Does land tenure security reduce deforestation? Evidence for the Brazilian Amazon

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Abstract

We evaluate the extent to which farms with secure land rights are less prone to deforest and more likely to comply with the Forest Code in the Brazilian Amazon. We use a unique dataset with farm-level information for the whole population of farms in the state of Acre, Brazil. We work with a proxy for land tenure security defined as the absence of overlapping property rights, which means that for each rural plot, there is only one land title attesting to whom the legal ownership belongs. We evaluate the impacts of secure land right on the farm's share of the deforested area and the likelihood that farmers comply with the Brazilian Forest Code, which defines a limit of 20% of the deforested area in each farm. The non-randomness between the treatment (land security) and control (land insecurity) groups is controlled using the inverse probability weighting regression adjustment. Our results highlight that land tenure security reduces the deforested area and increases compliance with the Forest Code.

Keywords: Land governance; Security of tenure; Deforestation; Brazilian Amazon.

Introduction

The deforestation of the Amazon forest is the main responsible for the CO_2 emissions in Brazil and one of the main threats to mitigating the impacts of climate change in the world (Cohn et al. 2019; Marengo et al. 2018). Forest fragmentation is another effect of deforestation, promoting indirect forest carbon losses due to the edge effects (Silva et al., 2020). Some studies also suggest that deforestation in the Amazon can change the rainfall regime in Brazilian regions, potentially impacting agricultural productivity (Leite-Filho et al., 2021).

The deforestation rate in the Brazilian Amazon followed a U-shaped trend in the 2000s (PRODES 2019): deforestation dropped to less than 5,000 km²/year in the early-2010s, and, in 2019, it started to grow again, surpassing 10,000 km²/year. Several studies highlight some critical drivers of deforestation in the Amazon, including access to land (Chomitz et al., 2003; Andersen et al., 2002; Pfaff et al. 2009), agricultural markets and prices (Hargrave et al., 2013; Assunção et al., 2015; Faria et al., 2016), agricultural technology and productivity (Cohn et al., 2014; Koch et al., 2019), land and environmental governance and security of tenure (Soares-filho et al., 2006; Arima et al., 2014; Börner et al., 2015; Moutinho et al., 2016; Wehkamp et al., 2018; Miranda et al., 2019; Brito et al., 2019).

Among the drivers of deforestation, we can highlight land governance and tenure security, which may be associated with a weak rule of law in the context of the Brazilian Amazon (Reydon et al. 2019). The land property rights in the region are subject to widespread uncertainties (Sparovek et al., 2019). The legal insecurity over the land tenure in the Amazon region has made the Brazilian government reinforce land policies to mainly facilitate individual land titling, arguing that this is a necessary measure to reduce deforestation (Chiavari and Lopes 2020). However, the individual land titling does not affect the landowners' right to decide how to use their land (Robinson et al. 2014). Landowners may have strong incentives for deforestation and non-compliance with the environmental legislation when undertaking

agricultural activities (Assuncąo et al., 2015) or through real estate speculation and land grabbing (Brito et al., 2019).

Studies have applied quasi-experimental methods to estimate the relationships between land tenure security and deforestation. Land titling formalization has shown to affect the deforestation in both collectively occupied areas, such as the indigenous lands (Buntaine et al., 2015; Blackman et al., 2017; Benyishay et al., 2017), and private titling areas (Liscow, 2013; Probst et al., 2020). One caveat of these studies is to assume that the formal land ownership registration is sufficient to protect and maintain land tenure security. To the best of our knowledge, no studies evaluated how good governance and proper enforcement of the property rights over land, in addition to formal land titling, can reduce deforestation and increase the chances of rural properties complying with forestry rules.

This work contributes to the literature on tenure security and forest conservation in two ways. The main applied contribution is to use a unique data source of almost all rural properties in the state of Acre with a quasi-experimental strategy to overcome possible selection biases in the exposure to good land governance. The main theoretical contribution is to present evidence that land tenure security, measured by the absence of overlapping land rights, is a fundamental approach to formulating land policies to reduce deforestation in the Amazon.

