of registration, 0.004. The second bar, shows this baseline effect plus the additional effect in 2010: $0.004 - 0.002 = 0.002$. The remaining bars show additional sums of coefficients for remaining years.

Given that not all land eventually enrolled in CAR, it is interesting to calculate how much CAR contributed to overall deforestation reduction in CAR-eligible areas in these two states. Using our average effect, we calculated avoided deforestation across all cohorts, which is the product of the forest area registered in each year and the treatment effect. Summing up these areas of avoided deforestation yields 223,768 hectares of forest conserved due to CAR enrollment during our study period, equivalent to 7.7 million tons of CO_2 emissions (Saatchi *et al.* 2011). Between 2009-2013, forest loss in the Amazon biome of the two states was 2,038,900 ha. Without the CAR and the programs affiliated with it, deforestation would have been nearly 10% higher $(223,768/(223,768 + 2,038,900) = 0.098)$.

Including points that were never registered for CAR as part of the counterfactual renders the effect less clear (columns (5)–(7)). The naive estimation with no controls and including non-CAR points (column (5)) shows a small and marginally significant impact of registration. Even with unit and state-time fixed effects, the estimation including non-CAR points showed lower average impact (column (6)). This is consistent with our observation that areas enrolled in the CAR had a higher deforestation risk than the areas that never registered, making those areas unsuitable as counterfactuals, and resulting in an underestimate of program impact. In both the naive and the preferred specification, when impacts were allowed to vary by state (columns (2), (4), and (7)), there was no observable difference in impact across states.

CAR effectiveness varied over time

We also tested to see if impacts varied by year of registration and by study year. Simple interaction terms showed that CAR had a greater impact after 2011, and a higher impact for early relative to later registrants (Section S6; Table S6, columns (3)–(5)). Because impacts on registered properties might change over time depending on changing linked incentives, we examined effectiveness each year. We generated dummy variables turning to one for years 2010, 2011, and 2012, and remaining one thereafter (column (6), Table S6). These terms, interacted with the CAR registration variable, capture effects of both newly registering and already-registered properties in these years, in addition to the baseline effect for years prior to 2010 measured by the CAR variable alone.[1] Estimated effects indicated high avoided deforestation in 2009 and earlier (Figure 2). Effectiveness decreased in 2010, increased again in 2011, and became much larger and statistically significant from 2012 onward.

Discussion and conclusion

Our results show that CAR enrollment from 2006 and 2013 in Mato Grosso and Pará was associated with avoided deforestation of over 220,000 hectares. While CAR effectiveness was not different across states, it varied over time. This may be because of private and public sector efforts that pressured land users to both reduce deforestation and register in the CAR, which intensified over time (Table S1). Early adopters had the fewest incentives to enroll. This indicates a predisposition toward forest conservation and/or legal compliance; thus, it is not surprising to find substantial deforestation avoidance effect on these properties. This observation also calls into question our counterfactual—if early registrants had stronger conservation tendencies, the impact of registration could be overestimated. However, we find no evidence of differences in deforestation behavior in our pretrend analysis.

We also found evidence of greater avoided deforestation on properties after 2011, as the set of incentives for enrollment was growing, although the effect was smaller for those properties that registered later. We cannot definitively separate the effects of policies rolled out during the study period because properties were frequently subject to various policies at the same time. However, these policy overlaps may have increased their effectiveness (Strassburg *et al.* 2009; Lambin *et al.* 2014). The potential of these synergistic effects is indicated by the variation in avoided deforestation by year rather than state, implying that state differences were less important.

Previous studies have suggested that CAR registration and land-use behavior are related, though our assessment shows the strongest evidence for positive forest impacts at an appreciable scale. Earlier work estimated that property registration in Mato Grosso had little impact on avoided deforestation (Rajão *et al.* 2012; Azevedo & Saito 2013). Later work reported small but significant reductions in deforestation among small properties in Pará (L'Roe *et al.* 2016). Most recently, other researchers have measured small effects that depended on property size and location (Azevedo *et al.* 2017).

Our results suggest that the initial impacts associated with CAR may be more promising and widespread than previous estimates. Our approach provides a more suitable counterfactual because we did not use unenrolled areas as counterfactuals, because we included suitability-conditioned time trends, and because our estimates are representative of forest cover rather than properties. Our results also suggest that there are incentives beyond land tenure concerns for small properties (L'Roe *et al.* 2016). Dropping points on smallholder properties from our regressions did not change the estimated impact. We conclude that the effects of other CAR-associated environmental policies, like threats to market access and expected command and control enforcement, were more important on the larger properties that dominate our sample.

We showed that there were significant differences between enrolled and unenrolled land across the two states, and the selection effect was larger in Pará. This finding is instructive to those conducting impact evaluations on conservation policy, where it is common to use "untreated" areas as "controls" whether these be nonparks, nonpayments for ecosystem services, or other unaffected pieces of land (Baylis *et al.* 2015). Land which is unaffected by a policy is generally unaffected for a reason, particularly if the policy is voluntary, and these reasons are often correlated with the outcomes of interest. Because of this, using unaffected land to proxy for a "control" often leads to misestimated impacts (Miteva *et al.* 2013). In our case, the use of unenrolled land for counterfactual comparison attenuated estimates; registration occurred first in areas with higher deforestation risk. However, it is also the case that limiting the comparison to only those properties that already registered narrows the group of landowners analyzed, and the registration effect estimated from these individuals could differ from the effect in the overall population.

Remarkably, CAR registration within the states of Mato Grosso and Pará is now at 93% and 100%, respectively (CAR 2016). Additional validation work is needed, but this level of registration is a huge achievement and provides a scaffolding for comprehensive enforcement of forest policies. Despite the fact that the CAR was not used systematically for enforcement against illegal deforestation during the study period, it was still associated with avoided deforestation. We conclude that investment in property registration even before robust monitoring systems are in place may pay dividends for forest conservation. Furthermore, we expect the conservation outcomes linked to CAR will be more substantial once the registry is used for Forest Code enforcement. However, the temporal heterogeneity in CAR effectiveness suggests that there is nothing inherent about registration that automatically protects forests. Continued avoided deforestation depends on maintaining and expanding the complementary policies that discourage deforestation.

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Endnote

1. We cannot include additional effects for 2013 and 2014, since these variables are already included as year dummies, and all of the points in our samples have CAR equal to 1 from 2013 onward. This generates collinearity for 2013 and 2014.

Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web site:

Table S1: Selected policies promoting CAR enrollment

Table S2: Sampling intensity across the study area
Table S3: First year of CAR registration, by state
Table S4: Few differences in covariates between early cohorts and 2011-2013 cohorts
Table S5: Pretrend analysis: no differences across cohorts
Table S6: Effect of registration larger for earlier registrants and in later years
Table S7: Event study–subsample ever treated
Table S8: Robustness check on starting point
Figure S1: Point and property characteristics by year of registration

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