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 multiple 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 to implement avoided deforestation policies targeting private landholders.

1 Introduction

Forest conservation has the potential to provide as much as 40% of the emission reductions needed to mitigate climate change[1;2]. Brazil houses nearly 13% of the world's remaining forests[3], and although its deforestation rate has slowed in recent years, it remains the second highest contributor to global forest loss[3]. Efforts by private and public sector actors have turned Brazil's Amazon into a laboratory for deforestation policy, especially for conservation on private properties[4;5].

A variety of interventions have aimed to control deforestation on private lands in the Brazilian Amazon, including improved satellite monitoring[6;7], increased enforcement of the Forest Code[8;9], credit restrictions for areas involved in excessive deforestation[10;11], and private sector zero-deforestation agreements[12;13]. 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[14]. 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[15]). This paper 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[16].

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[17;18]. Mato Grosso began offering the LAU (Liçensa 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[19]. In addition, multiple non-governmental organizations launched campaigns to promote registration, sometimes with support from producers' unions and municipal governments[20]. Many of these programs were still focused on promoting registration during the study period and had not yet used the CAR to sanction non-compliant deforestation, with the exception of the zero-deforestation cattle agreements[12]. 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[21]. 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[22]. Brazil's national SiCAR process parallels that of Pará.

This paper 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.

2 Methods

2.1 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[16]. A key control variable, potential for agricultural productivity, was extracted from a soy production suitability map[23]. For the purposes of assessing selection bias, we also examine other geographic grid point characteristics, including elevation, slope, distance from nearest city and highway, and deforestation risk (see Appendix for further clarification).

FIGURE 1.

2.2 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.

3 Results

3.1 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. Though 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 towards registration of land more actively being brought into production was stronger in Pará, where there is a more pronounced forest-agriculture frontier.

TABLE 1.

3.2 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 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 two 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 .8% of its forest due to background trends, but because it is registered, it only loses .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).

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[24]. Between 2006-2013 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 $(223,768/(223,768 + 2,038,900) = .098)$.

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.

TABLE 2.

3.3 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 onwards.

FIGURE 2.

4 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

[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 onwards. This generates collinearity for 2013 and 2014.

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 over-estimated. However, we find no evidence of differences in deforestation behavior in our pre-trend 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[25;26]. 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[14;27]. Later work reported small but significant reductions in deforestation among small properties in Pará[28]. Most recently, other researchers have measured small effects that depended on property size and location[29].