Theoretical background

The effects of securing individual land tenure rights on the deforestation of tropical forests are still controversial in the literature. Meta-analysis studies have not identified consistent evidence that land tenure security is associated with deforestation (Robinson et al., 2014; Busch et al., 2017). Three main factors help to explain the controversy behind these results: (1) the institutional context in which land tenure is established; (2) the tenure security indicator

adopted in the surveys; and (3) the possibility of endogeneity or reverse causality since the deforestation can be a form of illegal land occupation.

The institutional context may refer, for example, to the effect of land titling on community and private lands. For example, studies indicate that titling indigenous land possessions significantly reduced deforestation in Peru within 2 to 5 years after titling (Buntaine et al., 2015; Blackman et al., 2017). In Brazil, Benyishay et al. (2017) indicated that such titling did not affect deforestation when compared to untitled indigenous lands, suggesting that other contextual factors may be more important in explaining deforestation.

Evidence for the impacts of land titling on private lands is not less controversial. Liscow (2013) studied the effects of agrarian reform in Nicaragua and found that improvements in private land tenure rights are associated with more deforestation. Probst et al. (2020) identified that small and medium-sized landowners in the Brazilian Amazon increased deforestation in response to an official land titling program, while deforestation rates have hardly changed among large landowners.

Overall, these studies suggest that land titling alone may not reduce deforestation. Other institutional factors may also make the difference, for example, the presence of agrarian conflicts and violence (Fearnside, 2001; Araujo et al., 2009; Sant'anna et al., 2010); contentious social processes regarding land occupation and changes (Aldrich et al., 2012; Brown et al., 2016); incentives for real estate speculation and land grabbing (Brito et al., 2019). Given these factors, general guarantees for the protection and maintenance of land rights with adequate land governance may be more important to explain a reduction in deforestation.

Despite evidence linking deforestation to failures in land governance, no studies have yet established causality. Some challenges to be faced in these analyses are the sample selectivity and reverse causality between land tenure problems and deforestation. For example, for Brown

et al. (2016), occupations may not simply be the cause but also an effect of deforestation itself. The proportion of forest cover is another critical factor to explain the risk of occupation (Aldrich, 2015). Several justifications could explain this relationship: the risk of violence when occupying a forest area is lower since its value is lower than that of pastures; it is easier to convince the authorities that the land is unproductive; access to wood, which is a source of income for squatters; and, once deforested, forest areas are more suitable to cultivate temporary crops than pastures that suffer greater soil compaction (Fearnside, 2001; Araujo et al., 2009; Sant'anna et al., 2010; Aldrich et al., 2012; Brown et al., 2016).

Hypotheses

Our central hypothesis is that deforestation is directly associated with institutional failures in land governance in the Brazilian Amazon. These institutional failures would encourage irregular possessions in public or private areas, mainly motivated by real estate market speculation (Reydon et al., 2019), producing a generalized environment of tenure insecurity in the region (Sparovek et al. 2019). Even individually titled properties would be subject to more deforestation (Probst et al. 2020), because the guarantees that the acquired land rights will be maintained are fragile. In other words, in an environment with institutional failures, the title itself could stimulate new deforestation and other irregular occupations.

Given that a frequent failure in land tenure security in the Brazilian Amazon is the land overlapping, which occurs when two or more property titles refer to the same land plot, our hypotheses are:

Hypothesis 1. Rural properties without overlapping land rights, i.e., where there has been no more than one declaration of ownership over the same area, deforest less.

Hypothesis 2. Rural properties with secure land tenure are more likely to comply with forestry regulations in Brazil.

Material and methods

Data

We access the complete database of the Rural Environmental Registry (*Cadastro Ambiental Rural – CAR*)[1] from the state of Acre, with information on the total population of rural properties registered in the Rural Environmental Registry System of Acre between 2014 and 2018 (SICAR-Acre 2018). We included only property records that do not overlap with any legally protected areas, such as indigenous lands and conservation units. Our sample contains a total of 35,067 properties, which represent about 36% of the Acre's territory. Deforestation data were obtained from PRODES satellite images (2019), the Brazilian government's official information source on deforestation in the Amazon. Data from PRODES indicate that more than 70% of the total area deforested between 2009 and 2018 occurred in private rural properties (Figure 1).

1 Created by the new Brazilian Forest Code (Federal Law 12.651/2012) as a nationwide electronic public registry, mandatory for all rural properties, with the purpose of integrating georeferenced environmental information on rural properties and possessions to compose a database for controlling, monitoring, environmental and economic planning and combating deforestation.

