UNIVERSIDADE FEDERAL DO RIO DE JANEIRO
INSTITUTO DE ECONOMIA
PROGRAMA DE PÓS-GRADUAÇÃO EM ECONOMIA
DANIEL CASPAR WALLMANN

A FRESH START?: Impacts on land-use and agricultural productivity of the Brazilian Forest Code Revision of 2012

RIO DE JANEIRO
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Orientador: Dr. Romero Cavalcanti Barreto da Rocha

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RESUMO

No dia 25 de maio de 2012 a Presidenta Dilma Rousseff decretou a lei nº 12.651, o novo código florestal do Brasil. Foi o resultado de uma negociação árdua e longeva tanto no congresso como no senado entre políticos “ruralistas” e a base do governo. O compromisso alcançado melhora as possibilidades de fiscalização das autoridades ambientais mas em troca afrouxa as regras ambientais. Por cima disso, ele inclui uma anistia para certos tipos de remoção illegal de vegetação nativa ocorridos antes do 22 de julho de 2008. Este trabalho visa investigar o efeito da lei sobre o uso da terra e a produtividade agropecuária na Amazônia, dado a sua elevada importância ambiental. Usando dados no nível da propriedade rural, encontra-se que propriedades que não foram anistiados tiveram uma taxa de conversão de pastagem para a agricultura em média 0.6% menor do que propriedades que foram anistiados, depois do decretamento do código florestal. As análises da produtividade no nível municipal mostram que um 1% em área não-anistiada diminui a taxa de lotação de gado por 0.1%. Esta diminuição coincide com uma redução do valor do crédito para capital operacional da pecuária por 0.032%.

Palavras chave: uso da terra, produtividade agrícola, crédito rural, leis ambientais

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ABSTRACT

On the 25th of May 2012, Dilma Rousseff, the president of Brazil, decreted the law nº 12.651, the new forest code of Brazil. It was the result of a long-running and complex negotiation between politicians of the rural caucus and the parties supporting the government. The eventual compromise that was reached improved the possibilities of environmental monitoring of private properties but at the same time loosened conservation requirements. More importantly, it also included an amnesty for certain kinds of illegal deforestation that occured before the 22nd of July of 2008. This work investigates the effect of this law on land use and agricultural productivity in the Amazon, given its high relevance for our planets' environment. Using property-level data, it is found that after 2012, properties that did not receive an amnesty had a conversion rate from pasture areas to agricultural uses that was on average 0.6% smaller than the one of amnestied properties. Municipality-level analyses of productivity show that a 1% increase of the share of non-amnestied private property area reduced cattle-stocking rates by 0.1%. This reduction coincides with a reduction of the value of credit for operational capital for cattle ranching by 0.032%.

Keywords: land-use, agricultural productivity, rural credit, environmental laws

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1. Introduction

The passing of the new Brazilian forest code in 2012 was met by great controversy. Supporters of the law celebrated it as a way to increase productivity and legal land use to protect the forest. Detractors pointed out that it would lead to a marked increase in deforestation and destroy what is left of the Amazon rainforest (BRANCALION *et al.*, 2016). This text will investigate this question empirically.

Undeniably, the Amazon rainforest is vitally important for the conservation of the planetary conditions for human life. On a global scale its role as a carbon sink helps to control climate change. It is estimated that the forest processes annually through photosynthesis and respiration more than twice the carbon emitted by fossil fuel combustion worldwide (PHILLIPS *et al.*, 2009).

Tropical forests also regulate the global climate more directly, for example by evapotranspiration or interception of solar energy by the canopies. In a recent review article of different modelling efforts that consider these factors, (LAWRENCE; VANDECAR, 2015) it is described that complete deforestation of the Amazon could have impacts all around the world, from the US over Europe to Asia. For instance in the midwestern region of the United States, it could cause a reduction in rainfall, specifically in the months relevant for agriculture. On a more regional scale, evaporation from the Amazon is an important factor for precipitation in the south of Brazil and Paraguay, as well as Uruguay and central-eastern Argentina (LOVEJOY; NOBRE, 2018). These areas are highly relevant for the agricultural production of their countries.

Apart from the relevance of the Amazon for regional and global climatic conditions there are also very real benefits generated directly by the standing forest and many livelihoods depend on them (LAURANCE, 1999). First we can mention the extraction of food and other usable natural products. In terms of food important examples in the Amazon are the Brazil nut and the Açaí-Berry which are collected in the wild. For other than food items usually both natural rubber and wood itself are highlighted (HOMMA, 2012). Additionally, potentially new plants could be discovered for pharmaceutical uses. One successful example is the jaborandi tree which now is being cultivated to treat certain types of glaucoma (GUMIER-COSTA *et al.*, 2016).

Secondly there are traditional people and societies in the Amazon which depend on the forest for their traditional way of life and in many cases for their survival. Economic analysis faces two distinct challenges when analyzing their importance. On the one hand even if the indigenous people use the concept of money or are acquainted to it sufficiently, since their very life depends on the natural resources, often they would pay infinite valuations for its preservation (CHOY, 2018). On the other hand there are very few indigenous people left. This means that when weighing their own preferences against the economic interests of the society at large, they could very well lose. This problem is prevalent in large infrastructure projects such as dams in the Amazon (for example DE SOUSA; REID, 2010) where national interests supersede those of local residents. However when weighing the conservation of the Amazon on a more global scale, the forests end up winning most of the time. There is a variety of studies in which preferences and implicit valuations are elicited in surveys and workshops. More specifically, regarding the Amazon forest researchers found that households were willing to pay on average 92$ per year to avoid forest loss (SIIKAMÄKI *et al.*, 2019). This kind of studies can form the basis for eventual payments to countries or forest owners for the conservation of their lands.

The total economic benefits or ecosystem services provided by different ecosystems can be aggregated. Considering climate regulation, provision of food, medicine and shelter, revealed preferences and some other factors, a recent meta-study found a total average value for tropical forests of 5264 US$ per hectare[1] and year (GROOT *et al.*, 2012). Specifically for tropical forests, there also exists an estimation in terms of welfare (CARRASCO *et al.*, 2017).

We have seen that there is potentially a lot of value in a standing Amazon forest. Admittedly, this figure is largely hypothetical because the many non-exclusionary services provided by the forest are essentially public goods and difficult to market. It is true that

[1] Deflated to the base year of 2007.

some international initiatives, such as the Amazon Fund could be interpreted as payments for the services rendered but they do not directly pay for conserved hectares and their overall impact on deforestation reduction has not been proven (CORREA *et al.*, 2020).

Still, given the potential of the standing forest, it is surprising that the productivity of deforested land is very low in large parts of the Amazon. Specifically for cattle-ranching (which is the primary use of recently deforested land) the gains obtained only by the sale of cattle often would not justify the clearing of additional land. The primary reasons for this are low stocking rates. In Brazil they are in general very small, at about 30% of sustainable capacity (STRASSBURG *et al.*, 2014).

Specifically in the northern region of Brazil which encompasses most of the Amazon biome, average stocking rates were about 1.22 heads of cattle per hectare in 2014/2015 whereas for the region a sustainable stocking rate of around 3 heads of cattle is estimated in Arantes *et al.* (2018). Notably there are other Brazilian regions for which higher stocking rates are possible, as soil-fertility and climatic variations are not necessarily optimal for cattle-ranching in the Amazon. Combined with infrastructure issues and distances to slaughterhouses the low-productivity has the consequence of making cattle-ranching very little profitable in many parts of the Amazon.

Yet the region has seen a remarkable expanse in pasture area at the cost of reduced forest cover. Recent studies estimate that pasture coverage increased by about 25 million hectares in the Amazon from 1995 to 2005 and continued to increase albeit at a somewhat slower pace after this (SOUZA *et al.*, 2020). There are two reasons identified for this in the literature that complement each other. First land in the Amazon can or at least could historically be acquired at little to no cost, simply by deforesting available public or unguarded private lands and establishing a farm on it. Having done this it is possible to falsify documents and bribe public officials to immediately receive legal rights to the land (INTRATOR, 2011). Secondly the new occupant can have the reasonable expectation that the deforested land will appreciate in value. There are several pathways for this.
First if the occupant did not acquire legal land titles immediately, he can simply wait for one of the periodic amnesties for occupants of public lands, such as those given for

example in 2017 and 2019 (SOUSA, 2020). Notably in this case he usually has to prove the productive use of the property by farming some cattle on it. Secondly with expansions in infrastructure, slaugther-house establishments and scarcity of pasture because of extensive deforestation the landowner can also expect to see his land appreciate in value. Finally even if the land-owner manages to acquire the land title and is ready to sell it, it could be impossible because of illegal deforestation. Both fines for which the land-owners are liable as well as production embargoes can substantially lower the speculative value of the property. However similarly to the land titling also in this case amnesties are possible.