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[28]. 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 non-parks, non-payments for ecosystem services, or other unaffected pieces of land[30]. 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 mis-estimated impacts[31]. 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[32]. 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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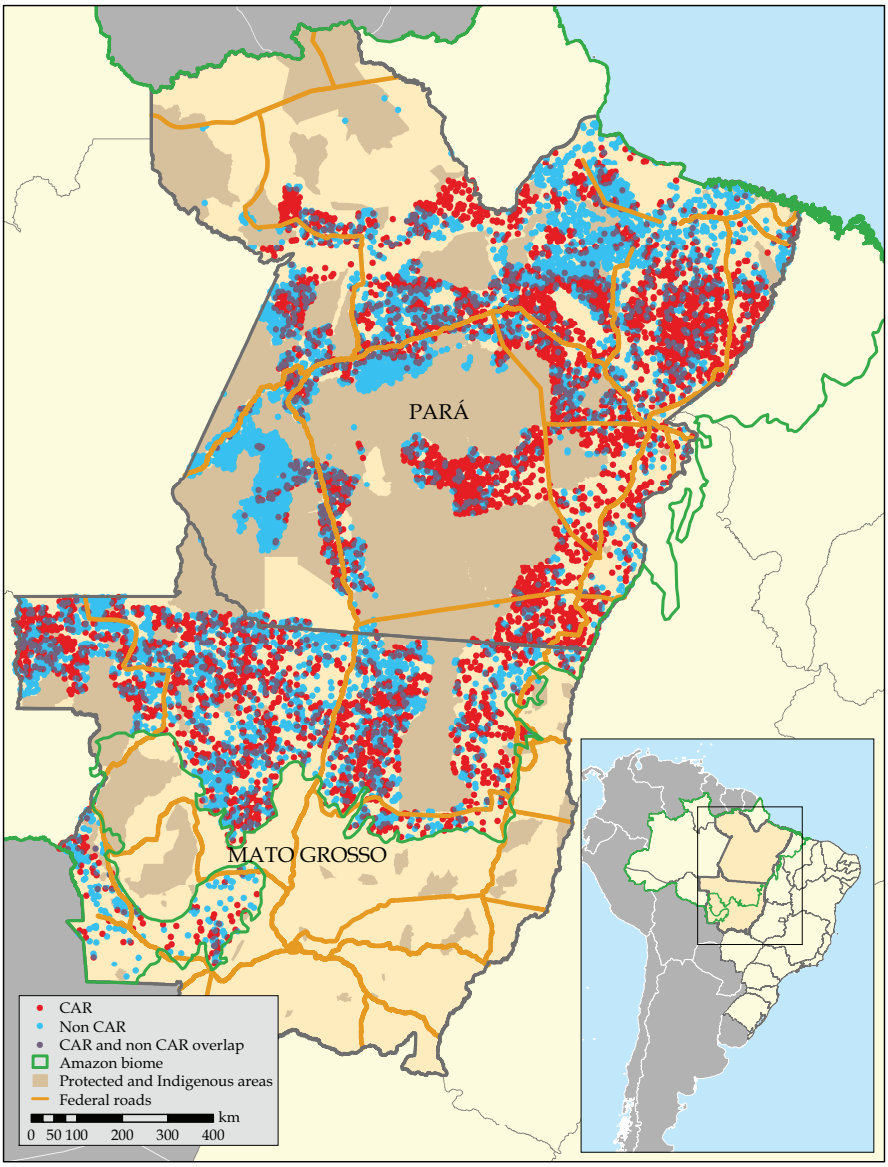
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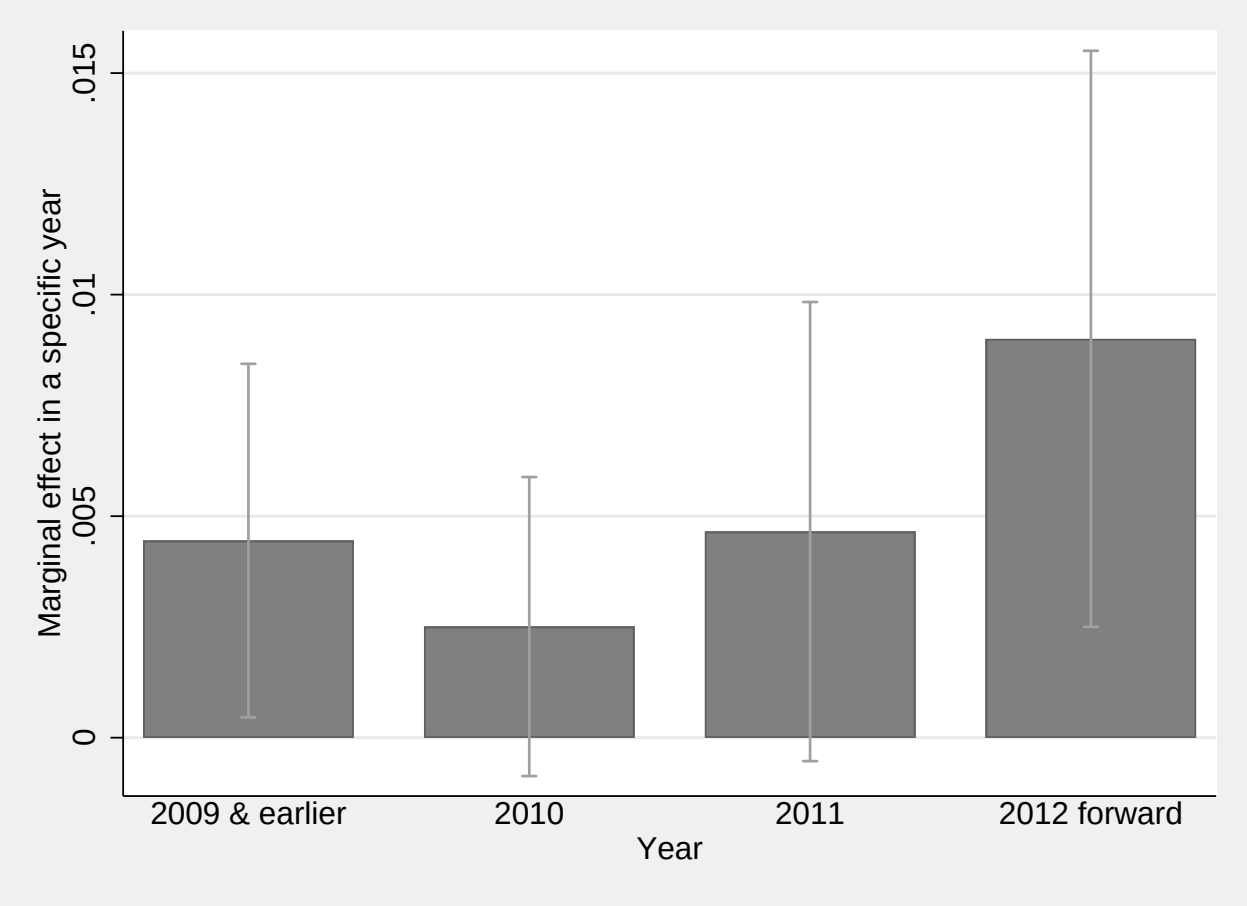
5 Tables and figures

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.

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.