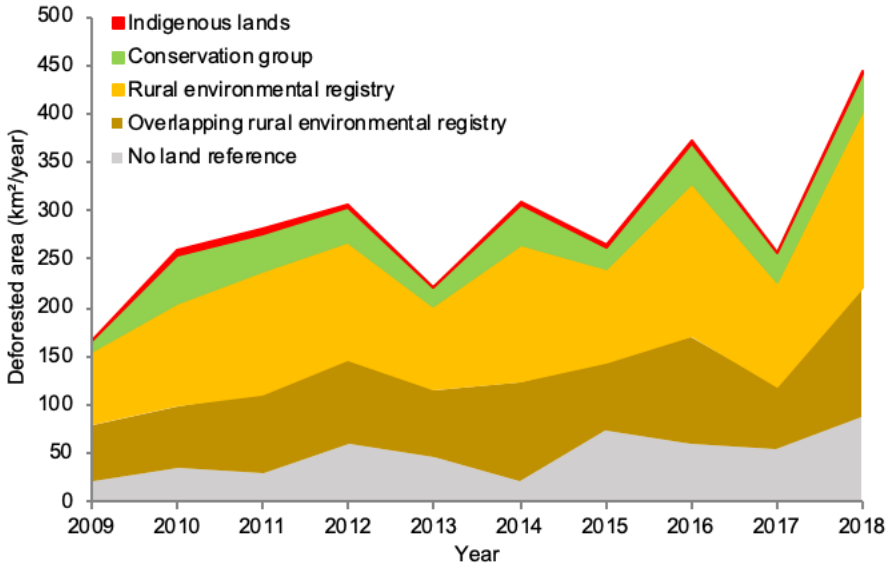

Figure 1. Deforested area in the state of Acre by land title category between 2009 and 2018. Source: (PRODES 2019).

Almost 30% of deforestation occurred within areas with overlapping land rights, i.e., more than one ownership declaration over the same land (Table 1).

Table 1. Proportional share of land ownership categories in the total area deforested between 2009 and 2018 in the state of Acre.

Land category	Deforested area (km²)	Percentage (%)
Indigenous Lands	26.326	0.9
Conservation group	321.929	11.2
Rural environmental registry	1,197.165	41.6
Overlapping rural environmental registry	847.449	29.4
No land reference	485.131	16.9
Total	2,878.000	100.0

Source: (PRODES 2019).

In addition to the technical problems of the declaration itself, the overlapping of records indicates the presence of agrarian conflicts or squatters occupying irregularly. Thus, such

overlapping is our land tenure security indicator. We created a binary variable that assumes one for those farms with no overlap of boundaries with other farms (land tenure security). Only 10,6% of the farms in our sample declared land tenure security (Figure 2).

