Don't fight the law, change it: the recent upsurge in deforestation in Brazil and the New Forest Code*

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Abstract

We study the impact of the revision of the Brazilian Forest Code - the national law that governs land use - on deforestation in the Brazilian Legal Amazon. Our empirical strategy exploits the fact that the Forest Code establishes two distinct legal regimes to landowners according to their fulfillment of to the previous law. Basically, those that were not abiding by the former law gained special conditions - even amnesties in some cases - to regularize the environmental liabilities, whereas those that were in accordance with law did not receive any benefits. Given the historical of debt renegotiations and political power held by the rural sector, we argue that this structure of incentives led to a moral hazard behavior and was conducive to an increase in deforestation activities. We investigate our hypothesis using data on yearly deforestation from 2009 to 2017 by rural private properties in the Brazilian Legal Amazon. We first show that the new Forest Code has had a significant impact on deforestation. Then, we exploit some heterogeneity related to size of farms and biomes. We extend the analysis to show that there was no associated increase in agricultural output. Finally, we conduct an counterfactual analysis and show that the Forest Code revision led to an additional loss of 420 thousand hectares between 2012 and 2017, which represents a loss of USD 1 billion considering only carbon emissions.
Keywords: Land regulation, Deforestation, Amazon

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1 Introduction

Decisions regarding land use have important economic implications. Both in urban and rural landscapes, land regulation can significantly impact welfare and affect how externalities are produced (Turner et al., 2014). As regards land use decisions, the deforestation of rainforests represents, arguably, one of the most fundamental challenges that land regulation must address. Rainforests provide a handful of environmental services such as the absorption of carbon dioxide, maintenance of biodiversity, stability of water resources and soil erosion control. Therefore, the understanding how land use regulation can protect or foster the clearing of land has crucial importance to climate change policy as well as other environmental policies.

As the Brazilian Amazon forest is, by far, the largest rainforest in the world, Brazilian land use policies can have global impacts as regards the potential effects on carbon emissions, loss of biodiversity and the like. Until mid 2000's, Brazil had high rates of deforestation in the Amazon, reaching almost 28 thousand km^2 in 2004. In the last decade, the adoption of command and control policies drove down deforestation, as widely documented (Assunção et al., 2015). However, as those policies started to increasingly affect important rural interests, the lobby has re-organized to change the rules of the game.

It is in this context that the Brazilian government, especially the Congress altered the law that regulates private land use in Brazil, the Forest Code. The former Forest Code was written in 1965 and has been revised recently, with the law approved by the House of Representatives in 2011. In this context, it can be said that the law revision was a response to the stricter laws passed by 2008, as put explicitly by former Brazilian Senator, Blairo Maggi:

> "Until 2008, until the day that President Lula issued a decree demanding the environmental regularity of the properties, he forced the National Congress to take the project of almost 14, 15 years, that was here of the Forest Code and bring for discussion. Otherwise, the State and Federal Public Prosecutions would act with the same rigor and same determination they were making in the Legal Amazon." (Blairo Maggi, former Brazilian Senator, in interview to the documentary "The Water Law - New Forest Code" (Peres, 2016))[1]

The revision of the Forest Code entailed vivid discussions in the Brazilian society about the expected effects of the new law. On the one hand, there were those that argued about its im-

[1] https://vimeo.com/147384933

portance to protect rural producers from jurisdictional uncertainty and, therefore, would be an important tool to increase production. On the other hand, there was a group that foresaw huge impacts on conservation efforts. According to this group, the amnesties profited by landholders that did not abide by the law represented a misalignment of incentives regarding conservation (Sparovek et al., 2012).

The main feature of the new law that leads to incentives to deforestation lies in the two distinct regimes that were created within the same Forest Code (Chiavari and Lopes, 2015). The first regime is more general and restrictive regarding the compliance with requisites of Permanent Preservation Areas and Legal Reserve.[2] The second is a special legal regime that applies to those rural properties that had deforested area within Permanent Preservation Areas and Legal Forest Reserve before July 2008. It is significantly more flexible, as it gives special conditions to comply with the law. [3]

It is clear from these segmented regimes that the New Forest Code has benefited landowners that have previously deforested and were non abiding according to the former law. We argue that - in a dynamic setting where agents adjust their priors regarding the odds of being punished for being caught under illegal deforestation - the New Forest Code has entailed incentives to law-abiding landowners to engage in deforestation activities, in the expectation of receiving future amnesties, as well. Therefore, the Forest Code revision, by turning non abiding properties into law abiding, has produced incentives conducive to moral hazard behavior.

We argue that these incentives are stronger among those landowners that because, borrowing from the strategic default literature (Guiso et al., 2013), the reduction in the expected cost of non compliance with the law is much higher for this group. This is the result of two important features of Brazilian institutions.[4] First, the amnesty conceded need not be unique. Indeed, this is not new to Brazilian landholders. As the majority of rural credit is conceded by public banks, it is recurrent in Brazil to observe political processes of debt renegotiation - conducted at the Legislative, as well as the Forest Code revision - that lead to significant waivers to landholders (Távora, 2014). By knowing this history, landholders can expect with a high prior that if they increase deforestation, there will be a renewed waiver in the future. In addition, there is a crucial effect related to the heterogeneity engendered by the new law. Landholders that did not receive benefits from the Forest Code - i.e.,

[2]Permanent Preservation Areas are basically composed of riparian areas and Legal Reserve is the share of private farms that must be kept under native vegetation.

[3]In addition to this regularization plan, rural properties have benefited in other parts of the Forest Code, which led to a significant reduction in their environmental liabilities.

[4]The sectoral capability to engage in lobby that will provide several types of amnesties is not a feature unique to Brazil however.

those that were in compliance with the law as of July 2008 - are relatively less distressed regarding land-use choices. Moreover, as they were not benefited by previous amnesties, it is conceivable that these landholders might expect a similar treatment in the future.

Hence, applying this framework to our context, we argue that the creation of two legal regimes within the same law, without providing a scheme of payment for environmental services to conservation, has created a structure of incentives conducive to the increase in deforestation by landholders that lie in the general, more restrictive, legal regime. Thus, we investigate whether rural properties that were abiding by the law as of 2008 have deforested relatively more after the Forest Code revision.

Given this context of a significant policy change regarding land use in Brazil, this paper investigates its impacts on land use in the Brazilian Amazon. More specifically, we estimate the effects of the Forest Code revision on deforestation at the rural property level. Our identification strategy relies on the fact that the new Forest Code splits rural properties into two distinct legal regimes and that it has created different incentives to clear forest areas.

We implement a differences-in-differences strategy to test our hypothesis. This strategy is made possible by the construction of a novel dataset of yearly deforestation at the property level. We merge a dataset of geolocated rural properties for the whole country provided by the Institute of Agricultural and Forest Management and Certification (IMAFLORA) with data of yearly deforestation at the pixel level (as detailed as 30 meters x 30 meters) provided by the Brazilian National Institute of Space Research (INPE) that covers the Brazilial Legal Amazon.[5] These data on deforestation are used to monitor and improve command and control policies to reduce deforestation in Brazil.

Our findings point to a positive effect of the Forest Code revision on the rate of forest loss in the Brazilian Legal Amazon. Based on these results, we have conducted a counter-factual and a partial cost benefit analysis to assess the impacts of the change in land use regulation. The effects are sizable and have had significant negative impacts: we estimate an accumulated loss of nearly 420 thousand hectares of forest between 2012 and 2017. This amounts to a loss equivalent to USD 1 billion only with carbon emissions. Moreover, we test for the impacts on agricultural output, crop area and cattle herding and find no significant effects.

When we look at additional effects, our findings point that deforestation did not occur up to the legal threshold. Landholders continue to clear land even when turning illegal. This result reinforces our hypothesis that landowners believe in their power to lobby for future

[5]Both IMAFLORA and INPE provide raster files that were used in this research.

amnesties and, thus, engage in moral hazard behavior. Therefore, our results reinforce the already established result that increases in the rural sector in Brazil are mainly based at the extensive margin. As described by Dean (1997), the process of occupation of the Brazilian territory has been based at the extensive margin with no significant efforts to increase land or labor productivity. As a result, as describes the author, Brazil has witnessed the degradation of its Atlantic Rainforest.[6]

This paper contributes to the literature in two ways. First, we provide additional evidence on the effects of public policies on deforestation in the Brazilian Amazon. When deforestation rates dropped from 2004 on, a significant literature emerged to understand what was the contribution of the governments command and control policies. Assunção et al. (2015) investigate how prices and policies contributed to the decline in deforestation. The authors estimate that 56% of the curbed deforestation between 2005 and 2009 was the result of the policies adopted from 2004. Some authors have tried to investigate in detail the effects of some of the policies adopted in Brazil during this period. The improvement in the technology of monitoring through satellites led to better designed task forces, which resulted in less deforestation (Assunção et al., 2013a; Hargrave and Kis-Katos, 2013). Another important change in policy was the establishment of stricter credit conditions in the Brazilian Amazon. Assunção et al. (2013b) investigate the effects of this policy and find that the decrease in rural credit curbed deforestation.