The forest code of 2012 constitutes the largest of these kinds of amnesties given up-to-now to Brazilian landowners. That is why it is important to study its effect on agricultural productivity. By some estimates over 30 million hectare on private properties were liberated for agricultural uses by the new law (SOARES-FILHO *et al.*, 2014). It was passed with heavy lobbying efforts from private landowners who wanted relief from the environmental regulation and enforcement that had intensified since the early 2000s (BRANCALION *et al.*, 2016).

The argument laid out above makes two possible consequences of this amnesty plausible. First of all the amnesty increased the value of properties that had deforested illegally before the cut-off date as they became free of fines and commercial embargoes. To completely capture this increase in value the landholder can sell it or - if it is possible - increase its productivity. If its potential maximal productivity has not yet been reached, it is likely that buyers will increase productivity as well in order to make a return on their investment.

Before elucidating the second possible and opposite effect that the amnesty can have, I briefly need to comment on the ways that agricultural productivity can be increased. While we have seen above that on average the productivity of cattle-ranching can be doubled or even tripled without exceeding the sustainable capacity of pastures, the land can also be used for crop production which can significantly increase profits. For example researchers found for a municipality in the State of Mato Grosso do Sul, that soy had almost 4 times the profit margin per hectare than cattle ranching for the agricultural year of 2013/2014

(DOS SANTOS *et al.*, 2015). Even a temporary switch to soy can be interpreted as an investment in increasing cattle-productivity. A survey of cattle-ranchers in the state of Pará (PEREIRA *et al.*, 2020) found that many of them plant soy to regenerate pasture areas and some even rent their property to soy producers for a certain time-frame to do this if they lack the capital themselves. The productivity of soy plants themselves can be increased substantially as well. Relevant techniques include double-cropping and direct sowing systems (ASSUNÇÃO; BRAGANÇA; HEMSLEY, 2019).

Secondly as argued by Santanna and Costa (2019) the amnesty can also have an adverse effect on productivity since it functions as a signal that future amnesties are possible. Especially landowners that had only deforested up to the legal limit on the cut-off date could interpret the amnesty given to other properties as a signal that they could themselves receive one in the future. Deforestation thus allows them to increase their production extensively, maintaining low-productivity or decreasing it further, and increasing its speculative value for future amnesties. Notably this causal mechanism could also happen in properties that received an amnesty. However since they had already deforested more than the legal limit at the cut-off date, they do not have as much native forests left to deforest.

Which of these effects prevails is highly relevant for agricultural policy in the Brazilian Amazon. Proponents of the forest code argued for the first effect. More juridical security and a fresh start for producers would allow them to increase productivity, raise agricultural production and improve the livelihood of farmers and thus ultimately put less pressure on forests (YOUNG, 2006 and FERRANTE; FEARNSIDE, 2019). On the other hand opponents of the forest code frequently alleged that the second effect would prevail. An amnesty would only fuel land-speculation and deforestation and perpetuate low-productivity and low-profitability cattle farming in the Amazon.[2]

[2] It should be noted that there exist theoretical considerations that link increased productivity to increased deforestation both for the cases of cattle (BOWMAN *et al.*, 2012) and soy (GARRETT; LAMBIN; NAYLOR, 2013) in the absence of strict enforcement of land regulations. One empirical example for this can be found in Assunção *et al.* (2017) who relate the expansion of the electrical grid to deforestation in the Amazon. However in the case of the forest code, the driver of increased productivity would actually be compliance with land regulations. Thus I disconsider this causal pathway.

This is the question that I will address in this research paper. Before starting with my own analysis, I will provide a literature review in the next chapter. I start with contributions covering the forest code itself and then move to assessments of other public and private policies which explicitly aimed to curb deforestation in the Amazon. This serves two purposes. First it is necessary to understand the forest code as a part of a set of public policies that influenced agriculture in the Amazon. Secondly, some of these policies changed productivity in a way that is very similar to the forest code and thus are interesting for this text.

After that, I explain in-depth the changes that were made in the new forest code and the legislative process that led to its enactment. This is vital to understand the different angles of analysis that I use in the subsequent chapters. I start the empirical part with a description of the data and the data sources. Then I head off to the results and their discussion. Finally, some further research possibilities are explained before concluding the thesis

2. Related Literature

2.1 Evaluations of the Forest Code

As an evaluation of the impact of the forest code, my text is most closely related to Santanna and Costa (2019). They find evidence that the amnesty of the forest code increased deforestation more on non-amnestied properties than on amnestied properties. Additionally in terms of agricultural production, on the municipality level they found an increase in cattle-herds and a decrease in agricultural production when considering municipalities with more compliant properties as opposed to municipalities with less compliant properties. In terms of the impact on productivity these results are somewhat inconclusive. The decrease in agricultural production in “compliant municipalities” could mean a switch from cattle-ranching to agriculture in the comparison group, the municipalities in which more amnesties were received. This would point to the first effect identified above. On the other hand regarding cattle ranching, there was an increase in deforestation, which in principle could mean an increase in pasture area. So this implies that the increase in cattle heads was not necessarily achieved by intensification of production.

In this text, I extend the analysis of Santanna and Costa (2019) in order to clarify whether the forest code had an effect on productivity. In order to do so I use the same property level data set and similar sources for agricultural production data. Then I depart from it in two major ways. First I use spatial data on types of land use to be able to assess land use changes on the property level and not only changes in deforestation as Santanna and Costa (2019). Secondly on the level of the municipality I combine the spatial data from the first step with data from agricultural production from the same sources used by these authors in order to be able to assess productivity. Finally I investigate data on rural credit in order to see whether there also was a switch in the financing of agricultural enterprises as a consequence of the forest code.

Since the forest code is relatively new and there were some delays in its full implementation which will be detailed below, there is relatively scant evidence on its impact. Most investigators focussed on using georeferenced data of the CAR (*cadastro ambiental rural)*, the rural environmental registry. Inscription in it is a requirement to receive the amnesty of the new forest code. While it became available throughout Brazil only with the new forest code, some states implemented predecessor projects earlier. An evaluation of properties that joined the CAR from 2009 to 2011 showed that joining the CAR initially reduced deforestation but later differences between properties that had joined and those that had not diminished (AZEVEDO *et al.*, 2017). Interviews with farmers confirmed that the CAR was not seen as an efficient tool to force compliance with the forest code (Ibid.) For our analysis this means that there is less incentive for properties which received an amnesty to keep their deforestation within the limits of the amnesty. Thus they also have less incentive to invest in increased productivity.

2.2 Other Public Policies

Apart from the forest code there is a rich literature on other government initiatives to curb illegal deforestation which I will resume in the next chapter. This will serve to elucidate the relationship between exogenous changes in land values due to changing environmental rules and increased enforcement, land use and productivity. Additionally it will serve to better understand why landholders were interested in the passing of the amnesty.

Although tropical deforestation has been a pressing issue also internationally at least since the 1970, the Brazilian Government began to fight seriously against it only in the beginning of this century. Already in the 90s the gradual commercial opening of Brazil and monetary stabilisation increased the exportations of the Brazilian agribusiness. Moreover it also permitted the import of fertilizers and machines which led to a substantial increase in productivity (VIEIRA FILHO; FISHLOW, 2017, cap. 6). Starting in the early 2000s this increase was put into use for supplying agricultural commodities to booming emerging markets such as China and India (Ibid).

However this growth in agricultural production also made the deforestation of the Amazon much more intensive. Some measures were passed in the end of the 90s but they were not really effective since they did not increase local governmental capacities in a way that could stem the loggers. This would only occur in 2004 as the government - confronted with a high deforestation rate and international pressure - created the Plan for the Prevention and Control of Deforestation in the Legal Amazon (GANDOUR, 2018).

This plan included a set of ambitious measures that were intended to curb deforestation from different angles. For example a presidential decree augmented the speed and simplified the sanctioning of environmental crimes (Ibid, p.20). Moreover the names of infractors were published and widely exposed. Another major improvement was the introduction of the DETER system (*Sistema de Detecção do Desmatamento na Amazônia Legal em Tempo Real,* System for Real-Time Detection of Deforestation in the Legal Amazon) in 2004. Before its introduction the data was only produced in yearly intervals, the new system first produced biweekly and starting in 2011 even daily deforestation alerts. An empirical study (ASSUNÇÃO *et al.*, 2019) concluded that DETER significantly reduced deforestation while having no significant impact on municipal agricultural GDP and agricultural production values from local survey studies. (The same that will be used in this text). The authors speculate that there might have been an impact on the intensification of production, i.e. productivity, but do not test this hypothesis.