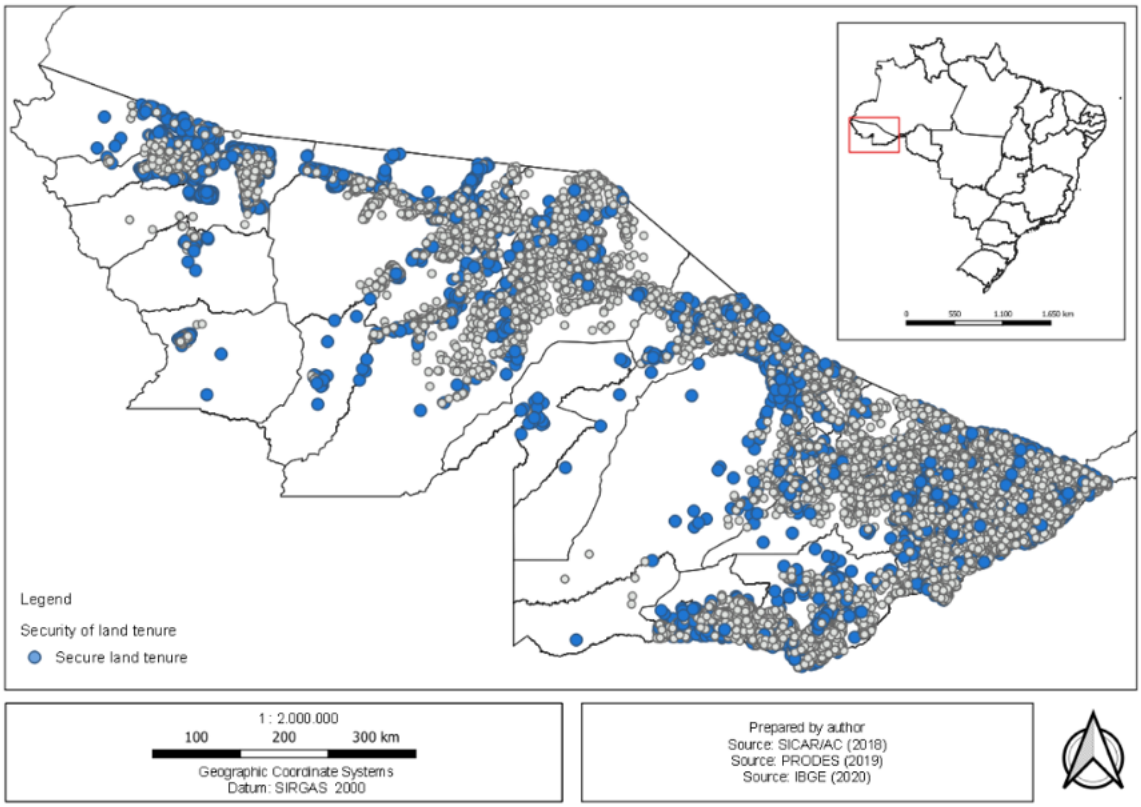

Figure 2. Ownership security of rural properties registered in the state of Acre's CAR. Source: (SICAR-Acre 2018; PRODES 2019; IBGE 2020)

Outcome variables

To compute the deforested area in each farm, we merged georeferenced farms' boundaries from CAR with deforestation data provided by project PRODES. Then we analyzed two outcomes: (i) deforested area and (ii) compliance with the Forest Code. The first outcome is represented by the farm's share of the deforested area between 2009-2018. On average, 7,3% of the farms' total area was deforested between 2009-2018.

The Brazilian government approved a new reform of the Forest Code in 2012 maintaining the limit of 20% of the total area of the farm that could be deforested in the Amazon. The law also granted amnesty to those who illegally deforested before July 2008. One of the main instruments for monitoring compliance with the Forest Code is the CAR. The absolute majority of rural properties had up to 20% of their area deforested, while less than 5% had more than 75% of their area deforested (Figure 3).