Burgess et al. (2018) present additional evidence on the effects of Brazilian policies by comparing deforestation near to national borders. The authors implement a regression discontinuity design between pixels located in Brazil and in neighbours. Brazil had significant higher rates of forest loss until 2005. From 2006 on, the difference vanished. Interestingly, this difference becomes positive again in 2013 and 2014. Though Burgess et al. (2018) do not relate this late increase to the Forest Code revision, we believe it can represent additional evidence to our findings.

A few papers also assess deforestation at the property level. Alix-Garcia et al. (2018) analyze the effects of the first programs of environmental land registration in two Brazilian states - Mato Grosso and Pará. Their estimates imply a significant reduction in deforestation rates among those properties that enrolled in the programs. Using the same framework - environmental registration in these two Brazilian states-, Assunção et al. (2017) show that landholders responded strategically to stricter monitoring by increasing the participation of small deforestation patches in order to avoid monitoring.

[6] Recently, there was an significant expansion in agricultural productivity, mainly based ion the introduction of genetically engineered soybeans (Bustos et al., 2016).

We improve on this literature by providing the first causal estimate of the effects of the recent upsurge in deforestation in the Brazilian Amazon after many years of declining rates of forest loss. Another contribution relates to the utilization of property-level estimations to the whole region and not only in some states. Finally, our results relate to the literature on land-use regulation in a developing country context which has a vast stock of rainforest and its wide range of environmental services that go from biodiversity to carbon.

Our paper is organized in six sections, including this introduction. Section 2 describes the institutional context and discusses the reasons for the incentives to the upsurge of deforestation after the Forest Code revision. In section 3, we describe the construction of our dataset. Section 4 presents the empirical strategy and discusses the identification strategy. Section 5 presents and discusses the results of the paper, points to some caveats and adds robustness checks and a partial cost-benefit analysis. Finally, section 6 brings on the main conclusions of the paper.

2 Institutional Context

2.1 Environmental and Land-use policy in Brazil

The Brazilian Forest Code - the Law that governs land use in private properties - was created in 1934. Though its main motivation at that time was to ensure the provision of timber and firewood, the former code (revised in 1965) already recognized the public good features of forests in its very first article.[7] Indeed, since its first version, the Brazilian Forest Code imposes the maintenance of areas of forest composed of native trees in every rural property in Brazil. These area are known as legal reserves.[8] In addition to that, the Forest Code also imposes the need of forest nearby riparian areas.

In spite of existing for more than 80 years, the *de facto* enforcement of the Forest Code was basically nonexistent until the mid-1990s (Chiavari and Lopes, 2015). Since then, several measures were taken to reduce the deforestation process, especially in the Amazon, and to enforce the rules imposed by the Forest Code.[9] This process has began in 1998, with the approval of the Act 9605/1998, which sets the conditions that govern environmental crimes. In 2001, the Executive presented Provisional Measure (2166-67/2001), which

[7] http://www.planalto.gov.br/ccivil_03/decreto/1930-1949/D23793impressao.htm

[8] The definition of legal reserve appears in the Forest code revision of 1965.

[9] Alston and Mueller (2007) analyze how the legislative process that led to the criminalize deforestation in legal reserve areas.

amended points of the Forest Code and instituted the compulsory recovery of Legal Reserve.

Despite these measures, until mid 2000s, the Brazilian Amazon Forest has been severely deforested. As compared to its neighbours, immediately at the Brazilian international border, deforestation in Brazil was 3 times higher (Burgess et al., 2018). In November 2004, the Brazilian government has launched the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (Plano de Ação para a Prevenção e o Controle do Desmatamento na Amazônia Legal - PPCDAm) whose aim was to reduce deforestation rates. With the PPCDAm, the government was able to improve command and control policies as it charged legal penalties to illegal deforestation.[10].

In 2008, the Executive reinforced the fight against illegal deforestation with the presentation of Decree no. 6514/2008, aimed at ensuring compliance with Law no. 4771/1965 (Forest Code in force until then). Among the measures included, Article 55 imposed a daily fine for producers who did not have recorded the Legal Reserve after a period of 120 days. In addition, the Central Bank, pursuant to Resolution n.3545/2008, established the following conditions as a criterion for granting rural credit in municipalities of the Legal Amazon: certificate of rural property registration; nonexistence of embargoes for the economic use of illegally deforested areas and environmental regularity document (Ganem, 2015).

As a result of this process of enhancing law enforcement led by the Executive, the cost of illegal deforestation has soared and led to an effective reduction in deforestation rate (Assunção et al., 2015; Sant'Anna, 2017). This tightening of the environmental policy led to a reaction of rural producers. However, instead of directly confronting the Executive or trying to win causes in the Judiciary, the sector tried the path of least resistance: lobbying the Legislative to change the Law (Castelo, 2015; Horochovski et al., 2016).[11]

Indeed, the Brazilian House of Representatives has listened to the yearnings of the rural sector. In 2009, after being rejected in two permanent committees - Committee on Agriculture, Livestock, Supply and Rural Development and the Committee on Environment and Sustainable Development - in 2007, the legislative bill 1876/1999 that proposed the revision of the Forest Code has been assigned a special committee to evaluate it. After two years of discussion, the new Forest Code has been approved by the House of Representatives in May 2011. After being sent to Senate, the new law was finally sanctioned by the Brazilian president in May 2012, with minor revisions.

[10] Assunção et al. (2015) provide an evaluation of the policies led by the Brazilian government during the period 2004-2008.

[11] Kang (2015) estimates that average returns from lobbying expenditures are over 130% in the US context for energy firms.

The New Forest Code is significantly more lax than the former. By introducing amnesties to those that have deforested areas until July 2008, it has reduced the need to recompose riparian areas - legally defined as Permanent Preservation Areas (APP) - and legal reserves that were deforested as of July 2008. This has resulted, according to Guidotti et al. (2017), in a reduction in the environmental liability - understood as the area that does not need anymore to be recomposed - of nearly 40 million hectares.[12]

2.2 Why the new Forest Code might foster deforestation

As the previous version of the Forest Code (from 1965), the New Forest Code imposes two command-and-control conservation policies into private lands: (i) Permanent Preservation Areas, which are designed to protect essential environmental services, such as water supply and soil erosion; (ii) Legal Reserve that has the objective of preserving native vegetation (Chiavari and Lopes, 2015).

Chiavari and Lopes (2015) discuss how the new Forest code gives rise to two distinct legal regimes. The first one is more general and restrictive regarding the compliance with requisites of Permanent Preservation Areas and Legal Reserve. The second is a special legal regime that applies to those rural properties that had deforested area within Permanent Preservation Areas and Legal Forest Reserve before July 2008. It is significantly more flexible, as it gives special conditions to comply with the law.

Basically, those properties that fit into the special regime, according to Articles 59 and 60 of the Forest Code, can engage in the Environmental Regularization Program. By engaging in this program, administrative sanctions - like fees - as well as criminal punishments related to deforestation are extinguished.[13] The regularization of Legal Reserve can occur within the own property or by the acquisition of environmental reserve quotas, among other possibilities.[14]

Moreover, the special regime is even more flexible to small landholders, which are considered as those with less than 4 fiscal modules.[15] On Article 67, the Forest Code simply allows smallholders to declare legal reserves below the minimum established by the law if deforestation happened before July 2008 (Chiavari and Lopes, 2015).

[12]See Machado (2016) for an analysis of the Articles that provide amnesty to rural properties.

[13]In February 2018, the Brazilian Supreme Court has declared that Art. 59 is constitutional.

[14]This possibility of creation of a market of quotas is one of the most interesting innovations of the new Forest Code (May et al., 2015).

[15]A fiscal module is an unity created in 1979 for fiscal purposes and varies from 5 to 110 hectares, according to each municipality. It is defined by the Brazilian Institute of Colonization and Land Reform - INCRA.