Next I want to describe the so-called priority municipalities. Basically a certain threshold for deforestation is defined and those municipalities which surpass it in a given year are put on a priority list. Apart from the mere loss of reputation, increased control by environmental authorities is the causal mechanism through which this system exerts influence. Empirically they have been shown to reduce deforestation however their effect on agriculture is mixed. While Assunção and Rocha (2019) find no significant effect on agricultural production Koch *et al.* (2019) find evidence for an increase in productivity in cattle production in the priority municipalities.
Another assessment of the productivity impact of the priority municipalities can be found in Moffette *et al.* (2019). Here the authors only find an impact of the priority municipalities on cattle-stocking rates when not controlling for the presence of conservation units and no impact on agricultural credits. The difference between the results of these two papers can be explained by the non-consideration of the cattle agreements (see next chapter), different data sources, and the inclusion of only the initial priority municipalities and a smaller time frame in Koch *et al.* (2019). I will further expand on the article by Moffette *et al.* (2019) when discussing the impact of the cattle agreements in the next chapter.

One quite efficient strategy has been the restriction of financing for properties which were deforested illegally. A resolution of the Brazilian central bank established in 2008 that rural credit with special conditions could only be lent to landowners who could prove ownership and compliance with environmental regulations with important exceptions for owners of small properties. In a study using contract-level data Assunção *et al.* (2020) established that reductions in credit concession and contemporaneous reductions in deforestation were concentrated in municipalities with cattle-ranching as the main economic activity. The reason for this is that there are other more common forms of financing for crop-raising such as anticipated payments by the buyers. Moreover due to several technological advancements in Brazilian agriculture it is easier to invest credits to improve production at the intensive margin. When disaggregating the credit concessions by loan size the reduction becomes only apparent for larger credits for cattle-ranching. Small credits and those for agriculture do not undergo a reduction due to the new restrictions imposed by the central bank. This thesis is related to the work by Assunção *et al.* (2020) as it also explores the relationship between land use and rural credit. However, for the forest code the causal relationship between credit concessions and land use changes is bi-directional.

Finally the last of the government initiatives would be the increase of protected territories among which are also counted indigenous territories. This increase was intended to occur strategically in areas with great risks of deforestation to form a shield against the advancing agriculture (GANDOUR, 2018). In practice there is evidence that they indeed lead to diminished deforestation when compared to areas with similar deforestation pressure (Ibid.). However when considering the total amount of deforestation, they have a negligible effect. The reasons are spillovers to non-protected areas and their location in areas in which agriculture is less productive, as measured by distance from commercial centers and soil suitability (ANDERSON *et al.*, 2016). The type of protected area does also change the impact on deforestation with indigenous territories being less effective than traditional protected areas (BENYISHAY *et al.*, 2017). Notably these assessments of the effect of protected territories do not include evaluations of agricultural output nor ex-post measurements of agricultural productivity. In principle given our conceptual considerations from above I would not expect a measurable effect of the creation of new conservation units on agricultural productivity, given that they do not appear to restrict deforestation effectively and thus do not act on land availability for speculative purposes. Additionally considering their distance to markets and low viability for agriculture, it seems unlikely that they were primary targets for land speculation anyway.

An assessment of various governmental policies can be found in Assunção; Gandour; Rocha (2015). Here the authors create a new measure to control for the effect of agricultural prices on deforestation and find significant effects for a collection of public policies most of which have been described above, such as the PPcdam, the priority municipalities and the DETER system. The effect of prices has also been investigated in Bragança (2018) where the author finds that an increase in the relative price of crops in relation to beef increases pasture to farmland conversion and reduces deforestation. Since this work is focussed on the impact of a specific public policy I will not develop the impact of agricultural prices much further. However I include them as controls using an adaptation of the formula provided in Assunção; Gandour; Rocha (2015).

Apart from the government programs to curb deforestation in the Amazon there are also important private-sector initiatives with the same goal. The most important will be described in the next chapter. Since they interact more directly with agricultural supply chains, their impact on agricultural output and productivity has been explored more profoundly.

2.3 Private Policies

2.3.1 The Soy Moratorium

Soy itself has been a great driver of direct deforestation, at least in the early 2000s (MACEDO *et al.*, 2012). Subsequently it became much less important due to the soy moratorium. It was first established after intense pressure by Greenpeace in 2006 (GIBBS *et al.*, 2015) and established a cut-off date in July 2006. Major international buyers would not buy from soy fields that were deforested after this date. Remarkably there were no other restrictions on land use imposed, a farmer could deforest lands for other uses and still supply these buyers. Compliance is monitored via satellite. In 2016 the agreement was changed to equalize the cut-off date with the cut-off date of the forest code amnesty, 22nd of July of 2008. The agreement is monitored by satellite and crucially does only focus on the Amazon biome leaving the adjacent cerrado biome open to deforestation. In general it was found to be effective to reduce direct deforestation of soy plantations in relevant properties (GIBBS *et al.*, 2015). However this did not cause a reduction in the overall rate of expansion of soy plantations as they shifted to land that was cleared previously for pasture or other purposes. These results are largely confirmed by Gollnow *et al.* (2018), although they find very small increases in deforestation for pasture and then conversion to soy for later years.

In terms of productivity of soy plantations themselves, there exists an interesting evaluation by Kastens *et al.* (2017) for the state of Mato Grosso. Using satellite-data and ground observations they develop a spatial data set that registers multiple crop cycles per year. Overall the area of single-cropped soy fields remained somewhat stable, while the area on which soy was planted twice a year increased from 2001 to 2014. While there is an inflection point in the expansion rate of double-cropped soy in 2006, the authors do not conclude that the soy moratorium was directly responsible for it. Additional property-level analysis of this phenomenon is warranted.

In sum we can identify two possible pathways by which the increased land constraint and environmental enforcement of the soy moratorium has influenced agricultural productivity. First there is a positive influence that follows the first effect identified in the initial chapter. Since additional deforestation for soy field expansion was made much less lucrative because of the market exclusion imposed by the soy moratorium, it became profitable to convert pasture areas into soy plantations even when accounting for the lost revenue due to a possible reduction in the cattle herd. The second effect is the increase in double-cropping that is possibly due to less available land for soy. So overall, the soy agreement had a positive effect on productivity, at least on a local scale and on soy. I have not found evaluations of the productivity impact of the soy moratorium on cattle-ranching. However, there are concerns that pasture areas were displaced to more distant areas. Since I do not account for this kind of effect in my investigation, I will discuss it in the last part when talking about further research opportunities,

2.3.2 The Beef Moratoria

Complementary to the soy moratorium there are two interventions in the beef supply chain which aim to reduce deforestation. First we have the *Terms of Adjustment of Conduct* (TACs) which were agreed upon between federal public prosecutor's offices and individual meatpacking companies. These are a species of settlement agreements in which the companies committed to monitoring their supply chain in exchange for reduced liability to criminal proceedings. Secondly the four biggest meatpacking companies signed the separate G4 agreement in 2009 with Greenpeace with slightly different but similar provisions. Both prohibited the companies from buying from properties deforesting after 2009 (GIBBS *et al.*, 2016). However the TACs mandated only compliance with current forest law, thus deforestation of up to 20% of the property was possible, as it continued to be after the passing of the forest code in 2012. On the other hand the G4 agreements excluded all properties that deforested any part of their property after 2009 from supplying to the slaughterhouses. Initial evidence indicated the success of these interventions as the introduction of them coincided with an overall reduction of deforestation (NEPSTAD *et al.*, 2014). Additionally, one study found slaughterhouses that were covered by the G4 agreements did actually change their buying behavior to buy from compliant properties and these properties reduced deforestation (GIBBS *et al.*, 2016).

However in recent years several studies have been published that identify weaknesses in these policies. For example one study exploited temporal differences in the adherence of slaughterhouses to any of these agreements (ALIX-GARCIA; GIBBS, 2017) and found that there were on average no significant effects of the moratorium on deforestation in the areas around adhering slaughterhouses between 2007 and 2014. While properties which registered earlier in the CAR experienced a slight reduction in deforestation, later registrants deforested more in comparison. I would postulate that later registrants only entered once they perceived the CAR as no obstacle to deforestation. The authors themselves point to the different possibilities of cattle-laundering which still exist under the cattle agreements to explain the lack of an effect.

The most specific evidence for the failing of the beef policies comes from vaccination records. An analysis of the vaccination records for foot-and-mouth disease for one municipality in the state of Pará in 2014 found more than half of the cattle herd was vaccinated on illegally used land. Given the high vaccination rate and improbability of moving herds to illegal lands just for vaccination this is a clear indication that the agreements are not working (KLINGLER; RICHARDS; OSSNER, 2018).