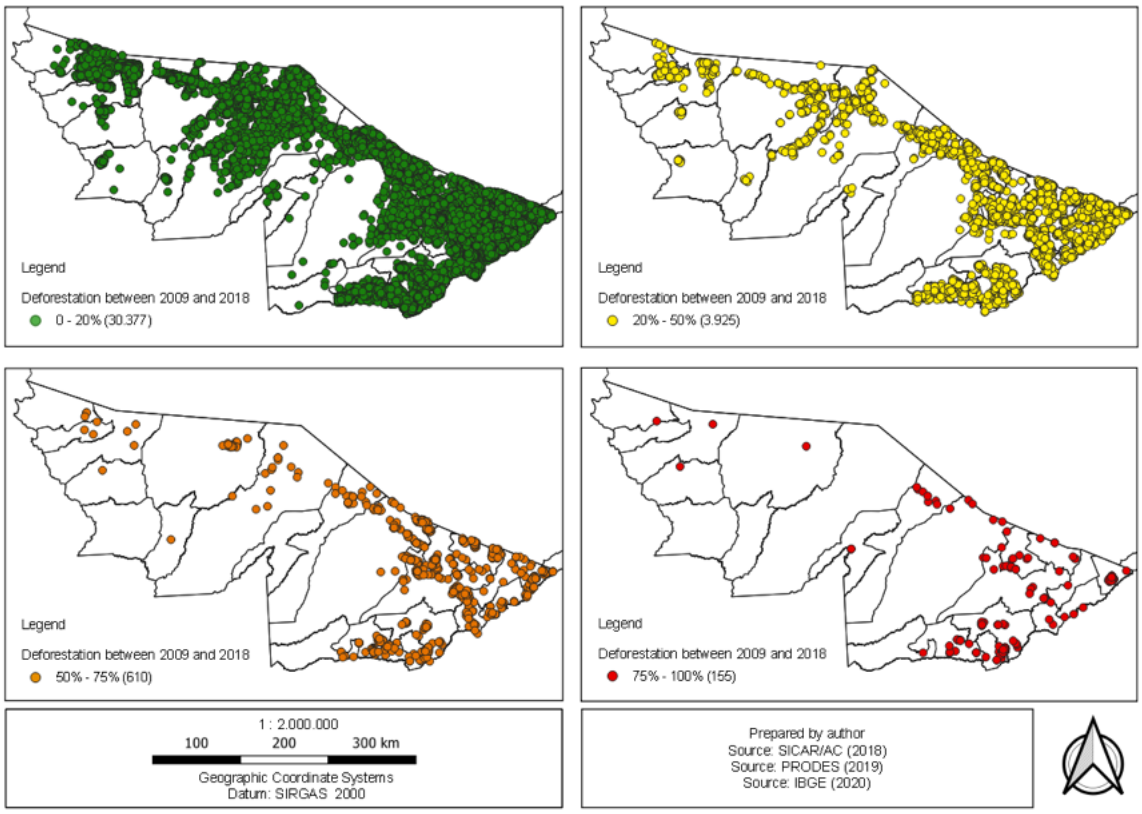

Figure 3. Number of rural properties by percentiles of the deforested proportion between 2009-2018. Source: SICAR-Acre (2018); PRODES (2019); IBGE (2020).

We defined four binary variables to measure compliance with the Forest Code, establishing 2008 as the cutoff date (Figure 4). For rural properties complying with the Forest Code in 2008, we defined: (i) compliers post-2008, which assumes one for those who did not deforest irregularly between 2009 and 2018 (13.7% of farms); and (ii) non-compliers post-2008, which

assumes one for those who deforested more than 20% of the area between 2009 and 2018 (8.2% of farms). For rural properties not complying with the Forest Code in 2008, we defined: (i) compliers post-2008, which assumes one for amnestied farmers (more than 20% deforested) who did not deforest between 2009 and 2018 (46,3% of farms); and (ii) non-compliers post-2008, which assumes one for the amnestied farmers who resumed deforestation between 2009 and 2018 (31,7% of farms).

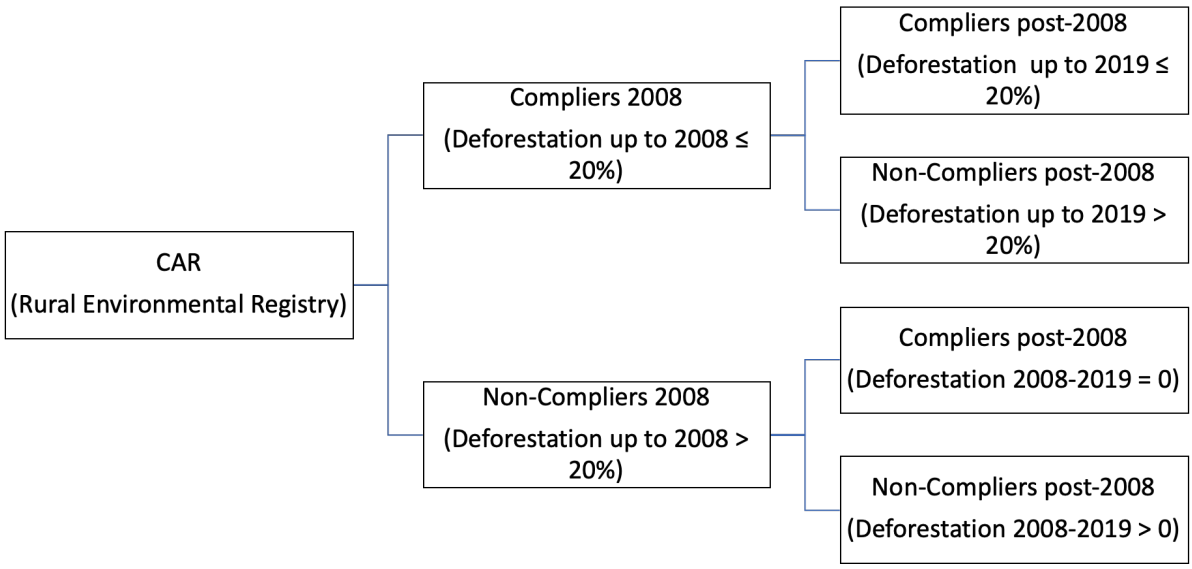

Figure 4. Outcome variables, groups of compliance with the Forest Code

Figure 5 shows the spatial distribution of properties according to the groups of compliance with the Forest Code.