As a result of this complexity, the New Forest Code has benefited heterogeneously rural producers. In a nutshell, it has paid-off to clear forest, even if illegally, until 2008. At that year, the Executive , by the Decree 6154/2008, was trying to enforce the former Forest Code and imposing fines for landholders not abiding by the law. The response from the rural sector came in the form of a change in the law, which gave those that were not in compliance an amnesty.[16]

Following the amnesties and the heterogeneity of the New Forest Code, we argue that more deforestation is an expected outcome of this law revision. This comes for two reasons. First, the amnesty conceded need not be unique. Indeed, this is not new to Brazilian landholders. As the majority of rural credit is conceded by public banks, it is recurrent in Brazil to observe political processes of debt renegotiation - conducted at the Legislative, as well as the Forest Code revision - that lead to significant waivers to landholders (Távora, 2014). By knowing this history, landholders can expect with a high prior that if they increase deforestation, there will be a renewed waiver in the future. There is, therefore, a moral hazard effect that comes from this expectation.[17]

In addition, there is a crucial effect related to the heterogeneity engendered by the new law. Landholders that did not receive benefits from the forest code - i.e., those that were in compliance with the law as of July 2008 - are relatively less distressed regarding land-use choices. Moreover, as they were not benefited by previous amnesties, it is conceivable that these landholders might expect a similar treatment in the future. Therefore, the moral hazard effect should be stronger among this group. As Mukherjee et al. (2014) highlight, in the context of an Indian rural debt waiver program due to adverse weather shocks, strategic responses by borrowers were conditional on being effectively distressed by weather shocks.

Given this institutional background and the usual strategic behavior of landholders,[18] one might expect that the heterogeneous effects of the Forest Code might affect differently the odds to clear land according to being in the restrictive or flexible mode of the new Forest Code. We argue, in this paper, that properties in the restrictive regime are more prone to exhibit higher rates of deforestation after the Forest Code approval due to expectations of future waivers. This is the main hypothesis of this paper.

[16]This amnesty implies a significant reduction in the need to regenerate native vegetation. Estimates range from 29 million to 41 million hectares (Soares-Filho et al., 2014; Guidotti et al., 2017).

[17]Melo and Resende Filho (2017) describe this setting in rural debt renegotiations.

[18]Especially, in a repeated game setting as happens with Brazilian rural sector wit debt waivers.

3 Data

3.1 Dataset contruction

This paper uses detailed data on deforestation at the property level for the Brazilian Legal Amazon. One of the new requirements of the new Forest Code is the need to register the Rural Environmental Registry - CAR, as its acronym in Portuguese - that provides geolocated data on private properties. Despite its innovative feature, as it is self-reported by the landholder, there are still too many overlaps between the shapefiles described by distinct properties.

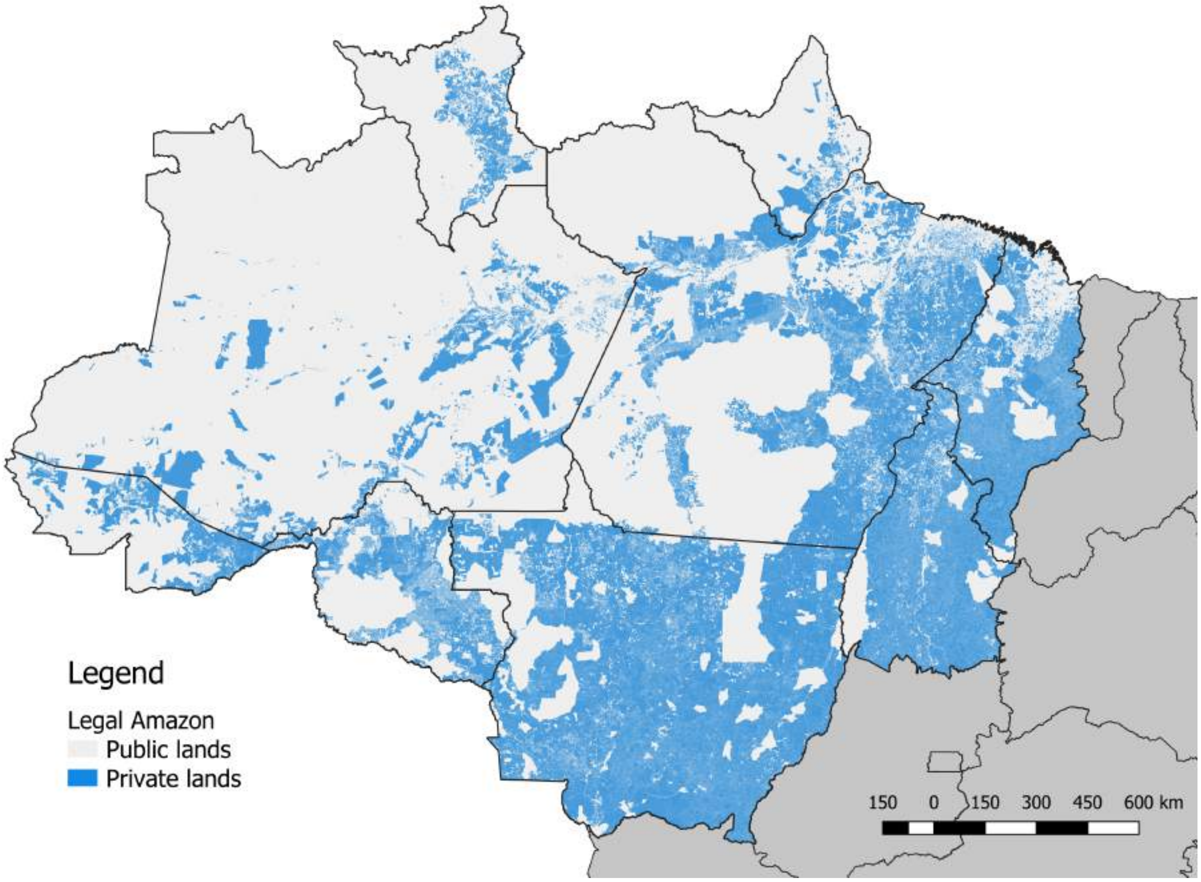
The Institute of Agricultural and Forest Management and Certification - IMAFLORA - recognizes this potential caveat of utilizing solely the Rural Environmental Registry and develops an Agricultural Atlas, which is a database that compiles several sources of geolocated properties for the whole country (Freitas et al., 2018). The authors utilize data from the Ministry of Environment on Protected Areas, Indigenous Land and Military Area and from the National Institute of Colonization and Land Reform on private properties and rural settlements. Moreover, the authors consider as well roads and railroad, urban areas and the hydrography of Brazil.

Freitas et al. (2018) utilize these distinct sources and use an hierarchical model that overcomes the problems of overlapping properties. Therefore, the authors are able to build a complete dataset on Public and Private rural properties in the whole country. The resulting dataset is a raster layer public available with a resolution of 50 x 50 meters.[19]

Figure 1 plots the resulting map of Brazilian rural private properties in the Legal Amazon.

[19]http://www.imaflora.org/atlasagropecuario/

Figure 1: Private rural properties in the Legal Amazon



Source: IMAFLORA

Once we had a raster layer with every rural property (public as well as private) for the Legal Amazon, we proceeded to input annual deforestation rates at the property level. To do so, we relied on a raster layer of land use by pixels sized 30 x 30 meters for the whole Legal Amazon. These information are provided by the Project for Monitoring Deforestation - PRODES - led by the National Institute for Space Research that monitors deforestation in the Brazilian Amazon. The Institute makes use of images provided by distinct satellites, but are mainly from LANDSAT 5.[20]

The corresponding raster file provides information on: annual deforestation (from 2008 to 2017), the stock of deforested area as of 2007, forested area in 2017 and remaining categories such as hydrography, clouded area and non-forested areas.

Based on the raster layers of land tenure and land use, we used the function "Raster calculator" on ArcMap to reckon the share of each land use category of PRODES at each rural

[20]More on the methodology used by the National Institute for Space Research, see http://www.obt.inpe.br/OBT/assuntos/programas/amazonia/prodes/pdfs/metodologia_taxaprodes.pdf

property in the Legal Amazon. From Figure 2, we show an extract of a map which show land use change by rural property.

Figure 2: Land use change by rural property: 2008-2017

Source: own elaboration based on IMAFLORA and PRODES/INPE

3.2 Dependent variable

Therefore, we are able to compute annually the share of deforested area in each rural property from 2008 to 2017. In order to build our main dependent variable, we calculate annual forest loss, as:

$$Forest\ Loss_{it} = \frac{Deforestation_{it}}{Forest\ Area_{it-1}} \tag{1}$$

Where $Deforestation_{it}$ is the share of deforested area of property i in year t and $Forest\ Area_{it-1}$ is the share of remaining forest area in property i at year t-1. Therefore, $Forest\ Loss_{it}$ represents the share of forest that is lost in year t by property i. We prefer to use $Forest\ Loss_{it}$ as the dependent variable since it represents more accurately the decision a landholder faces: how much of remaining forest to clear.