The greatest deficiency of the agreements is commonly found in the lack of control of indirect suppliers, farmers and local officials. Pereira *et al.* (2020) confirmed that non-compliant property owners could easily sell their cattle to compliant property owners which sell them legally to slaughterhouses. Another possibility is to rent out illegal pastures to property owners which were certified as compliant.

In terms of productivity the most relevant article is Moffette et al. (2019) which has already been cited above for the impact of the priority municipalities. The authors use temporal differences in slaughterhouse adherence to the cattle moratoria. For cattle-ranching they confirm earlier results that there is no significant effect of the moratoria on deforestation. However there is an effect on productivity measured in cattle heads per hectare of pasture. This increased productivity coincided with an increase in the number and the value per hectares of rural credits for cattle ranching. Disaggregating this result they found that the increase was more pronounced for investment credits as opposed to credits to cover operational expenditures. This article is relevant for this thesis, as I also study the development of rural credit as an indicator for investment in productivity. In principle, the positive effect on productivity as a consequence of the cattle-agreement can be interpreted as a sign of the first effect mentioned above. An increase in enforcement lessens the expected value of deforestation and increases the potential value of existing pasture areas. Farmers can capture this increase in value by increasing their productivity.

Stil, it might be asked why deforestation rates themselves did not diminish. One possibility that Moffette *et al.* (2019) point out is that they are looking at too short a time-frame to capture a reduction in deforestation due to the cattle-agreement. They posit that farmers who deforest to substitute depleted pasture would have deforested only a little amount anyway during the short time frame since it takes some time for pasture to become exhausted. Thus there is only a non-significant difference. However given the evidence on the ways to subvert the agreement and evidence that there was no overall reduction in deforestation another possibility would be that innovations to subvert the agreement are the main driver of an increase in productivity. As we have seen above in order to sell illegally-fed cattle to slaughterhouses that adhere to the moratorium, cattle-ranchers may sell to middlemen or rent land from others. It is possible that these practices generate increased specialization and the exchange of innovative production practices which might increase cattle-productivity.

Having revisited the literature on the impact of public and private sector policies against deforestation on agriculture and agricultural productivity, I next want to describe my object of analysis, the forest code of 2012. It can be seen as a reaction of landowners to the policies that I described above (BRANCALION *et al.*, 2016). Since they were for the first time seriously enforcing already existing rules for private land use in Brazil in the beginning of the 2000s, the landowners saw that the best way to fight back would be to change the very rules that the federal government was enforcing. Thus the legislative project to revise the forest code took shape which I will describe in the next chapter.

3. Changes in the Forest Code in 2012

The forest code of 2012, as the earlier forest codes of 1934 and 1965, sets the rules on how private landowners can make use of their lands. Notably it clarifies and updates the earlier codes but the basic types of protected areas in private properties remain the same: legal reserves (RL, *reserva legal*) and permanent protection areas (APP, *área de proteção permanente*).

Permanent protection areas are determined by existing geological, hydrological and environmental features of the property (for example rivers, springs or mountains) and consist of a specific area around or alongside these which can not be deforested or put into economic use under usual circumstances. Secondly, the legal reserves are quotas of native vegetation that has to be kept intact independently of existing features of the property (BORGES; REZENDE, 2011). In contrast to the permanent protection areas in the legal reserve sustainable economic exploration can be permitted by the relevant authorities. Usually the legal reserve has to be kept in addition to the permanent protection areas, exceptions will be detailed below.

For the purpose of this thesis, I will divide the alterations that the forest code made to the existing rules governing forest use into two areas: First, changes in the statutes which form the new status quo and are in principle valid for all properties. Secondly, there are transitory dispositions, an amnesty and easier proceedings for properties which were deforested before the 22nd of July of 2008. To conclude I will explain delays in its implementation which might impede the identification of an immediate effect of the forest code.

3.1 Permanent Changes

The forest code of 2012 brought changes for the permanent protection areas of all properties, the most important are described in Brancalion *et al.* (2016). First of all intermittent springs which do not carry water year-round were initially excluded from this category. This provision was ruled unconstitutional by the Brazilian federal supreme court and thus is currently not relevant anymore. Secondly natural and artificial accumulations of water (for example lakes and reservoirs) smaller than 1 hectare do not generate permanent protection areas anymore. In third place hilltops and inclined areas need double the height and a higher inclination in order to fall into the protected category when compared to the earlier rules. This decreases the area protected by hilltops by 87% (SOARES-FILHO *et al.*, 2014). Next there is also a striking change in the way that the sizes of the permanent protection areas alongside rivers and other courses of water are determined. Before the revision these were demarcated considering the maximum water level, after the revision the demarcation utilized the medium level. Given that many rivers in Brazil vary greatly in their extension due to seasonal differences in precipitation, this also represents a major reduction in protected area.

Specifically for the Amazon biome, there exists now the possibility to add the permanent protection area to the legal reserve. This means that if the sum of the area of existing or planned permanent protection area and existing native vegetation is greater than 80%, the landholder is able to deforest areas of the property that are not permanent protection areas up to the limit of 80%. This is also valid for the recuperation of properties as detailed below.

The required size of the legal reserve itself which is computed as a share of the property was not changed in the forest code of 2012. It remained 80% for properties inside the Amazon biome, 35% for properties of the cerrado biome inside the legal Amazon and 20% for the remaining properties. However, two exceptions for the Amazon were made possible in specific cases. First, states can set a legal reserve of 50% of the property as a target for recomposition if at least 50% of the municipality in which the property lies is composed of publicly protected land or indigenous territories (SOARES-FILHO *et al.,* 2014). Secondly if at least 65% of the state is covered by publicly protected land or indigienous land and the state has an ecological-economic zoning law, the size of the legal reserve can be set to 50% of the property. At the moment this is true only for the state of Amapá. However the state only began the process of elaborating an ecological-economic zoning law this year, thus its impact can not yet be evaluated (GOVERNMENT OF THE STATE OF AMAPÁ, 2020). An estimation of the maximum possible effect of this rule on legal deforestation can be found in Freitas; Sparovek *et al.* (2018).

3.2 Transitory Provisions

The changes that we have seen in the last sub-chapter are valid for all deforested areas after the 22nd of July of 2008. Forest owners can deforest up to these limits and if they do not comply with them then they are legally obligated to reforest their land. However the principal part of the forest code concerns the so called transitional provisions for properties that deforested their RL and APP illegally before the 22nd of July of 2008. While the permanent changes detailed above essentially only amount to differences in the calculation of RL and APP the transitory provisions are meant to create a fresh start and an easy path to compliance for landowners who deforested before the cut-off date.

The fresh start means that all environmental fines and criminal proceedings regarding the illegal deforestation before the cut-off date can be pardoned if the land-owner completes two steps. First registration in the rural environmental registry (CAR, *cadastro ambiental rural*), secondly the start of the environmental regularization programme (PRA, *programa de regularização ambiental*).

The rural environmental registry (CAR) is an electronic, nationwide registry which includes geo-referenced data on the property limits and the preserved areas inside the properties. Once property owners register in the CAR they can start the easy way to compliance, the environmental regularization programme. In order to enter, they need to present to the environmental authorities a plan detailing how they want to recover the areas that they need to recover. If the authorities agree a binding agreement is signed. Apart from the elimination of fines, properties that deforested before the 22nd of july of 2008 do not have to restore the native vegetation to the legal requirements, neither those that were valid in 2008 nor the updated requirements of the forest code of 2012. The reductions in restoration requirements will be explained in the next paragraphs.

In some cases the size of the reduction is determined by the size of the property with the argument that smaller properties need a greater share of their property for agriculture to be economically viable. Property sizes are measured in so-called fiscal modules which is a measure in hectares that is determined for each municipality individually. Throughout Brazil it varies between 5 and 110 hectares.

Starting with the permanent protection areas, regardless of property size, native vegetation on inclinations, hilltops and in high altitudes does not have to be reforested or recomposed. Secondly there is a reduction in the sizes of areas to be reforested or recomposed alongside watercourses and around lakes. For small properties (smaller than 4 fiscal modules), the areas have a fixed size and are smaller than in the normal regime described above. In the case of larger properties the sizes of the areas to be recovered vary with the size of the watercourse but they are in every case smaller than those required in the normal regime.

For the legal reserves, the amnesty provided by the forest code is at least as generous. First for all property owners the permanent protection areas that they recover can be counted towards the legal reserve to be recovered. Secondly for small properties (less than 4 fiscal modules) the legal reserve to be recovered is equal to the size of native vegetation remaining on July 22nd of 2008 in the property. In practice this amounts to an amnesty for deforestation before that date for small landholders (for more information, see for example Chiavari; Lopes (2015)).