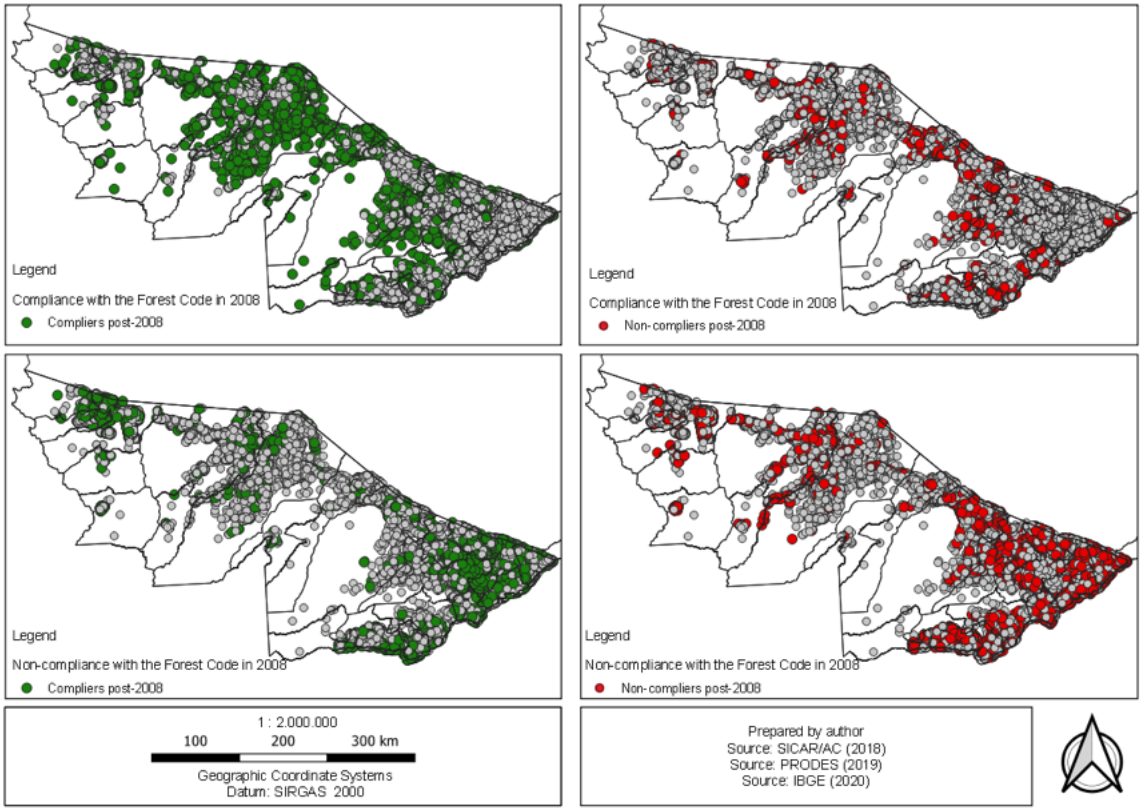

Figure 5. Number of rural properties by categories of compliance with the Forest Code. Source: SICAR-Acre (2018); PRODES (2019); IBGE (2020).

Control variables

We included control variables for farm size, accessibility, agricultural suitability, altitude, and the share of the area occupied before 2008 (Table 2). Accessibility data, represented by the travel time to the nearest city and the rural property's altitude, were obtained in Schielein (2018). Agricultural suitability was determined according to criteria suggested by the Brazilian Agricultural Research Corporation (EMBRAPA 2020), which is based on recommended classes for land use and land slope. Finally, we included fixed effects (binary variables) for the municipalities of Acre, which control unobservable regional heterogeneity.