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/Para	(7) Non-CAR/Para
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
Km to nearest highway	83.272	73.675	0.109	98.056	89.134	74.037	63.988
Km 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	13721	16263	29984	4358	5644	9995	9987

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*** (0.002)	0.005* (0.003)	0.005*** (0.002)	0.004 (0.003)	0.003* (0.002)	0.003** (0.002)	0.006*** (0.002)
Additional CAR effect on forest in Pará		0.005 (0.004)		0.002 (0.004)			-0.004 (0.003)
Forest cover trend	-0.004*** (0.001)	-0.003*** (0.000)	-0.002*** (0.000)	-0.002*** (0.001)		-0.002*** (0.000)	-0.002*** (0.000)
Additional trend in Pará		-0.003*** (0.001)		-0.004*** (0.001)			-0.002*** (0.001)
Time effects	yes	yes	yes	yes	no	yes	yes
Time x Pará	no	no	yes	yes	no	yes	yes
Time x 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.

Supplemental Materials: "Avoided deforestation linked to environmental registration in the Brazilian Amazon"

S1 Policy timeline

Table S1: Selected policies promoting CAR enrollment

Year	State or Region	Policy	Description
1999	Mato Grosso	Environmental Licensing of Rural Properties System (SLAPR), project under the Ministry of the Environment's Pilot Program for the Protection of Tropical Forests in Brazil (PPG7)	Brazil's first georeferenced environmental licensing system, permitted the state to issue "Unique Environmental Licenses (LAU)" to private properties to certify compliance with federal Forest Code (1967) requirements; LAU required for licenses to clear, operate a farm with animals, forestry, etc.
2004	Pará	LAR, State Decree 857/04, 30 Jan. 2004	Pará's environmental license, known as LAR (Rural Environmental License) required for agricultural, ranching, and silviculture projects
2006	Pará	CAR + LAR, State Decree 2593, 27 Nov. 2006	CAR first introduced as a precondition for LAR; CAR also made available to properties not involved perusing a LAR, though not required.
2008	Pará	CAR, State Decree 1148, 17 July 2008	CAR made compulsory for all rural properties and separated from the environmental licensing process.
2008	Amazon Biome	Central Bank Resolution 3545	A 'license, certification, or similar document proving environmental compliance' now must be submitted to get rural credit (which is subsidized); CAR eventually becomes the defacto way to meet this requirement.

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Year	State or Region	Policy	Description
2009	Pará	TAC/ ZERO-DEFOR CATTLE AGREEMENTS	CAR required for direct suppliers to major slaughterhouses in Pará, not required in Mato Grosso until May 2016, though encouraged by many companies who need property boundaries to assess deforestation.
2009	Mato Grosso	CAR/MT Legal; State Decree 2238, 13 Nov. 2009	CAR legislated in Mato Grosso, but remains technically voluntary; registrants offered incentive of protection from new fines for old deforestation and a 90% discount on old fines under the program MT Legal (which ultimately ran from Dec. 2008-2012 in Mato Grosso).
2009	Amazon Biome	"Priority Municipalities", Decree 6321, 21 December 2007; Ministry of Environment Ordinance 103, 24 March 2009	Increased CAR registration (80% of eligible area or more) required for municipalities on federal Ministry of Environment's (MMA) "critical list" to leave the list; producers in municipalities on the list face credit restrictions and increased monitoring and enforcement of environmental laws.
2009	National	Mais Ambiente Program, Decree 7029, 10 December 2009	Offered CAR for the first time nationally to producers, though on a voluntary basis. Enrollees were allowed to recover areas cleared unlawfully prior to 2009, instead of paying fines. Some enrollees were eligible for extension services and technical support.

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Year	State or Region	Policy	Description
2009	Legal Amazon	Terra Legal, Law 11952, 25 June 2009	Accelerated the provision of land titles to claimants on federal lands. For properties > 100ha but up to 15 fiscal modules (appx. 1000-1500ha), requirement for delineation of boundaries, Legal Reserves, and other required preservation areas (analogous to CAR requirements).
2010	Pará	Normative Instruction 37, 2 February 2010	Facilitated property registration for properties below 4 "fiscal modules" (appx. 350ha) to obtain a CAR license, by lowering the amount of required information and increasing the number of agents authorized to register properties.
2010	Pará	Zero-deforestation Cattle Agreements	Deadline for TAC signatories to require proof of CAR registration from direct suppliers in Pará (February)
2011	Pará	Green Municipalities program, State Decree 54, 29 March 2011	State government initiative to reduce deforestation and promote improved environmental management of rural areas, including promoting enrollment in CAR.
2012	National	Federal Law 12651, 25 May 2012; Normative Instruction 2, 5 May 2014	Expectation set for CAR requirement for all rural properties, first legislated in 2014, with a deadline of May 2015, which was extended by a year in 2015 and again in 2016
Multiple years	Legal Amazon		Different NGO projects (usually focusing on one municipality or another, or several at once) to promote CAR, often based on going farm to farm to complete the application with the land owner.