3.3 Delays in the Implementation of the Forest Code

As we will see further below due to data restrictions this study uses data only up to the year 2017. However it is possible that the full effect of the forest code revision will only be seen some years from now because of delays in its implementation and enforcement.

First the technical details of inscription in the CAR for the whole country were resolved only in 2014 and landowners were given one year to complete registration. However both the legislative and the executive determined in total 5 extensions of this deadline, such that the inscription was to be mandatory only in the end of 2019. President Bolsonaro subsequently abolished this deadline completely. This means that in some cases access to the amnesty could have been delayed if a landholder wished to enroll and could not because the CAR was not yet ready. In addition to the problem of inscription in the CA, human verification of the entries is necessary to confirm sizes and locations of legal reserve and permanent protection areas. Since relevant government entities are often understaffed this hinders effective enforcement and application of environmental fines (VALDIONES AND BERNASCONI, 2019).

Secondly as noted above, receiving the benefits of the amnesty depends on the environmental regularization program (PRA). However the exact procedure for this was to be defined by the Brazilian states themselves. In 2018, only 18 of the 27 states of Brazil had conclusively determined the rules and procedures for this programme (Ibid.). For example, the state of Pará only created its environmental regularization programme in 2015 (Ibid.). Without this regularization property owners could not be completely certain that they ultimately would benefit from the amnesty.

Finally the most important reason for uncertainty around the forest code were juridical challenges that were launched immediately after its enactment by the legislature. The challenges concerned both the amnesty in itself as well as the extended amnesties for smaller properties, apart from other issues. However all of the challenged articles of the new forest code as described above were declared constitutional with the exception of the question of intermittent springs that was mentioned. Since this ruling only was reached in 2018, it is possible that the reaction to the amnesty could be delayed due to this (CAMPOS; PEREIRA, 2018).

I will discuss the relevance of these issues again in the final part of this text.

3.4 Expected Impact on Land Cover and Productivity

Given the changes described above I aim to investigate the effect of the amnesty on land use decisions and agricultural productivity. As we have seen, properties of all sizes that had illegally deforested before 2008 both in terms of their legal reserve and permanent protection areas were given the possibility of an amnesty. If they enrol in the environmental regularization program, they have to pay less or no fines and have to reforest less than the legally required amount. Hence for this analysis I distinguish between properties that were compliant with the law in 2008 and did not receive an amnesty and those which were not compliant and received the possibility of an amnesty. Notably I use a forest cover of 80% or more of the property as my condition for being compliant in 2008 since the available data does not allow me to identify requirements for the permanent protection area.

In order to investigate the effects found by Santanna and Costa (2019), I will first explore the relationship between the amnesty given in the new forest code and deforestation. As explained above they expected that properties which were legal in 2008 will increase their deforestation in expectation of another amnesty in comparison to the second group, those which received the amnesty. They reason that landholders can justifiably expect this amnesty as an indication that another amnesty will happen in the future. Another reason for this, which was not profoundly discussed by Santanna and Costa (2019) is the CAR. Landholders that want to receive the amnesty need to enter in the CAR as well as enroll in the environmental regularization program. Although the environmental regularization program itself was not available in all states right with the introduction of the program, the expectation in itself should deter deforestation. Apart from that, the registration in the CAR, where both legal reserve and permanent protection area are geo-referenced and satellite images are registered should in itself discourage deforestation.

Next I will discuss the expected impact on land coverage which extends the analysis of Santanna and Costa (2019). I will first investigate the effect of the forest code on the transitions of forest to pasture and forest to agricultural area. I expect that the results go along with those reported by Santanna and Costa (2019) with the exception of the conversion of forest to agricultural areas. Since I will be using annual data and most deforestation, even if intended for agriculture, passes through an intermediary phase of pasture area, I do not expect a significant effect on it.

Continuing this approach I investigate the effect on the land cover transition from pasture to agriculture. Here I expect that properties which did not receive the amnesty will have a lesser propensity to change land-cover from pasture to agriculture. This can be caused both by an increase in conversion rates in amnestied properties and a decrease in conversion rates in non-amnestied properties. First properties that received the amnesty increased in value as fines and embargoes were lifted. To capture this value owners can convert pasture to agriculture, as explained above. Secondly possibly increased deforestation on non-amnestied properties increases available pasture areas. These make it possible to increase production without having to improve productivity by converting pasture to agriculture

As a last step to explore further the connection between the new forest code and agricultural productivity we will use data on the municipality level. Apart from cattle stocking rate and agricultural production data per planted hectare, we will look at credit concessions for both cattle and agriculture. Our theoretical considerations predict that municipalities which had a higher share of private property area in 2008 that was compliant with the forest code and received no amnesty will decrease productivity and vice-versa. Thus we can expect lower cattle-stocking rates and agricultural production per hectare as well as less credits, since there is less necessity of obtaining capital.

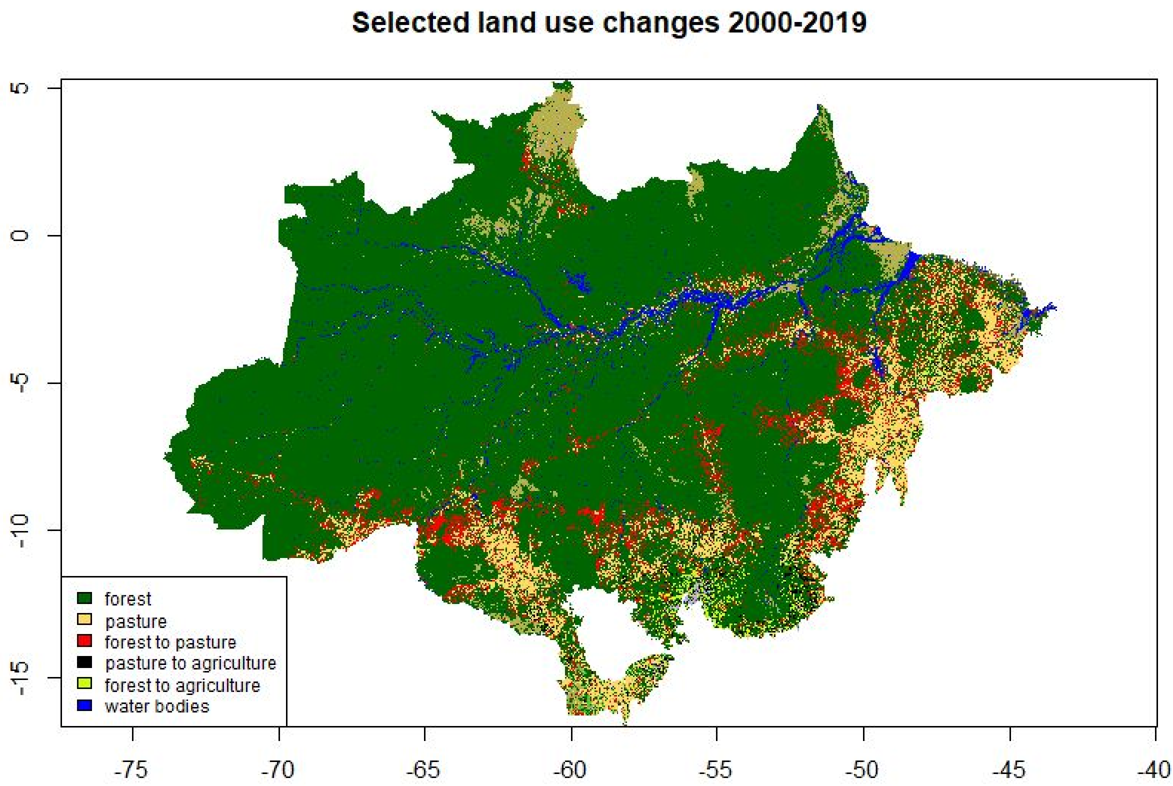
This concludes the theoretical part of my thesis. Next I will describe the data used in the empirical investigation, report my results and discuss them.

4. Description of the Data

4.1 Property Level Data

An overview of all data-sources has been prepared in the appendix I. Data from the project MapBiomas was used to create the main dependent variables. This is a multi-institutional effort to elaborate highly-detailed land use maps for Brazil. Annual data is available starting with 1985 until 2019 with pixels having the size of 30m x 30m. There are 19 categories in total. For this analysis, the relevant categories were natural forest, pasture, agriculture and the sub-category soy for agriculture. Apart from these static categories there were also transition maps used. Transition categories were coded by a 4 digit code with the first two digits being the land-use category in t1 and the third and fourth digit the land-use category in t2. The relevant transition categories used are forest to pasture, forest to agriculture and pasture to agriculture. In the empirical analysis, yearly transition data was used, for example t1=2000 and t2=2001. Exceptionally to illustrate the available data, I present in Figure 1 transition data from 2000 to 2019 for the Amazon biome.