3.3 Independent variables

As discussed before, our identification hypothesis relies on the distinct incentive effects of the Forest Code revision according to how the landholder was abiding by the law as of July 2008 or not. Based on information of forest cover in 2008, we build the variable *Restricted regime* that works as a proxy whether the rural property lies in the restricted regime of the new Forest Code. This variable is calculated as:

$$Restricted\ regime_i = 1\ if \begin{cases} Forest\ cover_{i2008} \geq 0.8\ if\ biome = Amazon \\ Forest\ cover_{i2008} \geq 0.35\ if\ biome = Cerrado \end{cases} \tag{2}$$

This is equivalent to assign value equal to one when the property met legal reserve requirements as of 2008. Legal reserve requirements vary by biome and this feature remains from the previous code. In the Amazon, landholders are required to maintain 80% of total property area as native vegetation. Legal reserve requirements in properties located at Cerrado are 35% and in the rest of the country, requirements amount to 20%. As legal reserve requirements are more restrictive in the Amazon and Cerrado, we believe this is a good proxy that asserts whether the property was in accordance with the prevailing Forest Code at that time.[21]

3.3.1 Agricultural prices

Our vector of covariates includes two variables that are usually associated to deforestation rates: agricultural prices and climate variables such as rainfall and temperature (Assunção et al., 2015; Sant'Anna, 2017). As for agricultural prices, we compute the prices of cattle, soybean, corn, rice, cotton, coffee and sugarcane available at the state of São Paulo in order to avoid endogeneity problems.[22]. We also compute the share of cultivated area for each crop, as of

[21]The previous Forest Code had stricter conditions for riparian areas. But, with these high levels of legal reserve requirement in the Amazon and Cerrado, we believe there is little room to add Permanent Protection Areas requirements. Thus, our *Restricted regime$_i$* is considered a good proxy for identifying those properties that fit in the restricted regime off the forest code.

[22]Prices were taken from https://www.cepea.esalq.usp.br/br

2008, by municipality. The source is the Municipal Agricultural Research from the Brazilian Institute of Geography and Statistics. We also consider the prices of cattle-ranching activities. In this case, we utilize the prices of cattle in São Paulo.

In order to assign values related these variables to the property level, we make use of the detailed land use categories of the *TerraClass* project, which divides the pixels by: (i) agricultural area; (ii) clear pasture; (iii) pasture in regeneration; (iv) forest; (v) others. In the following, we applied the weighted agricultural prices index for each rural property as defined by the following equation:

$$Agricultural\, Prices_{imt} = Ln(1 + (\omega_i * Cattle\, Prices_t + \alpha_i * (0.5) Cattle\, Prices_t + \epsilon_i * Crop\, Prices_t)) \tag{3}$$

Where ω_i is the share of property area with clear pasture in 2008 in property i, α_i is the share of property area with pasture under regeneration in 2008 in property i and

$$\epsilon_i = \frac{crop\ land_{m2008}}{agricultural\ land_{m2008}} * Agricultural\ Land_{i2008} \tag{4}$$

Therefore, ϵ_i is the share of each specific crop land in municipality m multiplied by total agricultural land in property i, as of 2008.

3.3.2 Climate variables

There is evidence that climatic variables might affect the decision to clear land (Aragao et al., 2008; Arima et al., 2011; Assunção et al., 2015). We control our estimates for rainfall and temperatures large deviatons from their climate means. Following Rocha and Soares (2015), we construct series of precipitation and temperature using the *Terrestrial Air Temperature and Terrestrial Precipitation: 1900-2017 Gridded Monthly Time Series, Version 5.01* (Matsuura and Willmott, 2018).

First, we calculated the historical precipitation and temperature averages and standard deviation between 1900 and 2017, for each grid of size 0.5x0.5 degrees in the Brazilian Legal Amazon. Then, for each property, we used their centroid to assign the exactly value of the intersected grid. Note that, assuming exogenous grids, this allows avoiding problems related to spatial correlation of those variables (Burgess et al., 2018). Therefore, our climate variables are defined as:

$$y\ deviation_{igt} = \frac{y_{igt} - mean\ y_{ig1900-2017}}{sd\ y_{ig1900-2017}} \tag{5}$$

Where y is a measure of rainfall or temperature for each property i that has its centroid within grid g at year t.

3.4 Summary statistics

According to data from IMAFLORA, the Brazilian Legal Amazon has 960,347 properties, 643,905 being private and 316,442 being public. This covers an area equivalent to 489 million hectares, of which 307 million hectares were covered by forest in 2017. We restrict our sample to private properties with positive forest area in the previous year. We end up with a dataset with 263,163 properties that cover around 125 million hectares of area and had, as of 2017, 61 million hectares of forests. Table 1 summarizes our main descriptive statistics.

Table 1: Summary Statistics: yearly rural property data 2009-2017, Brazilian Legal Amazon

Variables	Mean	Std. deviation	Min	Max	Number of properties	Number of observations
Forest Loss	1.669	9.465	0	100	263,163	2,351,907
Deforestation (hectares)	1.586	34.41	0	12,854	263,163	2,351,907
Forest	0.437	0.336	0	1.000	263,163	2,351,907
Deforested Area as of 2007	0.463	0.345	0	1.000	263,163	2,351,907
Forest as of 2008	0.471	0.340	0	1.000	263,163	2,351,907
Share Protected Area	23.82	26.01	0	99.16	263,163	2,351,907
Rainfall deviation	0.0821	1.009	-2.888	4.623	263,163	2,351,907
Temperature deviation	0.982	1.071	-3.004	5.731	263,163	2,351,907
Ln(1+Cattle Prices)	2.177	1.937	0	5.124	263,163	2,351,907
Ln (1+Agricultural Prices)	2.275	1.920	0	6.120	263,163	2,351,907

Note: Yearly observations by rural private property, from 2009 to 2017. Data originally from: (i) PRODES;(ii) the Terrestrial Air Temperature and Terrestrial Precipitation: 1900-2017 Gridded Monthly Time Series, Version 5.01; (iii) CEPEA/ESALQ Daily prices and TerraClass 2008 Land use.

4 Empirical Strategy

As discussed in the previous section, we expect that the Forest Code revision has created incentives to clearing new plots of land and, importantly, these incentives are heterogeneous according to the land-use made as of July 2008. As we predict, those landholders that suit in the restricted regime of the forest code are expected to clear more land in the expectation of new amnesties in the future.

Our sample comprises a panel with rural private properties between 2009 and 2017. We assume the the effects of the new Forest Code are already felt after its approval at the House of Representatives, in 2011. By that time, it was very clear that the Brazilian President would not have the power to impose significant vetoes.[23]

Therefore, our key identifying assumption is that landholders had similar behavior regarding decisions to clear land before the revision of the Forest Code. Moreover, as the revised Forest Code introduces two distinct regimes, we predict distinct behaviors after its introduction.[24] Hence, our main identification strategy allows us to estimate the effects of the forest code revision on deforestation by estimating a differences-in-differences model. Therefore, our benchmark specification is:

$$\begin{aligned} Forest\ Loss_{it} = \beta_0 + \beta_1 Forest\ Code_t + \beta_2 Restricted_i + \beta_3 Restricted_i \\ * Post2011_t + \gamma * X_{it} + \alpha_t + \lambda_i + \varepsilon_{it} \end{aligned} \tag{6}$$

Where $Forest\ Loss_{it}$ is the annual forest loss by property i, at year t. The interaction term - β_3 - is our coefficient of interest and measures the effects of the Forest Code revision. X_{it} is a vector of covariates that might also affect decisions to clear land. The term α_t is a time fixed effect, which captures trends common to rural properties, λ_i is the property fixed effect, which captures effects of unobservable and invariant variables in time. The model error term is ε_{it}.

The variable $Restricted_i$ potentially has spatial correlation problems since it relies on forest cover as of 2008 and the process of deforestation is spatially correlated (Mets et al., 2017). To overcome spatial correlation problems in the independent variable, standard errors should be adjusted using the procedure proposed by Conley (1999). However, our sample size imposes computational challenges to estimate using Conley correction. Thus, we follow Burgess et al. (2018) and cluster standard errors in blocks of size 0.5^o x 0.5^o to allow for geographical spatial error correlation.

5 Results

This section evaluates the impacts of the Brazilian New Forest Code (Law 12,651/2012) on deforestation in the Brazilian Legal Amazon. We start by providing preliminary evidence

[23] Carazza (2018) describes how the Executive position regarding the Forest Code revision was defeated in spite of the Brazilian political characteristics.