S2 Description of sampling and dataset construction

We generated points within the study area and assigned attributes to each point based on the cell or mapping unit on which it fell on layers depicting the spatial distribution of our variables of interest. The dependent variable, forested or non forested, was created from Brazils official annual deforestation maps, PRODES. Because PRODES is Landsat-based, the value assigned to the point is the value of the underlying 30 meter pixel. Similarly, we assigned each point values according to where it fell on maps of elevation, slope, and agricultural suitability, and we measured the distance from each point to the nearest highway and city (Euclidian). We also created a "risk of deforestation" variable at the point level by estimating a probit regression of deforestation on geographic covariates and state effects over the years 2001-2005. The coefficients from this estimation were used to predict the probability of losing forest over all time periods. While we recognize that this was a period of very high deforestation in the Amazon, the relevance of the geographic covariates in determining deforestation risk remains very strong. The correlation between this variable and deforestation in the years we analyzed is 0.64. Finally, we assigned each point the attributes of the CAR property on which it fell, if it fell on one.

Our study area excluded areas with legal classifications that prohibit agricultural activity on private properties because they are not eligible for the CAR. The excluded areas include the following: 1.) All "proteção integral" conservation units,[33]; 2.) "uso sustentável" conservation units within the categories "Floresta", "Reserva de Desenvolvimento Sustentável", and "Reserva Extrativista"[33]; 3.) Indigenous areas (Terras Indgenas) within the categories "Homologada", "Regularizada", and "Reserva Indígena"[34]; 4.) INCRA settlement areas within the categories "FLONA", "PDS", "RDS", and "RESEX"[35]. There were a small number of CAR properties located in these excluded areas, but not enough to merit inclusion (2.0% of CAR properties in Pará and 0.4% of CAR properties in Mato Grosso)

We included both CAR[36;37] and LAU[38] properties. Although LAU requires Forest Code compliance and CAR has no compliance requirements for enrollment, we included properties that had been granted LAU or CAR in Mato Grosso[2]. This is because enrollment in both parts of the license

[2]Pará's provisional CAR could be upgraded to a "definitive" CAR following official review (similar to the Mato Grosso CAR). In Pará, LAR remained an optional step following CAR enrollment and eventual

were available during the study period, depending on the property's level of Forest Code compliance, and both types of registrants appeared in the datasets obtained from SEMA-MT. Since we were ultimately seeking to measure the effect of mapping a property for environmental licensing purposes, we included LAU-only or LAU-first properties that registered as such during our study period, though the vast majority of properties enrolled in the CAR first. We did not include LAR properties because there were many fewer LAR issued than LAU, because during our study period LAR was only available to properties that also had CAR. Furthermore, as a practical matter, the data obtained from SEMA– PA contained LAR and CAR licenses in separate files.

The full sample included the following sets of points:

Table S2: Sampling intensity across the study area

Category	Area (sq km)	% of study area	Sq km per random point
Total study area	1,364,077	100	34.1
Pará CAR area	337,701	24.8	33.8
Pará non-CAR area	277,532	20.3	27.8
Mato Grosso CAR/LAU area	411,215	30.1	41.1
Mato Grosso non-CAR/LAU area	337,628	24.8	33.8
Pará excluded area	632,733	–	–
Mato Grosso excluded area (in Amazon Biome)	154,527	–	–

S3 Timing and characteristics of registrants by year

Although our fixed-effects estimation controls for time-invariant characteristics, it is still illuminating to examine these features of the points. We consider potential agricultural productivity, elevation, elevation, slope, distance from nearest highway and city and deforestation risk. Table S3 shows the percentage of total points registered in each year by state. As discussed above, Mato Grosso's registration process began much earlier, starting in 1999, though the earliest date given in the available data is 2005. Because Mato Grosso properties that are shown to be registered in this

compliance with Forest Code set-aside requirements, while all properties in Mato Grosso were expected to apply to LAU upon completion of their plan to achieve Forest Code compliance. Less than 5% of CARs proceeded to this second phase[28;39;21;40].

year may actually have completed their registration process earlier, we dropped these properties from the main analysis. Without these properties, by far the largest registration year in both states was 2010.