Figure 1: Land Use Changes in the Amazon

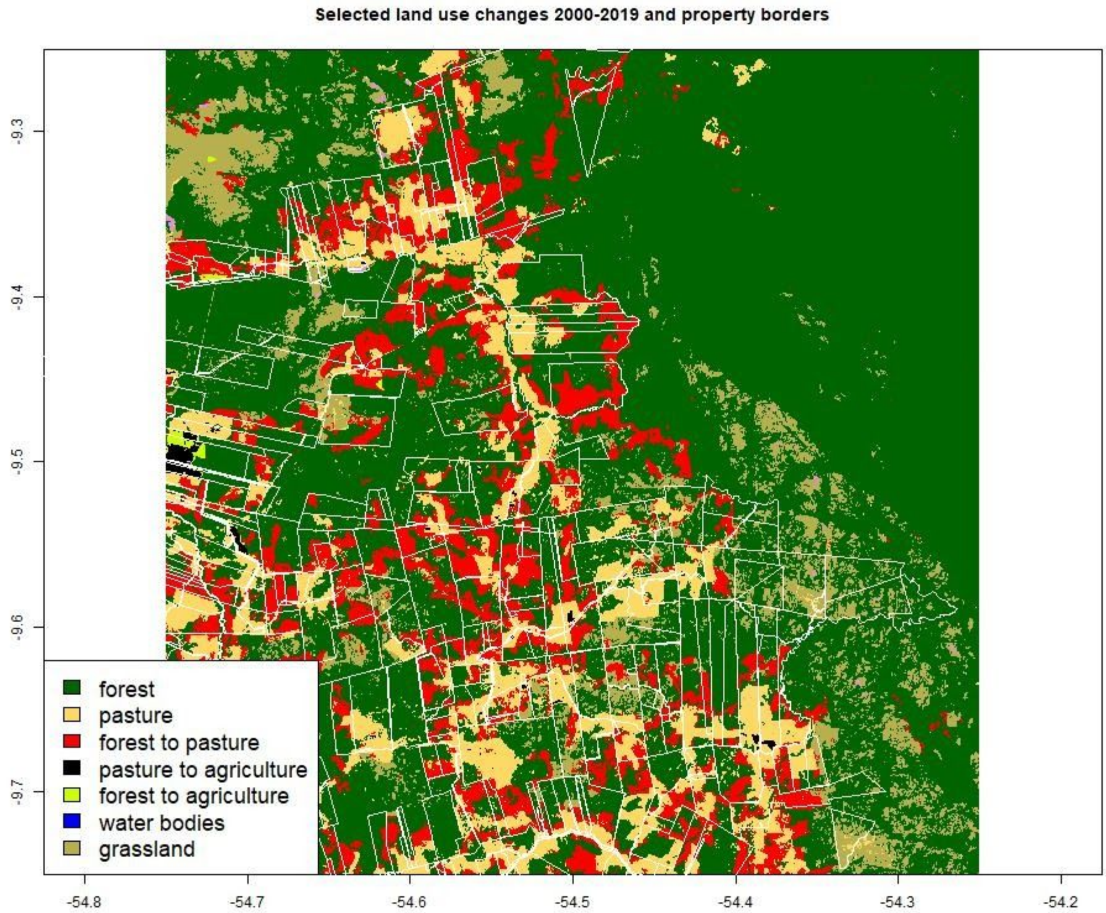


Three observations are warranted. First there already was in the year 2000 a massive influx of pasture area into the native forest, especially in the frontier areas. Secondly land-cover change from forest to pasture is focused alongside existing pasture areas and major infrastructure (i.e. roads and rivers). Third there is only very little conversion of forest to agriculture and from pasture to agriculture occurring mainly in the south-eastern part of the biome. It is necessary to highlight that the areas converted from forest to agriculture probably were converted to pasture as an intermediate step.

The unit of analysis is the private property. For this a geo-referenced data set constructed by a team at the University of Campinas (FREITAS; ENGLUND *et al.*, 2018) was used. They merged and cleaned data from different sources, such as the rural environmental registry (CAR) and the land-reform office INCRA. In total after cleaning and cutting the data set 331240 properties in the Amazon biome were used to start the analysis. There is no information on the creation date of the properties available but they represent the most accurate private property information for the Amazon for the year 2018. This naturally raises the question which properties existed throughout the whole period of the analysis. Adequate checks are provided in the empirical analysis. Apart from that it should be noted that the integration of data from the land-reform office is especially useful since the data from the CAR is auto-declarative and does not guarantee that the owner has a formal title to the property. By combining it with the data from the land-reform office which is compiled from legally authoritative property registers the overall accuracy of the data is substantially improved.

For each property there was then extracted the number of pixels of each category that was covered by the property. Partially covered pixels were included proportionally. This was divided by the total number of pixels covered by the property. The same procedure was employed for both static shares and the transition data to generate our main variables of interest. In figure 2 we can see an example of an area on the frontier of the states of Pará and Mato Grosso. White lines indicate property boundaries. While most deforestation occurs inside of property boundaries, the deforestation patterns themselves are erratic and do not follow neatly along the property lines. This gives credence to the assumption postulated above that in most cases the deforestation occurs first and then property lines and land titles are created and obtained. These are drawn up less to conform to existing deforestation patterns and more for convenience and possibly to obtain specific benefits such as the small status discussed above.

Figure 2: Land Use Changes on the Property Level



Having thus summarized the dependent variables the next step is the description of the independent variables. First of all there is a dummy variable indicating years later than 2011 to assess the impact of the forest code. Secondly there is a dummy indicating if a property was complying with the legal reserve stipulation of the forest code in 2008. This means that it is equal to 1 if the area of the property that is covered by forest in 2008 is greater than or equal to 80% of the total property area as calculated above in the independent variables.

Finally there are the controls starting with measures for soil aptitude, temperature and precipitation, since they are highly relevant for the possibility to convert a given piece of land to agricultural uses. Data on soil aptitude has been adapted from Soares-Filho *et al.* (2014). They provide gridded data with a resolution of 60m x 60m. Aptitude scores are given on a scale ranging from 0 (inapt) to 2 (very apt). For the purpose of this analysis, 1 and 2 were assigned to the value 1 and then a unique score for each property was calculated with a procedure analogous to the extractions of land use above.

Temperature and precipitation data was included following Santanna and Costa (2019) who use a method initially described in Rocha and Soares (2015). As the first step gridded data from the Terrestrial Air Temperature and Terrestrial Precipitation: 1900-2017 Gridded Monthly Time Series, Version 5.01 (MATSUURA; WILLMOTT, 2018) was used to calculate historical averages and standard deviations for each node of the target area. These are used to calculate standardized values for each grid node. Then for each property the 4 nearest grid nodes and the weights of their distances are calculated using the centroids of the properties. In the end these 4 weights are used to create unique temperature and precipitation time-series for each property. As there is no climate data available before 2017, this is the last year of the analysis.

Price-data has been included following a procedure initially developed in Assunção; Gandour; Rocha (2015). First of all, price series from the secretary of agriculture of the state of Paraná are used to create one index for agricultural prices and one for beef prices, adequately corrected for inflation. For the agricultural prices, soy, maize, rice, sugarcane and cassava were used. Then for each municipality production data from municipal surveys was used to create cross-sample variation. Multiplying these municipal weights with the price indices gives us municipal agricultural prices series. As a last step each property is assigned the time series of the municipality it lies in.

Table 1: Summary Statistics - Property Level

	Compliant in 2008	Not compliant in 2008	Full sample
Observations[1]	1511982	4450338	5962320
Properties	83999	247241	331240
Forest to Pasture (%)	0.762	1.285	1.152
	(3.934)	(4.994)	(4.753)
Forest to Agriculture (%)	0.014	0.025	0.022
	(0.635)	(0.764)	(0.733)
Pasture to Agriculture (%)	0.016	0.128	0.1
	(0.609)	(1.832)	(1.613)
Temperature Deviation	0.016	0.128	0.1
	(0.609)	(1.832)	(1.613)
Rainfall Deviation	0.138	0.11	0.117
	(0.964)	(0.97)	(0.969)
Agricultural Prices	-0.186	-0.175	-0.178
	(0.712)	(0.766)	(0.752)
Beef prices	0.019	0.031	0.028
	(0.959)	(0.97)	(0.967)
Soil Aptitude	0.742	0.78	0.77
	(0.38)	(0.36)	(0.365)

[1]Note: Means of dependent variables and controls. Standard deviation in brackets. Values are disaggregated by compliance in 2008 (forest cover in 2008>80%). I use yearly data from 2000 to 2017.

Summary statistics for the property-level analysis are reported in the table above. They are disaggregated by the status of compliance in 2008 which is equal to having a forest cover of 80% of the property in 2008.