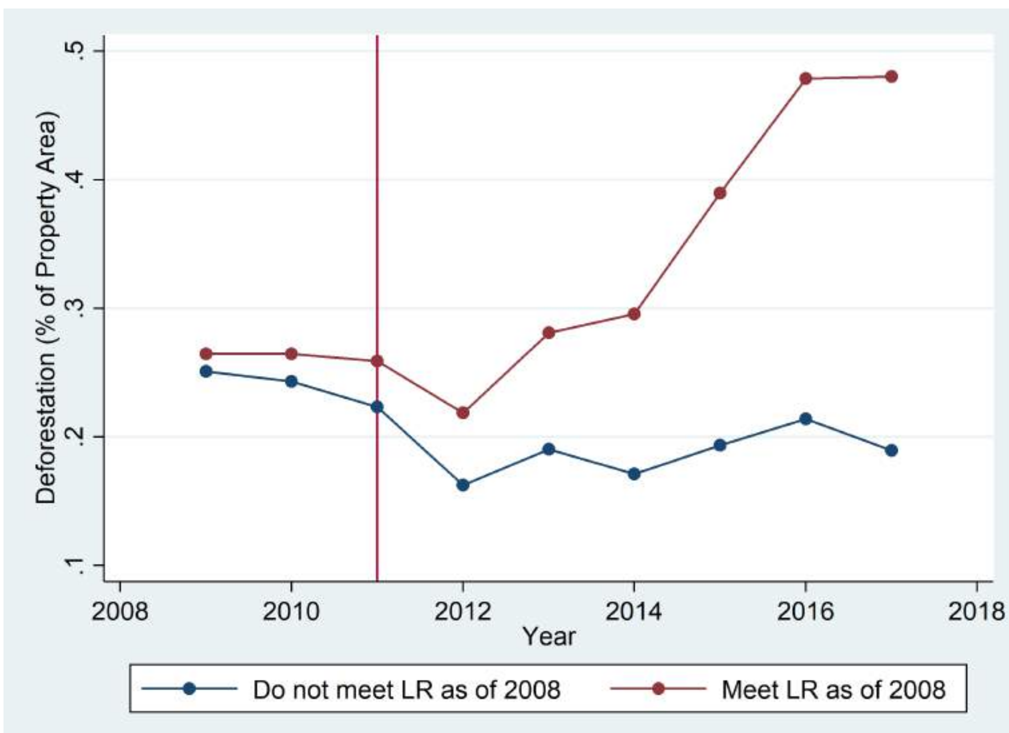
[24] In an alternative specification, we test the effects when considering the timing of Presidential sanction in 2012.

and then go on to the describe the main results obtained. We then explore possible heterogeneity in the impacts and additional effects on other variables. Finally, we perform some robustness tests and discuss caveats related to our results.

5.1 Preliminary evidence

To anticipate part of the discussion, Figure 3 presents average forest loss by group of properties before and after Forest Code approval at the House of Representatives. This is not the variation used in our identification, since we use property-by-year deforestation. Nevertheless, the figure illustrates a pattern of similar trends before the law approval and a significant change afterwards. This is quite similar to the pattern that arises in our regression setting.

Figure 3: Deforestation - properties that met legal requirements as of 2008 and those that did not meet



Source: own elaboration based on PRODES/INPE and IMAFLORA data

In order to further evaluate the common trend assumption, Table 2 reports estimated parameters and their standard errors from a version of equation (6), where, instead of using a dummy of Post treatment, we use a specification that interacts dummies of each year (with 2009 as the baseline year) in sample with treatment status. Column (1) reports results without controls, whereas columns (2) and (3) add climate and agricultural prices controls.

Our results imply that the estimated coefficients for year 2010 are not different from 2009. However, from 2011 on, with a peak in 2014, the estimated parameters are positive and statistically significant. These results reassure our confidence in our common trends assumption.

Table 2: The effect of the Forest Code revision on forest loss in the Brazilian Amazon

VARIABLES	(1) Forest Loss (%)	(2) Forest Loss (%)	(3) Forest Loss (%)
2010 x Restricted Regime	0.171	0.150	0.191
	(0.117)	(0.126)	(0.121)
2011 x Restricted Regime	0.872***	0.879***	0.896***
	(0.098)	(0.098)	(0.095)
2012 x Restricted Regime	0.963***	0.991***	1.002***
	(0.153)	(0.147)	(0.147)
2013 x Restricted Regime	0.932***	0.958***	1.004***
	(0.120)	(0.119)	(0.119)
2014 x Restricted Regime	1.042***	1.048***	1.084***
	(0.147)	(0.145)	(0.144)
2015 x Restricted Regime	0.337***	0.351***	0.393***
	(0.103)	(0.102)	(0.101)
2016 x Restricted Regime	0.774***	0.772***	0.783***
	(0.127)	(0.128)	(0.122)
2017 x Restricted Regime	0.791***	0.780***	0.802***
	(0.108)	(0.112)	(0.108)
Observations	2,351,390	2,351,390	2,351,390
R-squared	0.173	0.173	0.174
Property FE	Y	Y	Y
Year FE	Y	Y	Y
Climate variables	N	N	Y
Agricultural Prices	N	Y	Y
Cluster	Grid	Grid	Grid
Number of properties	262646	262646	262646
Number of clusters	1128	1128	1128

Note: Robust standard errors are clustered by grids of 0.5 x 0.5 degrees. We cluster standard errors by these blocks to allow for geographical spatial correlation due to the extremely large number of observations, as in Burgess et al. (2018). Significance: *** p<0.01, ** p<0.05, * p<0.1.

5.2 Baseline results

We begin by examining the effects of the Forest Code on rural private properties in the Brazilian Legal Amazon. As aforementioned, the timing of the Forest Code revision dates back from 1999. However, it was in September 2009 that a special commission was created at the House of the Representatives to analyze and built on the former law project. By July 2010, the representative responsible for presenting a report, Aldo Rebelo, submitted his suggestions to the special commission, which were approved. At that moment, the main propositions were already in the text, specially those that are important to our analysis, as Articles 59, 60 and 67.[25] After the approval at the special commission, the report took one more year to be approved at the House of Representatives, in May 2011 and another year to finally be transformed into Law 12,651/2012, in May 2012. Thus, we have three important dates related to the process of Forest Code approval that might have impact the decisions to clear land.[26]

The main results of this paper are outlined in Table 3. We test for the effects of the Forest Code on deforestation using different timing for treatment: *Post*2010, *Post*2011 and *Post*2012. The option for these distinct timing of treatment reflects the important landmarks discussed before. We estimate our difference-in-differences model with property and year fixed effects. Moreover, we add property-specific linear time trends to account for specific unobserved factors varying in time. Finally, we consider as climate variables - precipitation and temperature deviations from the long-term mean - and agricultural prices as controls that can affect decisions to clear land, as well. We report results with contemporaneous and lagged covariates, since it might be these that affect the landowner's decisions regarding land use. The sample period covers the years between 2009 and 2017 and standard errors are clustered at the grid level to allow for geographical spatial error correlation, as in Burgess et al. (2018);

Column (1) reports results considering *Post*2010 as the timing of treatment: the impact of the forest code revision on the treated group is associated with an increase of 0.21 p.p. in the deforestation and is statistically significant at the 10% level. This represents 12.6% of the average forest loss and 2.2% of its standard deviation. Column (2) reports results with lagged covariates. In this case, the coefficient estimated for $Post2010xRestrictedRegime$ is not statistically different from zero. In column (3), we consider the effects occurring after 2011, when the new Forest Code was approved at the House of the Representatives.

[25] For the full report, see: http://www.abce.org.br/downloads/PL_1876_99.pdf

[26] For our purposes, the timing coincides with the PRODES year, since satellite data is collected from to August from the previous year to July of the current year to compose the statistics of deforestation of the current year. For more details, see Assunção et al. (2015).

According to column (3), rural private properties that lie in the restricted regime of the new forest code - i.e., that were in accordance by the law as of 2008 - have deforested 0.325 p.p. more forest area than other rural properties after the forest code revision. The coefficient has statistical and economic significance: it represents respectively an impact of 19.5% and 3.4% of the mean and standard deviation of the dependent variable. Results from column (4), also based on $Post2011$ as treatment timing, are positive and statistically significant: its sized as 21.4% and 3.8% of the mean and standard deviation of the dependent variable. Moreover, it seems that lagged variables are, indeed, more relevant in explaining part of the forest loss. Therefore, this is our preferred estimate since it was, given the efforts put by rural lobby and the Congressmen with associated interests, that the Law Project would ultimately be transformed in law. Finally, in column (5) and (6), we consider the moment when the new Forest Code became the Law 12,651/2012. In this case, albeit positive, the estimated coefficients are smaller and are not statistically different from zero.

In sum, these results document a substantial positive effect of the forest code revision on the rates of forest loss in the Brazilian Amazon. It seems, nevertheless, like the effect of the policy was felt already in 2011.