Table S3: First year of CAR registration, by state

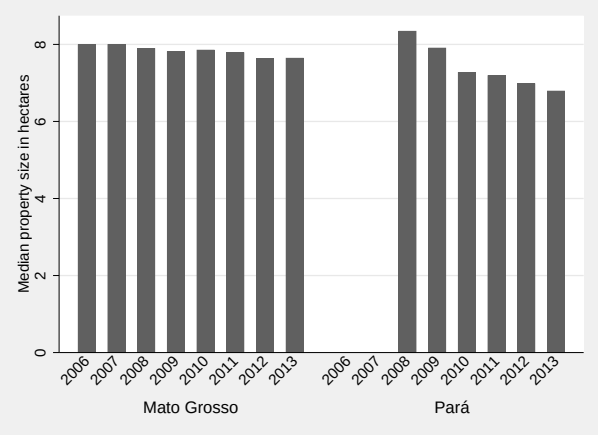
	Mato Grosso	Par	Total
2006	13.57	0.00	4.29
2007	13.99	0.00	4.42
2008	16.94	1.60	6.45
2009	8.57	12.91	11.54
2010	20.55	31.57	28.09
2011	14.91	25.46	22.12
2012	9.24	16.74	14.36
2013	2.24	11.73	8.72
Total	100.00	100.00	100.00
N	13721		

By way of better understanding our counterfactual, which requires that later registrants serve as controls for earlier registrants, Figure S1 shows characteristics of points by year of registration. Note that these statistics represent points over space, and hence yield different medians than would be calculated using a census of properties that enrolled in CAR. In particular, the medians calculated here are much higher, since property sizes are highly skewed, so large landholders own by far the majority of the registered land.

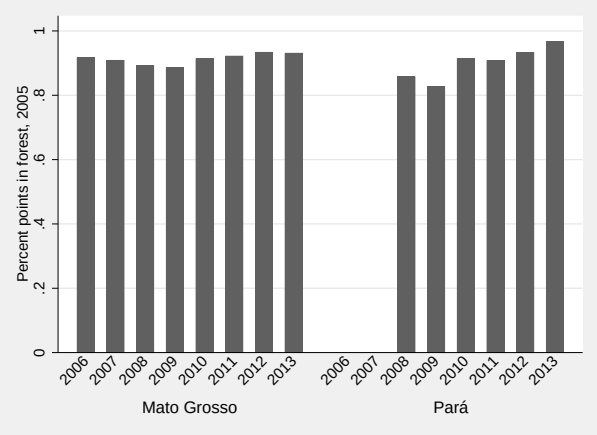
In both states, the earliest registered points come from larger properties, their agricultural aptitude (soy aptitude) is slightly increasing over time, though in Pará it appears to increase and then decrease (Figure S1). Municipal deforestation rates prior to registration slightly increase across cohorts in Mato Grosso and tend to decrease over cohort age in Pará. The earliest registrants in both states come from fairly forested properties, although this trend quickly becomes relatively constant.

We also conducted a statistical test for differences across cohorts. Table S4 shows tests for the difference between early-registering cohorts and those that registered in 2011, 2012, or 2013. These omitted cohorts are the ones that provided much of the counterfactual trend for the estimation, the

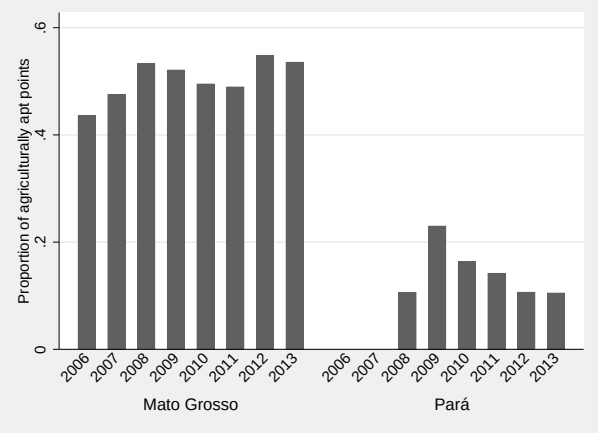
Figure S1: Point and property characteristics by year of registration



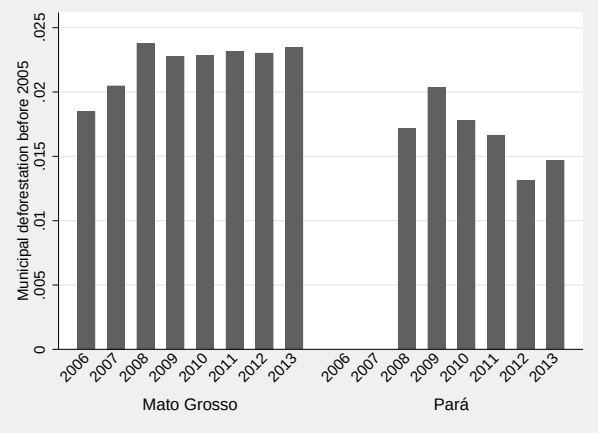
(a) Property size



(b) % forest on property, 2005



(c) Agricultural suitability



(d) Municipality deforestation, pre-2005

coefficients shown are beta coefficients, which represent the change in the standard deviation change in the dependent variable with a one standard deviation change in the covariate. The results here confirmed our assessment that the earlier registrants (2006, 2007) in both states tended to be larger properties. In Mato Grosso, points in early registering properties also came from municipalities with less deforestation, although these sizes are relatively small – between .08 and .12 standard deviations. In Pará, the earliest registrants were properties with slightly less baseline forest, but again, not very large differences in magnitude (.04 to .11 standard deviations).