4.2 Municipality Level Data

In the second part of our empirical approach, we will change our approach to the municipality level in order to assess agricultural production and productivity. Recall that the main causal treatment that we are investigating is the amnesty received in 2012 by properties which were covered by more than 80% forest in 2008. To scale this property-level analysis to the level of municipalities, we divide the total area of compliant properties in each municipality by the total area of all properties in the municipality. This way, we have a measure of the degree of compliance of each municipality which ought to cause different responses to the introduction of the forest code. As before we use a dummy variable for the period of 2012-2017 after the introduction of the forest code.

To generate the dependent variables, data from IBGE’s municipal livestock and municipal agriculture surveys were used for the number of cattle and the production value of agricultural crops and soy individually. In order to assess agricultural productivity, the land use category Agriculture from MapBiomas was used to create yearly time-series of planted hectares for the municipalities in the sample. The same procedure was employed to obtain data on pasture sizes in hectares per municipality and for soy plantations. Cattle number, total production value of agricultural crops and production value of soy were then divided by the respective land-use category from MapBiomas in hectare for the given municipality and year.

Data from the central bank was used to get an understanding of the financing of livestock production. Here we assessed total credit value by pasture area for livestock as well as the number of contracts made each year. Monetary values were adjusted to 2000’s prices. These measures are disaggregated into credits destined for operational capital and for investment purposes.

Finally as in Moffette *et al.* (2019) data from the laboratory of image processing and geo-processing of the Federal University of Goiás (LAPIG/UFG) was used to assess cattle stocking rates in terms of their sustainability. The laboratory created a map detailing sustainable cattle stocking rates for each municipality as determined by climatic and soil conditions for pasture growth. For my analysis the actual stocking rate obtained above was divided by the sustainable stocking rate of LAPIG/UFG to understand in how far the current stocking rate is sustainable. As before links to these data-sources from LAPIG and IBGE can be found in the annex.

As controls, first we included the mean of the precipitation and temperature measures of the properties (calculated above) contained in each municipality. This was seen as preferable to recalculating only one time series based on the centroid of the municipality, given the enormous size of municipalities in the Amazon. Secondly agricultural prices were included as before since they were already calculated on the municipality-level. Finally soil aptitude was re-calculated, using the same procedure and data as for the properties but using the limits of the municipalities as the basis for the extraction of the values.

Summary statistics for the municipal analysis are reported in the table below. In this approach, the impact of the forest code is modelled as a continuous treatment, depending on the share of compliant property area in the municipalities. For a better overview of this relationship, I divided the data by the quartiles of this variable.

Table 2: Summary Statistics - Municipality Level

	1. Quartile	2. Quartile	3. Quartile	4. Quartile	Full Sample
Observations[1]	2196	2196	2196	2196	8784
Municipalities	122	122	122	122	488
Forest cover in ha	61766.361	205637.858	777822.202	1748513.96	698435.095
	(120921.063)	(282328.06)	(1687662.917)	(2263965.399)	(1567058.141)
Cattle per ha	7.093	1.558	0.938	0.689	2.574
	(68.056)	(4.461)	(0.744)	(0.657)	(34.245)
Percentage of sustainable capacity that is used in cattle	0.427	0.375	Inf	Inf	Inf
	(0.535)	(0.226)	(NaN)	(NaN)	(NaN)
Soy - Value per planted ha	107.924	59.511	69.205	9.503	72.555
	(590.096)	(490.326)	(593.56)	(21.161)	(543.092)
No of credit contracts (Cattle Ranching - Operations)	73.077	71.228	48.257	11.048	50.903
	(148.372)	(144.983)	(116.813)	(41.878)	(123.403)
Value of credit contracts per ha (Cattle Ranching - Operations)	0.111	0.083	0.065	0.073	0.086
	(0.335)	(0.107)	(0.092)	(0.311)	(0.233)
No of credit contracts (Cattle Ranching - Investment)	199.545	209.165	159.12	71.13	159.924
	(310.314)	(394.501)	(360.55)	(187.205)	(327.509)
Value of credit contracts per ha (Cattle Ranching - Investment)	0.297	0.142	0.122	0.188	0.188
	(1.879)	(0.193)	(0.185)	(0.499)	(1.021)

[1]Note: Means of dependent variables and controls. Standard deviation in brackets. Values are disaggregated by the quartiles of main variable of interest, the share of compliant property area by municipality. I use yearly data from 2000 to 2017.

5. Property Level Effects on Land Use

5.1 Estimation Strategy

As described above we pursue two distinct approaches in this text. The first based on properties as the unit of analysis, the second based on municipalities. For the identification of the differential effect of the forest code based on eligibility for amnesty we use a difference-in-difference framework with property and time fixed effects:

$$\gamma_{it} = \beta_0 + \beta_1 Post2011_t * compliance2008_i + \lambda * X_{it} + \alpha_i + \theta_t + \varepsilon_{it}$$

where γ_i is the different dependent variables, conversion from forest to pasture, to agriculture and from pasture to agriculture. Next, β_1 is our coefficient of interest that captures the effect of the treatment (the new forest code) on properties that were compliant in 2008 and thus received an amnesty and did not need to reforest as much as other properties. After that, I include the vector X_{it} of covariates, in this case climate, price and soil quality data. Climate and price data are introduced as lagged values since farmers usually commit themselves to land use and production of cattle or planting of crops well in advance. Finally there are fixed effects for each property α_i and year θ_t. They control for unobservable fixed characteristics of each property and for potential shocks affecting all properties in the same year.

5.2 Results

The results for the analysis can be found in the table below. All three coefficients of interest are significantly different from zero. The first coefficient informs about the percentage of the property that was converted from forest to pasture. If the property was compliant in 2008 the percentage of the property that was converted from forest to pasture in each year was 28.6% higher after 2012. Next, the coefficient in column (2) shows the percentage of the property that was converted from forest to agriculture. It is about 0.6% higher for compliant properties after 2012. Finally, for the conversion of pasture areas to agriculture, we found a coefficient of -0.006, indicating a decrease of 0.6% in the percentage of the property that was converted from pasture to agriculture in a given year.

Table 3: Results - Property Level

	(1)	(2)	(3)
Dependent variable[1]	forest to pasture cover (%)	forest to agriculture cover (%)	pasture to agriculture cover (%)
compliance2008:yrafter2011	0.286 * * *	0.006 * * *	-0.006 * * *
	(0.00124)	(0.00019)	(0.00038)
Observations	5962320	5962320	5962320
R2	0.235	0.134	0.228
Property FE	Y	Y	Y
Year FE	Y	Y	Y
Climate variables	Y	Y	Y
Agricultural Prices	Y	Y	Y
Terrain aptitude	Y	Y	Y
Property time trend	Y	Y	Y
Cluster	Grid	Grid	Grid
Number of properties	1058	1058	1058

[1]Note: Each column represents an individual regression. The dependent variable is always the the natural logarithm of the relative transition area of respective land cover in property i from year t-1 to year t. For each column, the coefficient of interest is the interaction of compliance2008 with a dummy indicating the years 2012-2017, so that the treatment begins in 2012. Standard errors in parentheses are clustered by grids of 0.5 x 0.5 degrees, as in Santanna and Costa (2019). Significance: *** p<0.01, ** p<0.05, * p<0.1.

5.3 Robustness

In order to assess the robustness of these results, I present three event studies in the figures below. Essentially, the graphs show the coefficient values and confidence intervals for regressions in which dummies for each year of the analysis are interacted with the compliance2008 dummy. If the significance of the coefficients in table 1 really is caused by the introduction of the forest code, then the interaction of the dummy with years before its introduction should not give any significant results.

For the two forest conversion categories, forest to pasture and forest to agriculture, we find a differential evolution before the treatment in 2012 as we can see in the first two figures. These diagrams show us that for both conversion categories, being compliant in 2008 was associated with less conversion from 2006 to 2008. This means that we have to assume that the coefficients do not only show the effect of the treatment, the new forest code in 2012. Rather they also include the effect of different forest conversion rates before 2008. It is possible that these are caused by the definition of compliance in 2008 as a forest cover of 80%. Before 2008, compliant properties had to have a somewhat smaller conversion rate otherwise they would fall out of the compliant group. Still, it is interesting to note in these diagrams that after 2008 forest conversion rates are somewhat equal and then increase after 2012. Thus, there still could be an effect of the amnesty on increased forest conversion rates. However given this timeframe it can not be confirmed.