Table 2. Summary statistics

Variable	Description	Mean	SD	Min	Max	*N*
Dependent Variables: Deforestation and Compliance with the Forest Code						
Deforestation 09-18	Proportion of deforested area within the rural property between 2009 and 2018	0.073	0.135	0	1	35,067
Compliers with the Forest Code in 2008						
Compliers post-2008	Rural properties that assume one if complying with the Forest Code in 2008 and did not deforest irregularly between 2009 and 2018	0.137	0.344	0	1	4,810
Non-compliers post-2008	Rural properties that assume one if complied with the Forest Code in 2008 and deforested irregularly between 2009 and 2018	0.082	0.274	0	1	2,888
Non-compliance with the Forest Code in 2008						
Compliers post-2008	Rural properties that assume one if did not comply with the Forest Code in 2008 and did not deforest irregularly between 2009 and 2018	0.463	0.498	0	1	16,243
Non-compliers post-2008	Rural properties that assume one if did not comply with the Forest Code in 2008 and deforested irregularly between 2009 and 2018	0.317	0.465	0	1	11,123
Treatment variables						
Landsecurity	Rural properties assume one if they do not have land title overlapping	0.106	0.308	0	1	3.732
Control Variables						
Consolidated	Proportion of deforested area by the year 2008[2]	0.557	0.345	0	1	35.067
ln size	Logarithm of the rural property size (hectare) registered in the CAR	3.825	1.181	-4.919	12.280	35.067
Accessibility	Travel time in minutes to the nearest city divided by 100 minutes	1.330	1.665	0	17.090	35.067
Altitude	Altitude in meters of the rural property divided by 100 meters	1.990	0.353	0	3.600	35.067
Aptitude	Binary to identify rural properties located on lands with greater agricultural suitability	0.392	0.488	0	1	35.067
Municipalities	Binaries (fixed effects) to identify the municipalities where rural properties are located	-	-	1	22	35.067

[2] Consolidated rural area was defined in the new Forest Code (Federal Law 12651/2012) as the area within the rural property with preexisting human occupation on July 22, 2008, with buildings, improvements or agroforestry activities.

Source: Prepared by the author

Empirical strategy

We want to estimate δ, the average impact of the treatment ($T = 1$ for land tenure security and 0 for land insecurity) on the outcome Y, controlling for farmers' characteristics:

$$Y_i = \alpha + \delta T_i + \mathbf{x'}_i\boldsymbol{\beta} + \varepsilon_i \qquad (1)$$

Where α is the intercept, $\mathbf{x}$ is a vector of control variables (Table 2) and $\boldsymbol{\beta}$ its respective vector of coefficients, and ε is the random error.

We estimated the average treatment effect on the treated (ATT) using the *Inverse Probability Weighting Regression Adjustment* (IPWRA). The IPWRA is a two-stage estimation strategy, with a selection model for farmers with land tenure security, p, in the first stage, and a model for the outcome variable, weighted for p, in the second stage. The IPWRA estimates the ATT using weighted regression coefficients, where the weights are the estimated inverse probabilities of treatment. The method obtains consistent estimates even when only one of the two equations (selection or outcome model) is correctly specified, i.e., the IPWRA is considered a doubly robust strategy (Imbens and Wooldridge 2009). The variables included in the selection are the same as those used in the outcome models.

Results

First, we fitted the model for the probability of the property having a secure land tenure (p), measured by the non-existence of overlapping land rights. The model fit the data well, with all estimates being significant at 1% (Table 3). The properties most likely to have secure tenure, according to our indicator, are the smallest, farthest from urban areas, with low agricultural aptitude, and a larger consolidated area within the rural plot.