If it is the case that deforestation is more likely to take place on properties that are more forested, then the results in columns (7) and (8) would imply that estimates of impact for early cohorts in Pará would be under-estimated. Since the earliest registrants in Mato Grosso came from

areas with lower municipal deforestation rates, this might result in underestimates. However, it is difficult to draw conclusions on the direction of bias from these covariates. For this reason, in order to more directly test the identification assumption, we conducted a test of pre-trends for early versus late registrants (Section S5), and also estimated our main result omitting registrants from 2009 and earlier (Table S8).

Table S4: Few differences in covariates between early cohorts and 2011-2013 cohorts

	Dependent variables:							
Cohort	Mun. deforestation		Ag. aptitude		Ln(Property in ha)		Baseline % forest	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
2006	-0.117*		-0.062		0.235*		-0.000	
	(0.001)		(0.054)		(0.323)		(0.019)	
2007	-0.085*		-0.047		0.126*		0.003	
	(0.001)		(0.048)		(0.217)		(0.017)	
2008	0.022	0.018	-0.023	-0.038**	0.081	0.024	-0.058	-0.045*
	(0.001)	(0.002)	(0.052)	(0.031)	(0.161)	(0.358)	(0.019)	(0.032)
2009	0.001	0.102	-0.031	0.036	0.019	0.127*	-0.030	-0.115**
	(0.002)	(0.002)	(0.045)	(0.024)	(0.247)	(0.368)	(0.020)	(0.021)
2010	0.045	0.054	0.005	0.051	0.063	-0.062	-0.028	0.005
	(0.001)	(0.001)	(0.052)	(0.019)	(0.216)	(0.288)	(0.023)	(0.015)
State	Mato Grosso	Pará	Mato Grosso	Pará	Mato Grosso	Pará	Mato Grosso	Pará
Observations	2076	4149	2076	4149	2076	4149	2076	4149
Adjusted R^2	0.022	0.010	0.002	0.004	0.041	0.024	0.001	0.014

Unit of observation is the point. Beta coefficients are shown. These represent the marginal effect on the outcome in standard deviations with a one standard deviation change in the covariate. In this case, the covariates are years of registration in the CAR, and the effects should be interpreted relative to the omitted years 2011, 2012, 2013.

S4 Formal presentation of estimation strategy

Our main estimation strategy used only those points located on properties that were enrolled in the CAR by 2013, thus excluded areas that never registered in the CAR. Since all points fell inside properties that eventually enrolled, this approach eliminated contamination of the results by unobservable factors that might have driven the enrollment decision. For example, if individuals were more likely to register properties with more deforestation, then an estimation that included non-CAR points would be biased towards zero, since the "control" group would have less deforestation than the "treatment" group even in the absence of the treatment.

The basic specification used a binary variable that changed from zero to one in the year after a point submits an application. The point estimate on this treatment variable, C_{pt}, gave the average difference in forest cover before and after registration in points that register early versus those that register late. We included fixed effects for each point (γ_p) and time effects for each year (γ_t), as well as interactions between time effects for each state and land productivity type (suitable or unsuitable for soy production, denoted by the matrix $\mathbf{X}$). The final specification was:

$$\text{Forest}_{pmt} = \alpha_0 + \beta C_{pt} + \gamma_p + \gamma_t + \sum_t \omega_{xt}\gamma_t \mathbf{X} + \epsilon_{pmt} \tag{1}$$

The point fixed effects controlled for all time-invariant characteristics (soil type, distance to market, etc.). The yearly time effects controlled for temporal shocks that impacted the entire sample, and the interactions by state and agricultural suitability allowed these temporal shocks to differ across states and the suitability of land for agriculture. These controlled for state-level differences in policy, and price shocks whose impact could vary by agricultural productivity. Because the states had substantial variation in their implementation of the program, we also tested whether impacts varied by states, and if they changed over time as the policy environment evolved.

The standard errors of the estimation, ϵ_{pmt} were clustered at the municipal level, allowing for arbitrary correlation between points within the same municipality. Observations were weighted to account for the slight stratification of the sample. We also examined heterogeneity in the impact of CAR registration using an interaction between C_{pt} and state. Because the dependent variable observations were coded as missing values after deforestation occurs, the panel was unbalanced,

and the estimator used similar variation to a discrete time duration model.

S5 Estimation assumption test: pretrends

The underlying assumption of our estimation strategy was that points that requested a CAR later can serve as a counterfactual for those that registered earlier. In order to examine whether this assumption was valid in earlier periods, we exploited the pre-program forest disturbance data. We ran fixed effects regressions on the subset of data from 2001 through 2005, using time effects to control for temporal shocks, and testing whether or not those properties that enrolled for CAR in 2009 or earlier showed different time trends than those that enrolled in 2010 or later. This test takes the form of an interaction term between a linear time trend and a dummy variable indicating the early registered cohorts (Table S5, columns (2)-(4)). In addition, we also tested whether or not there were differences in year to year trends using interaction terms between early registrants and each year of the pre-trend data (column (5)). Finally, we tested whether linear trends differed by cohorts (column (6)). There was no evidence of differential deforestation trends between early and later registered groups. This implies that the key assumption underpinning our estimation strategy is not violated.