Table 3: The effect of the Forest Code revision on forest loss in the Brazilian Amazon

VARIABLES	(1) Forest Loss (%)	(2) Forest Loss (%)	(3) Forest Loss (%)	(4) Forest Loss (%)	(5) Forest Loss (%)	(6) Forest Loss (%)
Post2010 x Restricted Regime	0.210*	0.169				
	(0.108)	(0.105)				
Post2011 x Restricted Regime			0.325***	0.358***		
			(0.106)	(0.115)		
Post2012 x Restricted Regime					0.015	0.009
					(0.091)	(0.090)
Rainfall	0.020		0.022		0.021	
	(0.043)		(0.043)		(0.043)	
Temperature	0.101***		0.100***		0.103***	
	(0.033)		(0.033)		(0.034)	
Agricultural Prices	0.612		0.412		0.526	
	(0.400)		(0.375)		(0.389)	
Lagged Rainfall		0.131***		0.131***		0.132***
		(0.033)		(0.033)		(0.033)
Lagged Temperature		0.073*		0.071*		0.073*
		(0.038)		(0.038)		(0.038)
Lagged Agricultural Prices		0.504		0.680**		0.620*
		(0.334)		(0.343)		(0.345)
Observations	2,351,390	2,351,390	2,351,390	2,351,390	2,351,390	2,351,390
R-squared	0.335	0.335	0.335	0.335	0.335	0.335
Property FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
Property Time Trend	Y	Y	Y	Y	Y	Y
Grid Time Trend	N	N	N	N	N	N
Cluster	Grid	Grid	Grid	Grid	Grid	Grid
Number of properties	262646	262646	262646	262646	262646	262646
Number of clusters	1128	1128	1128	1128	1128	1128

Note: Robust standard errors are clustered by grids of 0.5 x 0.5 degrees. We cluster standard errors by these blocks to allow for geographical spatial correlation due to the extremely large number of observations, as in Burgess et al. (2018). Significance: *** p<0.01, ** p<0.05, * p<0.1.

From now on, we extend our analysis having as our benchmark estimation the results in Table 3, Column (2). The results described above might be different according to some important features of the private properties. In Table 4, we investigate results considering two of these features: the biome where it lies in and size. The Brazilian Legal Amazon has two biomes within it: the Amazon rainforest, as well as the Cerrado - a Savannah style vegetation. Panel A displays results for properties located at the Amazon biome, whereas Panel B shows results for the Cerrado biome. For each biome, we investigate the effects of the forest code by subsamples according to three categories that define the size of the property.[27]

As already defined, Panel A presents results for the Amazon biome. In every specification, we include controls, property linear time trends, year and property fixed effects and robust

[27]The Law 8,629/1993 defines four categories of rural properties: minifundia (up to 1 fiscal module); small (between 1 and 4 fiscal modules); medium (from 4 to 15 fiscal modules) and large (above 15 fiscal modules). We collapse minifundia and small farms into one single category. This classification is utilized in a number of public policies, including some articles of the New Forest Code, which we will explore in the next subsection to look at heterogeneous effects.

standard errors are clustered at the grid level. Therefore, results follow the specification of Column (2) in Table 3. In column (1), we present results considering every private property. The coefficient estimated is positive and statistically significant: the law revision implied a loss of 0.288 p.p. in properties within the Amazon biome. Its is interesting to investigate how this result spreads between distinct classes of property size. Column (2) displays results from the same specification, but looking only to small farms.[28] The coefficient - 0.303 - is greater and, therefore, indicates a stronger effect on small farms. Column (3) analyses the effects on medium-sized farms. The effect is not distinguishable from zero. Finally, in column (4), we evaluate the impacts on large farms in the Amazon biome: there is a positive and statistically significant effect of the forest code revision on deforestation in large properties. This is important since deforestation is highly concentrated in large plots.[29]

Panel B from Table 4 display results for properties at the Cerrado biome. Overall, results are not statistically significant, albeit with positive signal as well. Therefore, it seems that the effects of the Forest Code revision were majorly felt at the Amazon biome. This might reflect the fact that the agricultural frontier, with the expansion of cattle ranching activity, is currently at the Amazon and the properties located at the Cerrado are, in general, already established and focused in agricultural activities.

[28]Small farms have average area of 69 ha, medium farms have average area of 650 ha and large farms have average area of 5,297 ha in the Brazilian Legal Amazon

[29]In section 5.6, we present an evaluation of costs and benefits of the policy and discuss how benefits are very concentrated among some large landholders.

Table 4: Effects of the Forest Code revision on forest loss in the Brazilian Amazon, by size of property and biome

	Dependent variable: Forest Loss			
	(1)	(2)	(3)	(4)
VARIABLES	All	Small	Medium	Large
	Panel A: Amazon Biome			
Post2011 x Restricted Regime	0.288***	0.303***	0.146	0.216**
	(0.089)	(0.105)	(0.097)	(0.086)
Observations	2,036,890	1,687,424	220,968	128,498
Number of properties	227,415	188,571	24,564	14,280
Number of clusters	995	923	826	868
	Panel B: Cerrado Biome			
Post2011 x Restricted Regime	0.230	0.240	0.109	0.142
	(0.305)	(0.323)	(0.255)	(0.276)
Observations	314,500	249,108	39,919	25,473
Number of properties	35,231	27,955	4,443	2,833
Number of clusters	231	222	199	194
Property FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Climate variables	Y	Y	Y	Y
Agricultural Prices	Y	Y	Y	Y
Property Time Trend	Y	Y	Y	Y
Cluster	Grid	Grid	Grid	Grid

Note: Robust standard errors are clustered by grids of 0.5 x 0.5 degrees. We cluster standard errors by these blocks to allow for geographical spatial correlation due to the extremely large number of observations, as in Burgess et al. (2018). Significance: *** p<0.01, ** p<0.05, * p<0.1.

5.3 Additional Effects

Once documented the positive effect of the Forest Code revision and its heterogeneity among biomes and classes of sizes, some more questions arise. The first relates to the fact that this whole increase in deforestation might be legal: as the properties under the restricted regime were above the legal requirements in 2008, the process of clearing land might only reflect a convergence of the level of forest cover to the level of legal reserve determined by law. It is interesting, therefore, to investigate if rural properties cleared land up to the limits of the law or if they deforested further. If this is so, we should observe - considering only the properties under the restricted regime - more deforestation among the properties that were still meeting legal requirements in the previous year. If this is the case, we can perform a regression discontinuity analysis:

$$Forest\ Loss_i = \beta_0 + \beta_1 Above\ Legal\ Requirement_i + \beta_2 f(Forest\ Cover_i) + +\gamma * X_{it} + \varepsilon_i \quad (7)$$

Table 5 tests this hypothesis using a regression discontinuity design approach. We use the legal threshold regarding the maintenance of legal reserve to explore the discontinuity that might affect the decision to clear land when going illegal. This threshold varies by biome - it is 80% in the Amazon and 35 % in the Cerrado. The assignment variable is the share of the property area covered by forest in the previous period. By exploring this discontinuity, we are able to capture the effects of the decisions of landholders who are on the edge to become illegal. We exclude the analysis for 2009 since being above the legal requirement in the previous year is the same as being under the restricted regime. Therefore, by construction, every property in 2009 under the restricted regime is also above the legal requirement.

In Panel A, we focus on the Amazon biome. Our results indicate a negative and statistically significant coefficient for the years 2012 to 2015, after the Forest Code revision. This indicates that properties with forest cover slightly greater than 80% of its area deforested less than properties with forest cover at the left side of the threshold. As discussed before, we interpret it as a sign that landholders accelerated the clearing of land even when going illegal. This result reinforces our main hypothesis that landholders under the restricted regime acted strategically in the expectation of future amnesties. Hence, going illegal should not, in this case, represent an important constraint. In Panel B, we follow the same analysis to the Cerrado biome. Albeit not significant in its majority - the year of 2015 being the main exception - we can see a signal change from positive to negative from 2012 on. Again, results go in the opposite direction if we were to expect a process of deforestation constrained to being exclusively following the legal regime.

Table 5: Effects on deforestation: effects of going illegal

VARIABLES	(1) 2010	(2) 2011	(3) 2012	(4) 2013	(5) 2014	(6) 2015	(7) 2016	(8) 2017
	Panel A: Amazon Biome							
Above Legal Requirement	-1.296	-0.390	-1.027***	-1.228**	-0.919**	-0.966*	-0.923	-0.584
at year *t-1*	(0.817)	(0.655)	(0.392)	(0.576)	(0.418)	(0.556)	(0.653)	(0.412)
Observations	56,895	56,800	56,686	56,618	56,559	56,482	56,377	56,297
	Panel B: Cerrado Biome							
Above Legal Requirement	1.216	0.361	-0.424	0.713	-0.510	-2.335**	-0.653	-0.542
at year *t-1*	(1.449)	(0.780)	(1.380)	(1.180)	(0.782)	(0.963)	(0.767)	(0.849)
Observations	15,475	15,425	15,389	15,329	15,278	15,242	15,172	15,145
Restricted Regime	Y	Y	Y	Y	Y	Y	Y	Y
Climate variables	Y	Y	Y	Y	Y	Y	Y	Y
Agricultural Prices	Y	Y	Y	Y	Y	Y	Y	Y
Cluster	Grid	Grid	Grid	Grid	Grid	Grid	Grid	Grid
Polynomial order	1	1	1	1	1	1	1	1

Note: Robust standard errors are clustered by grids of 0.5 x 0.5 degrees. We cluster standard errors by these blocks to allow for geographical spatial correlation due to the extremely large number of observations, as in Burgess et al. (2018). We conduct a RDD analysis, with optimal bandwidth and polynomial order equal to one. Significance: *** p<0.01, ** p<0.05, * p<0.1.