Table 3. Estimates (standard errors between parentheses) of the model for the probability of having land tenure security

Variables	*Land security*
Consolidated	-0.114***
	(0.035)
ln size	-0.208***
	(0.009)
Accessibility	0.088***
	(0.007)
Altitude	-0.389***
	(0.044)
Aptitude	0.052**
	(0.022)
Constant	0.037
	(0.098)
Binaries for municipalities	*yes*
Observations	35,067
Pseudo R^2	0.0841
AIC	21829.19
BIC	22057.74

Notes: *** p<0.01, ** p<0.05, * p<0.1 Standard errors in parentheses

The second stage of our empirical strategy estimates the outcome models weighted by the probability of having land security (Table 4). The share of deforested areas in the Brazilian Amazon increased by 3.5 percentage points between 2009 and 2018. Our estimates indicate that share of the deforested area in this period was on average one percentage point (p.p.) lower in farms with land tenure security than in peer farms without land tenure security (Model 1 in Table 4). Land tenure rights also increased the probability of compliance with the Forest Code among compliers in 2008 (Model 2) by 4.5 p.p. and compliance with the Forest Code among non-compliers in 2008 (Model 4) by 3.6 p.p. In contrast, land tenure security also reduced the probability of irregular deforestation among amnestied farmers in 2008 (Model 5) by 7.7 p.p.

We are further investigating the generalization of models (2) to (5) (multinomial probit models).

Table 4. Estimates (standard errors between parentheses) for the dependent variables

Variables	(1)	Compliers with the Forest Code in 2008		Non-compliers with the Forest Code in 2008	
	Deforestation 09-18	(2) Compliers post-2008	(3) Non-compliers post-2008	(4) Compliers post-2008	(5) Non-compliers post-2008
Landsecurity	-0.010***	0.045***	-0.004	0.036***	-0.077***
	(0.002)	(0.005)	(0.005)	(0.008)	(0.010)
Consolidated	-0.211***	-0.470***	-0.343***	0.898***	-0.085***
	(0.005)	(0.013)	(0.011)	(0.015)	(0.018)
ln *size*	-0.021***	0.007***	-0.031***	-0.031***	0.054***
	(0.001)	(0.003)	(0.002)	(0.008)	(0.008)
Accessibility	-0.007***	0.036***	-0.004*	-0.000	-0.032***
	(0.001)	(0.003)	(0.002)	(0.003)	(0.004)
Altitude	0.043***	-0.032**	0.049***	-0.119***	0.103***
	(0.005)	(0.014)	(0.011)	(0.023)	(0.026)
Aptitude	0.012***	0.002	0.018***	0.001	-0.021
	(0.003)	(0.005)	(0.005)	(0.012)	(0.013)
Binaries for municipalities	*yes*	*Yes*	*yes*	*yes*	*Yes*
Observations	35,067	35,067	35,067	35,067	35,067
R^2	0.263	0.448	0.181	0.479	0.068
AIC	-52645.3	6897.398	347.0406	28038.18	41659.59
BIC	-52408.3	7134.418	584.0611	28275.2	41896.61

Notes: *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses. Models use weighted least squares estimators.

Preliminary conclusions

We evaluate the impact of land tenure security on deforestation in the Brazilian Amazon. Our analysis brings both applied and theoretical contributions to the literature on land governance

and environmental preservation. The main applied contributions are (i) to use a unique dataset with georeferenced farm-level information and (ii) to propose a new indicator of land tenure security, the lack of overlapped property rights. Our main theoretical contribution is to prove that land tenure security can indeed be an essential mechanism for reducing deforestation in the Amazon. Our preliminary estimates are robust to different outcome indicators. The overwhelming lack of land tenure security in the Amazon helps explain increasing deforestation, including non-compliance with the Forest Code. If not followed by effective land governance in the Amazon, individual land titling policies may not produce the expected environmental results.

We developed our hypotheses under the assumption that the failures of land governance in Brazil, especially in the Amazon, promote significant uncertainties regarding the security of tenure, with direct impacts on deforestation. Our results demonstrate that deforestation between 2009 and 2018 should be significantly lower under more effective land governance.

To the best of our knowledge, this is the first study to use an indicator of land tenure based on governance rather than on individual land titling. Our results reinforce the idea that institutional failures play a major role in the deforestation of the Amazon. Land tenure overlaps may be linked to agrarian conflicts arising from the dispute for land (Araujo et al. 2009; Sant'Anna and Young 2010). Land tenure overlaps may also be due to contentious social processes for irregular land occupation (Aldrich 2015; Brown et al. 2016). Agrarian conflicts and irregular land occupations can also be associated with real estate speculation and land grabbing crimes on public or private lands (Reydon et al. 2019; Brito et al. 2019). In other words, individual land titling may not generate the expected impacts on deforestation if the land tenure rights are not guaranteed by good land governance.

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