By way of confirming the nature of selection into CAR registration, we also tested whether or not pre-CAR trends differed between properties that ever registered for the CAR (the samples used for estimation in columns (2) through (6)) and those that did not register within our study period. Here we observe significantly higher forest cover loss among CAR registering points in years 2002, 2003, and 2005, relative to 2001. This is consistent with our earlier observation that more productive lands tend to register. It also underscores why the comparison between registered and non-registered properties may yield biased impacts.

Table S5: Pretrend analysis: no differences across cohorts

	Dep. var.: Forested at year's end					
	Data 2001-2005					
	(1)	(2)	(3)	(4)	(5)	(6)
Time x registered pre-2009		0.001	-0.001	-0.001		
		(0.001)	(0.001)	(0.001)		
Ever CAR x 2002	-0.008*					
	(0.004)					
Ever CAR x 2003	-0.005**					
	(0.003)					
Ever CAR x 2004	-0.010					
	(0.006)					
Ever CAR x 2005	-0.014**					
	(0.007)					
Ever CAR x 2006	-0.008					
	(0.006)					
2002 x registered pre-2010					0.010	
					(0.007)	
2003 x registered pre-2010					0.010	
					(0.007)	
2004 x registered pre-2010					0.008	
					(0.008)	
2005 x registered pre-2010					-0.002	
					(0.011)	
2006 x registered pre-2010					-0.002	
					(0.011)	
Time x registered 2007						0.004
						(0.006)
Time x registered 2008						-0.001
						(0.004)
Time x registered 2009						-0.001
						(0.005)
Time x registered 2010						0.001
						(0.005)
Time x registered 2011						0.001
						(0.005)
Time x registered 2012						0.000
						(0.006)
Time x registered 2013						0.004
						(0.005)
Time effects	yes	yes	yes	yes	yes	yes
Time x Pará	yes	no	yes	yes	yes	yes
Time x soy	yes	no	no	yes	yes	yes
Observations	84725	40221	40221	40221	41911	41911
Adjusted R^2	0.039	0.036	0.037	0.045	0.091	0.091

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. Data in column (1) includes all points, while columns (2)-(6) include points which eventually registered for CAR. Only points with forest in 2001 are included in regressions.

S6 Detailed interpretation, main results

Table 2 shows a simple binary treatment effect, which estimates the change in the probability of forest in CAR points after registration compared to those which were not registered at that time. The table includes linear time trends (in addition to the time fixed effects), in some cases differentiated by state; these provide an estimate of the background forest cover trend in the data.

The first two columns show estimates that include only year effects, which remove the average forest cover change for each year across all points, but do not allow these deviations to vary by state or land quality. Estimations (3), (4), (6) and (7) included time by state and time by land quality effects. The inclusion of additional temporal trends reduced the magnitude of the overall impacts by better controlling for factors that might be confounded with the CAR impact – for example, differences in the timing of enrollment across states, and temporal shocks that might differentially affect land of varying quality or across states. The remaining columns show impacts estimated including non-enrolled points as part of the counterfactual, and are discussed in the main text.

Table S6 shows the coefficients for estimations that vary with time. The first column shows the baseline specification for comparison. Column (2) shows an interaction term between a dummy variable equal to 1 from 2011 onwards and CAR. It suggests greater but imprecisely estimated impact after 2011. Column (3) includes an interaction between CAR and properties that registered in 2009 or earlier. This shows positive and significant impacts for early relative to later registrants. Column (4) includes both of these plus an interaction between the two. The impact in years after 2011 for those who registered after 2009 is 0.006 (se 0.0038). The impact after 2011 for those who registered early is 0.017 (se 0.004). Effectiveness was therefore higher for early registrants, but for later years.

Table S6: Effect of registration larger for earlier registrants and in later years

	Dependent variable: Forested at end of year					
	(1)	(2)	(3)	(4)	(5)	(6)
Change in probability forest after CAR registration	0.005***	0.003*	0.001	-0.001	0.000	0.004*
	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)	(0.002)
Additional effect of CAR after 2011		0.004		0.008*	0.006	
		(0.004)		(0.004)	(0.005)	
Additional effect of CAR for those registered 2009 or earlier			0.007***	0.010***	0.009***	
			(0.002)	(0.002)	(0.003)	
Additional effect after 2011 for those registered before 2009					0.002	
					(0.003)	
Additional effect of CAR after 2010						-0.002
						(0.003)
Additional effect of CAR after 2011						0.002
						(0.004)
Additional effect of CAR after 2012						0.004
						(0.005)
Time effects	yes	yes	yes	yes	yes	yes
Time x Pará	yes	yes	yes	yes	yes	yes
Time x soy effects	yes	yes	yes	yes	yes	yes
Observations	58977	58977	58977	58977	58977	58977
Adjusted R^2	0.019	0.022	0.022	0.019	0.019	0.020

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.