Until now, we have discussed results based on the analysis of articles 59 and 60 of the Forest Code. However, as discussed before, the revised code brings additional articles that might have produced impacts on decisions to clear land. For instance, article 67 establishes that small farms (defined as properties up to 4 fiscal modules) that were not in accordance with legal requirements as of 2008 are exempted to reforest these areas. As extensively discussed (Soares-Filho et al., 2014), this is equivalent to providing free amnesty to smallholders that already fit in the special regime (Chiavari and Lopes, 2015).[30]

Hence, we further investigate whether the incentive to clear land among properties in the restricted regime is stronger for small farms. To do so, we estimate the following equation:

$$\begin{aligned} Forest\ Loss_{it} = \beta_0 + \beta_1 Forest\ Code_t + \beta_2 Restricted_i + \beta_3 Restricted_i * Post2011_t \\ + \beta_4 Restricted_i * Post2011_t * Small_i + \beta_5 Restricted_i \\ * Small_i + \beta_6 Post2011_t * Small_i + \gamma * X_{it} + \alpha_t + \lambda_i + \varepsilon_{it} \end{aligned} \tag{8}$$

[30]Indeed, article 67 represents a significant preoccupation to agents related to forest conservation. See, e.g., https://www.theguardian.com/world/2018/mar/01/brazil-amazon-protection-laws-invite-deforestation-ngo

Where the interaction term $Restricted\ Regime_i * Post2011_t * Small_i$ measures the differential impact of the forest code to small farms that were in accordance with the law as of 2008 in comparison with medium and large properties that were also in accordance with the law as of 2008. The coefficient on this interaction - β_4 allows us to interpret the effects of article 67 as previously discussed.

Furthermore, the Forest Code - in its Article 12, §4 - admits a reduction in Legal Reserve requirements in Amazon biome's properties from 80% to 50%. The condition for that is that the property must be located in a municipality that has at least 50% of its area occupied by conservation units or indigenous land. Thus, we test whether rural properties located in municipalities that meet those requirements have deforested more after the forest code approval.

Table 6 presents results based on these additional features of the Forest Code. In column (1), we analyze the effects of additional benefits to small landholders that were granted with article 67. The coefficient on the interaction *Post2011 x Restricted Regime* is still positive and statistically significant. Moreover, the additional coefficient of interest - β_4 from equation above is also positive and statistically significant at 10%. We interpret this as evidence that article 67 adds to articles 59 and 60 in providing incentives to those that were in accordance with the law as of 2008. That is to say, it seems that extending benefits to those that did not obey the law was a powerful incentive to the increase of moral hazard behavior. Finally, the coefficient of the interaction term *Post2011 x Small* is negative and statistically significant. This result, considering jointly with the previously discussed, can be interpreted as a sign that small farms that received amnesty did reduce deforestation rates after the Forest Code revision.

In columns (2) and (3) of Panel A, we investigate the effects of Article 12, which allows for a reduction in legal reserve requirements in properties located in municipalities with more than 50% of the area occupied by conservation units and indigenous land in the Amazon biome. In column (2), we only look at the interaction of a dummy for the forest code approval and a dummy that indicates whether the municipality meets article 12 requirements. We find a positive albeit not statistically significant effect. When we consider the possibility of distinct effects among our treated and control groups, results keep without significance. Though one might interpret as an absence of significant economic incentives from article 12, we must remind that the dummy - *Share Cons. unit >50%* - is measured at the municipality level and, therefore, its estimation looses power.[31]

[31] Though, not reported, we also estimated clustering standard errors at the municipality level and results are similar.

Table 6: Additional and heterogeneous effects of the Forest Code revision in the Brazilian Amazon

	(1)	(2)	(3)
VARIABLES	Art. 67	Art. 12	Art. 12
Post2011 x Restricted Regime	0.163**		0.291***
	(0.068)		(0.103)
Post2011 x Small	-0.543***		
	(0.115)		
Post2011 x Restricted Regime x Small	0.242*		
	(0.142)		
Post2011 x Share Cons. unit >50%		0.325	0.335
		(0.213)	(0.239)
Post2011 x Restricted Regime			-0.112
			(0.181)
Observations	2,351,390	2,036,890	2,036,890
Property FE	Y	Y	Y
Year FE	Y	Y	Y
Climate variables	Y	Y	Y
Agricultural Prices	Y	Y	Y
Property Time Trend	Y	Y	Y
Cluster	Grid	Grid	Grid
Number of properties	525292	454830	454830
Number of clusters	1128	995	995

Note: Robust standard errors are clustered by grids of 0.5 x 0.5 degrees. We cluster standard errors by these blocks to allow for geographical spatial correlation due to the extremely large number of observations, as in Burgess et al. (2018). Significance: *** p<0.01, ** p<0.05, * p<0.1.

5.4 Effects on Agricultural Production

Besides having effects on deforestation, it is plausible that the new forest code might have affected other land-use decisions. Since more land has been cleared, it is rational to make some other use of it. Therefore, we investigate what are the effects on the size of cattle herd, crop area and the value of agricultural output. These variables are all made available on a yearly basis at the municipality level, by the Brazilian Institute of Geography and Statistics.

Thus, differently from previous analysis, we focus on municipal variation after the forest code approval. As such, we estimate the following equation:

$$Y_{mt} = \beta_0 + \beta_1 Forest\ Code_t + \beta_2 Share\ of\ Restricted_m + \beta_3 Share\ of\ Restricted_m * Post2011_t + \gamma * X_{mt} + \alpha_t + \lambda_m + \varepsilon_{mt} \quad (9)$$

Where Y_{it} refers to the dependent variable in municipality m. We use four dependent variables: forest loss, as defined before; the natural logarithm of cattle herd; the natural logarithm of the vale of agricultural output and the natural logarithm of crop area. As when we move to municipality level it is not possible to have a dummy for restricted regime, we take the share of the area of private properties in each municipality that is under the restricted regime. This variable is a measure, at the municipality level, of continuous treatment and allows us to identify the effects at another geographical and institutional level. As before, X_{mt} is a vector that comprises rainfall and temperature deviations from the long-term mean and agricultural prices; α_t and λ_m are time and municipal fixed effects.

Table 7 reports the results from estimating equation (8) above. In column (1), we present the estimated coefficient for the forest loss at the municipality level. As before, the coefficient is positive and statistically significant. Albeit smaller, this coefficient is not readily comparable to those from previous tables since the treatment condition here is continuous rather than discrete. Anyway, the coefficient is economically significant: one standard deviation (i.e, 30.6 p.p.) in the variable *Share of Restricted* implies an increase of 0.14 p.p. in forest loss.

There is a significant debate on the existence of a trade-off between conservation policies and economic development. Sant'Anna and Young (2014) argue that deforestation in the Brazilian Amazon is generally positive correlated to higher homicide rates and negatively correlated with the Human Development Index. Similarly, Assunção et al. (2013a) show that decreases in deforestation are not associated to less Agricultural GDP or crop production. Therefore, from columns (2) to (4), we investigate the effects on variables related to agriculture production. Column (2) displays a positive, albeit non significant, effect of the forest code on the herd of cattle, by municipality. Results from columns (3) and (4) show no effect on agricultural activity. These results, at the municipality level, provide some evidence that deforestation is not directly linked to agricultural production. Results must be, however viewed with some caution, since we do not explore effects that are not immediate.

Table 7: The effect of the Forest Code revision on agricultural outputs in the Brazilian Amazon

VARIABLES	(1) Forest Loss	(2) Ln (Cattle)	(3) Ln (Agriculture Output)	(4) Ln (Crop Area)
Post 2011 x Share of Restricted	0.005***	0.001	-0.000	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Observations	5,161	5,161	5,161	5,161
Municipality FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Municipality Time Trend	Y	Y	Y	Y
Climate variables	Y	Y	Y	Y
Agricultural Prices	Y	Y	Y	Y
Cluster	Municipality	Municipality	Municipality	Municipality
Number of municipalities	1152	1152	1152	1152
Number of clusters	576	576	576	576

Note: Robust standard errors are clustered by municipality. *Share of Restricted* is the share of total private area by municipality that is under the restricted regime of the new forest code. Significance: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

5.5 Caveats and robustness checks

As discussed in the data description, we only observe the properties' polygon shape in one period. That is to say, we only have the polygons of the properties for the year 2016 (Freitas et al., 2018). This is a potential caveat to our results since there is the possibility of strategic property fragmentation in order to enhance the possible benefits related to the new forest code. If it has happens so, then our results might not be valid. Although we cannot deal directly with this caveat since there is not a dataset with properties' polygons before the law approval, we can impose some restrictions that might enhance confidence in our results.