S7 Robustness check: Event study

Our main robustness check was an "event study" of the impact of CAR registration, that is, we recode the first year of registration for the point as 0, the year before -1, two years before -2, etc... for years after code +1, +2, etc.... This allowed us to assess whether or not the results we observe in the simple treatment effect were driven by the pre-program deforestation. The results can be seen in Table S7. Column (1) shows positive and increasing results in the years after registration relative to the year of registration. Differential results for different cohorts suggest a possible pre-program deforestation among those who registered later (column(3)), although the magnitude of increase in forest loss pre-program was smaller than the post-registration avoided deforestation. This may mean that impacts for this subgroup of properties could be overstated.

Because an event study gives point estimates relative to an observed baseline (in our case, the application year), it is difficult to assess the total impact of the policy over the time period analyzed, and whether or not this biases our average effects. An alternative specification uses lags and leads of the impact variable. Usually, such specifications involve dropping years of data from the sample. However, because in the case of our treatment we knew the status of a property in every year, we were able to fill in what would normally be missing values. We show such a specification in columns (4) - (6). A lead of a variable is simply the enrollment variable moved forward one period in time. The interpretation of these coefficients is as follows: the two year lead gives the impact of enrollment two years before the application date. The one year lead is the additional impact one year before, etc... We calculate the total policy impact by summing these variables. This process took into account the fact that behavior might have changed prior to enrollment in the program. In these specifications, we found that the sum of behavior over the two years before and the two years after registration exceeded our simple treatment effect, suggesting that if anything, our treatment estimate was downward-biased.

Table S7: Event study – subsample ever treated

	Dep. var.: Forested at end of year					
		Registration year			Registration year	
	Full	2009 or earlier	after 2009	Full	2009 or earlier	after 2009
	(1)	(2)	(3)	(4)	(5)	(6)
CAR registration year -3	-0.000	0.008	-0.006			
	(0.003)	(0.006)	(0.005)			
CAR registration year -2	-0.004*	-0.002	-0.006			
	(0.002)	(0.004)	(0.004)			
CAR registration year -1	-0.002	0.004	-0.006**			
	(0.002)	(0.004)	(0.003)			
CAR registration year 1	0.003	0.007*	0.002			
	(0.002)	(0.004)	(0.003)			
CAR registration year 2	0.006**	0.009**	0.008*			
	(0.002)	(0.004)	(0.005)			
CAR registration year 3	0.010***	0.009**	0.011*			
	(0.003)	(0.004)	(0.006)			
Treatment effect, 2 years prior				0.001	0.004	-0.001
				(0.002)	(0.003)	(0.002)
Additional treatment effect, 1 year prior				0.002	-0.003	0.006**
				(0.002)	(0.004)	(0.002)
Additional treatment effect, application year				0.003	0.008**	0.002
				(0.002)	(0.004)	(0.003)
Additional treatment effect, 1 year post				0.004**	0.003	0.006*
				(0.002)	(0.002)	(0.003)
Additional treatment effect, 2 years post				0.004***	0.001	0.003
				(0.002)	(0.002)	(0.002)
Total treatment effect				0.015**	0.013**	0.016**
Time x Pará	yes	yes	yes	yes	yes	yes
Time x Soy	yes	yes	yes	yes	yes	yes
Observations	58977	18345	40632	58977	18345	40632
Adjusted R^2	0.019	0.015	0.021	0.019	0.014	0.021

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. Sample weights included.

S8 Robustness check: Variations in starting point

Table S8 drops all CAR properties that registered before 2009. Then it varies the start date of the estimation from 2005 (as in the rest of the paper) and 2006. The table shows that changing the start date of the estimation and using only later registrants did not affect the main results, and that the results remained indistinguishable between states.

Table S8: Robustness check on starting point

	Dependent variable: Forested at end of year			
	2005	2007	2005	2007
	(1)	(2)	(3)	(4)
Change in probability forest	0.005**	0.004*	0.002	0.001
after CAR registration	(0.002)	(0.002)	(0.006)	(0.006)
CAR x Pará			0.003	0.003
			(0.007)	(0.007)
Time effects	yes	yes	yes	yes
Time x Pará	yes	yes	yes	yes
Time x soy effects	yes	yes	yes	yes
Observations	47778	37620	47778	37620
Adjusted R^2	0.020	0.014	0.020	0.014

Unit of observation is the point. Standard errors are in parentheses and are clustered at the municipal level. All estimations include time by state and time by agricultural land effects. * p< 0.10, ** p<0.05, *** p < 0.01. All estimations drop CAR registrants prior to 2009. Years indicate starting year of estimation.