As a first approximation, we see that the distribution of the area of properties is highly skewed: we estimate the Land Gini index based on our sample of rural private properties and find a value of 0.858. This high level of inequality in landholdings seems to invalid the hypothesis of property fragmentation. Moreover, we present an additional test based on analyzing the neighbourhood of properties under the restricted regime. Basically, we test whether the share of properties under the special regime within the same grid affect the rate of forest loss. In the presence of strategic fragmentation of properties, we would expect to find a positive coefficient of the interaction $Post2011 * Restricted\ Regime * Share\ of\ special$. This is so because the separation of properties would be an effective way to allow for more deforestation in properties under the restricted regime.

Table 8 reports additional robustness tests based on the discussion above on the fragmentation of rural properties and some placebo tests exploring possible effects on Conservation Units and timing of treatment. In column (1), the coefficient of the interaction $Post2011 * Restricted\ Regime * Share\ of\ special$ is negative and significant. As discussed, this result is different from what one would expect if there was a strategic division of properties: if a landowner were to separate properties into two, one under the special regime and other under the restricted regime, we would expect to see properties under the restricted regime surrounded by more properties under the special regime to clear more land.

In column (2), we estimate our baseline specification for conservation units. These areas are part of the National System of Conservation Units and can be divided into units of integral protection or sustainable use. Both types are considered public protected areas, which are, therefore, excluded from the forest code revision that governs land use in private properties. Therefore, one should expect a zero effect of the forest code on conservation units, even if some of the conservation units did not meet the requirements of forest area as defined by the forest code. Indeed, the coefficient in column (2) is not distinct from zero. In column (3), we explore the timing of the forest code revision. As expected, when we use *Post2013* as the period of treatment, we see no significant effects. Overall, the results from Table 8 reinforce the confidence in our previous results discussed throughout the paper.

Table 8: The effect of the Forest Code revision in the Brazilian Amazon: testing some caveats

VARIABLES	(1) Forest Loss	(2) Forest Loss	(3) Forest Loss
Post2011 x Restricted Regime	0.850**	-0.025	
	(0.363)	(0.202)	
Post2011 x Restricted Regime	-0.010*		
x Share of properties under special regime	(0.005)		
Post2013 x Restricted Regime			-0.122
			(0.094)
Observations	2,341,643	96,275	2,351,390
Property FE	Y	Y	Y
Year FE	Y	Y	Y
Climate variables	Y	Y	Y
Agricultural Prices	Y	Y	Y
Property Time Trend	Y	Y	Y
Cluster	Grid	Grid	Grid
Number of properties	261,562	10,730	262,646
Number of clusters	984	660	1128

Note: Robust standard errors are clustered by grid. *Share of Special* is the share of total private area by grid that is under the special regime of the new forest code. Significance: *** p<0.01, ** p<0.05, * p<0.1.

5.6 Cost-Benefit Analysis

As shown before, the Forest Code revision has had a positive impact on deforestation rates in the Brazilian Legal Amazon. This decrease in forested land, however, was unaccompanied by increases in agricultural output and crop area. Therefore, there was no effect on agriculture both in the intensive and extensive margins. The only impact was on the size of cattle herd, which is a feature of the process of deforestation in the region extensively documented (Margulis, 2003).

In this section, we perform a partial cost-benefit analysis considering only the cost related to the emissions of carbon and that the cleared land is totally directed to cattle ranching. To assess these impacts, we conduct a counter-factual analysis based on the coefficient of our preferred estimation (Table 3, Column (2)).

Table 9: Counter-factual analysis for cost-benefit assessment - deforestation in hectares

Year	(1) Observed Deforestation Total	(2) Observed Deforestation: Private properties	(3) Predicted Deforestation: Private properties	(4) Difference Observed-Predicted
2009	620,841	452,073		
2010	619,755	441,249		
2011	561,011	412,292		
2012	433,605	312,600	241,491	71,109
2013	530,935	376,669	306,609	70,060
2014	502,476	356,768	288,176	68,592
2015	601,235	426,875	357,078	69,797
2016	710,555	492,371	421,875	70,496
2017	697,294	459,481	389,594	69,887
Total 2012-2017	3,476,101	2,424,764	2,004,823	419,941

Note: Counterfactual simulations are conducted using estimated coefficients from our preferred specification (Table 3, column (3)). Values of deforestation are in hectares.

Column (1) from Table 9 displays the actual yearly deforestation from 2009 to 2017. Total deforestation during the period after the Forest Code revision - that is to say, from 2012 to 2017 - has amounted to more than 3.4 million hectares, an area larger than Belgium. But, how much of this is due to the new Forest Code? To conduct this analysis, we compare the observed deforestation in private properties - Column (2) - to the predicted deforestation in the same set of properties if the Forest Code was not revised (Column (3)). The difference between them gives us an estimate of the effects of the Forest Code on deforestation. According to Column (4), Brazil has lost a total of 419,941 hectares due to the recent law approval. This represents a value 21% higher of deforestation in private properties that would have happened in the absence of the Forest Code revision.

To conduct our partial cost-benefit analysis, we consider that the whole extension of cleared land is devoted to cattle ranching. As Margulis (2003) argues, cattle ranching is the main driver of deforestation in the region. Young et al. (2016) estimate that cattle ranching in the Brazilian Amazon yields profits of BRL 160 (in 2013 prices) per hectare. Using 2013 average exchange rates, we assume that profitability of cattle ranching in the Brazilian Amazon is USD 71/ha/year. Multiplying this value by the total deforestation due to the Forest Code yields annual profits of USD 4.9 million on average due to cattle ranching activity in deforested areas.

According to the Brazilian Ministry of Environment, the average hectare of forest in the Brazilian Legal Amazon has of 485.1 tCO_2.[32] Thus, the deforestation of the 832,186 hectares have led to emissions of 203.7 million tonnes of CO_2. Note that in this estimation, we do not consider the methane that is emitted from cattle ranching activities. If we consider a

[32]See http://www.fundoamazonia.gov.br/export/sites/default/pt/.galleries/documentos/ctfa/Nota_Tecnica_2018.pdf

price of carbon of USD 5 per tCO_2, which is used as the reference for transfers to the Amazon Fund, for instance, we reach a cost of USD 1.0 billion. Alternatively, we can reckon what is the implicit value of carbon in the policy, by equating its value to the profit from economic activities. In order to compare a flow of annual profits with the once and for all loss of carbon, we reckon the present value of cattle ranching profits estimates using three different discount rates - 2%, 5% and 8%. Respectively, the present value of those prfits are: USD 249 million, 100 million and 62 million. By dividing each of these values by the value of carbon lost, we reach values of carbon that range from USD 0.06 to 0.24 per tCO_2, much less than the estimates provided by Jayachandran et al. (2017) and Simonet et al. (2018) - USD 0.46/tCO_2 and USD 0.84/tCO_2, respectively. Hence, a relatively cheap policy of payment for environmental services could have significantly reduced the impacts of the Forest Code revision.

Moreover, we have only taken into account the costs related to carbon emissions,, neglecting several environmental services provided by the tropical forest, such as water resources, soil erosion and biodiversity. If we were to consider these additional services, the ineffectiveness of the policy would be even wide open. As a final remark, one should take notice that the profits from cattle ranching are unevenly distributed - the Gini for deforested land is as high as for the estimated deforestation - and must have contributed to an increase in local inequality.

6 Conclusion

This paper has assessed the effects of the recent revision in the Brazilian law that governs land use - the Forest Code - in the Brazilian Legal Amazon. Using a differences-in-differences model based on the creation of two distinct legal regimes, we estimated an additional deforestation of 419 thousand hectares from 2012 to 2017 due to the new law. Moreover, we did not find any significant effect on agricultural production as well as crop area. The land cleared was diverted to cattle ranching activity, which is characterized by its low productivity.

Then, we conducted a cost-benefit analysis, considering only the loss with carbon emitted. Our results predict that social costs can be as as large as 16 times higher than private benefits from cattle ranching activity.

We believe that at the time of the Forest Code revision, Congressmen could have brought into light the discussion of using Payments for Environment Services as an alternative policy to landowners that preserved forests, as a way to align incentives in the right direction. Instead, incentives that aroused from the new Forest Code signalled - in a context of recurrent amnesties that the rural sector is used to lobby for and receive - for an increase in deforestation. Hence, we conclude that the policy revision was not designed in order to enhance social welfare.

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