Figure 3: Event Study - Forest to Pasture - Property Level

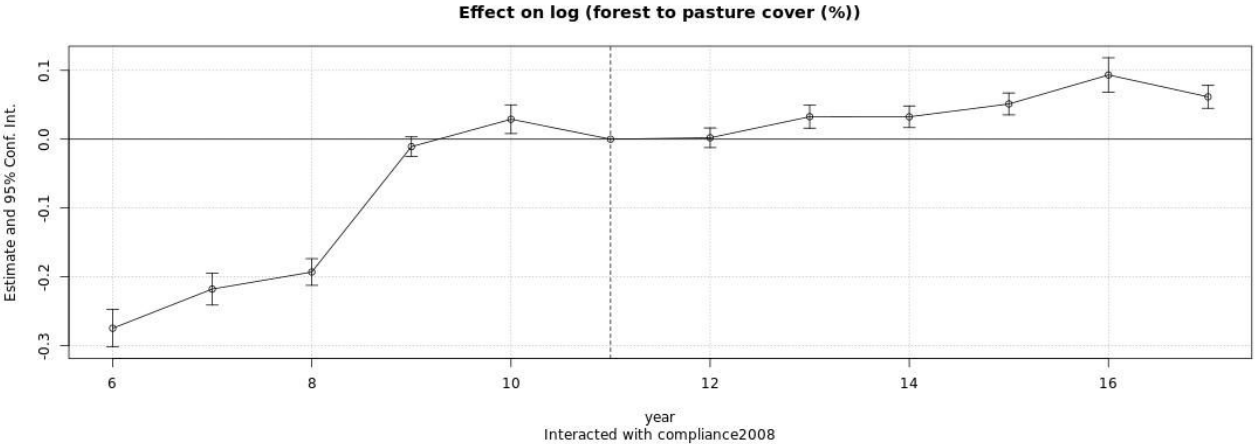
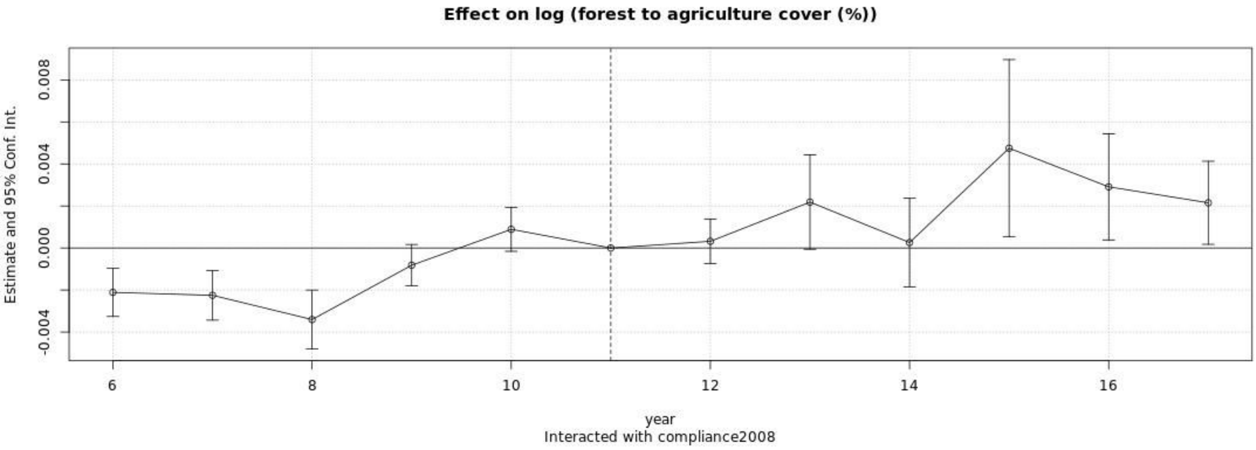
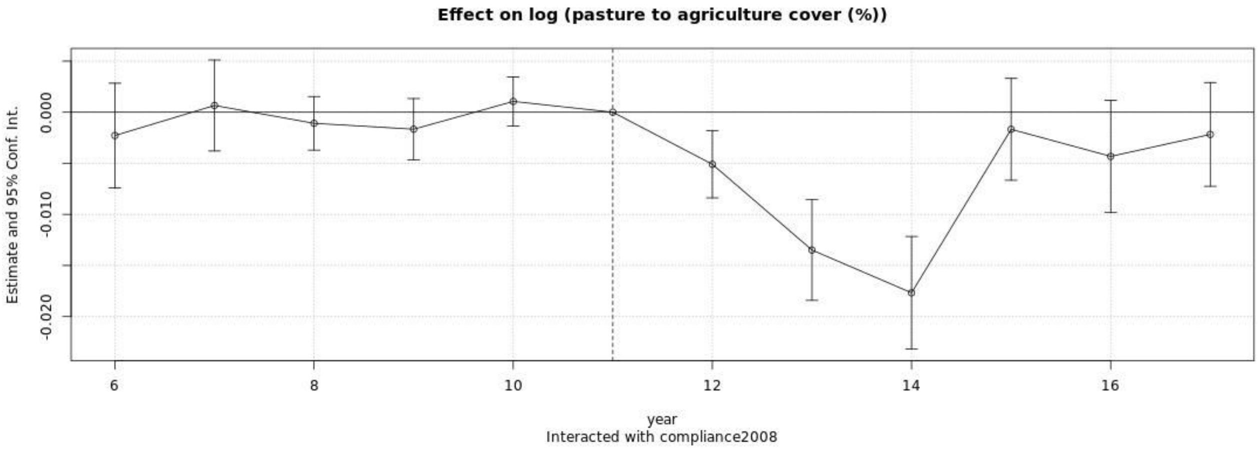


Figure 4: Event Study - Forest to Agriculture - Property Level



Finally, we will look at the effect of the forest code of 2012 on the conversion of pasture to agricultural areas. Here we can find no significant pre-trend. The conversion rates before the treatment are not significantly different and right in the first year of the treatment there is a significant drop in conversion rates until 2014.

Figure 5: Event Study - Pasture to Agriculture - Property Level

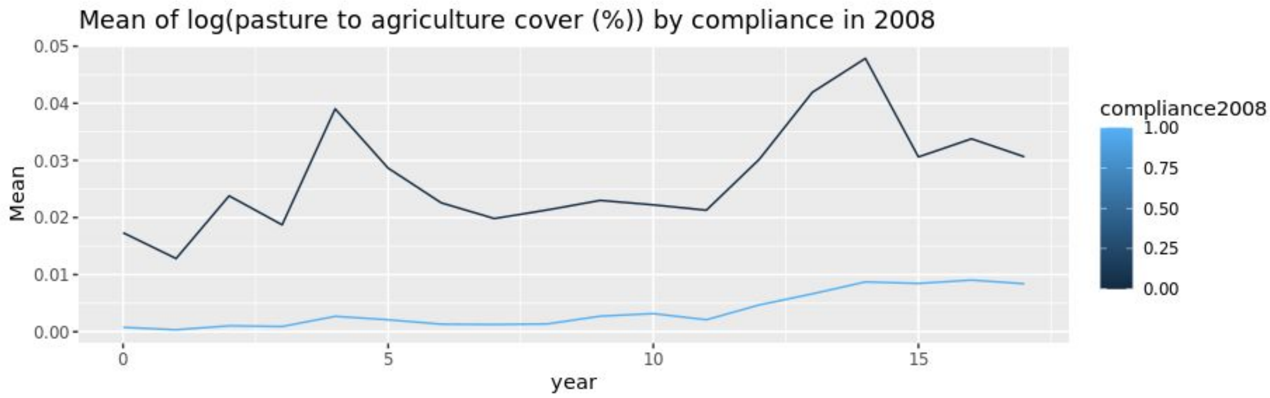


The coefficient of -0.006 can therefore be interpreted as a reduction of 0.6% of the percentage of the property that was converted from pasture to agriculture.

It is possible to interpret this as an indication of both causal effects discussed in the theoretical considerations. First, we may assume that non-compliant property owners increased their conversion rates from pasture to agriculture to capture the additional value of their properties obtained by the amnesty. As they became free from fines and embargoes they might have decided to invest in agriculture in order to capture the value. It is also possible that they sold their land or rented it out for a specific timeframe. Secondly, it is possible that non-compliant property owners converted less pasture to agriculture because they increased deforestation in expectation of further amnesties. Although we could not identify a direct effect on deforestation, indirectly the expectation of future pasture expansion by deforestation could already have lowered the value of additional pasture areas. Thus it became more profitable to increase production on the extensive margin by acquiring new pasture areas, than on the intensive margin by converting pasture to agriculture.

In order to get at least an idea on which of these effects prevail, I plot below the means of the logarithm of the conversion rate of pasture to agriculture for both groups, compliant (compliance2008 =1) and non-compliant properties (compliance2008=0). The important information is to be gained from the slope after the year 11 (2011) which increases for both but much stronger for non-compliant properties.

Figure 6: Mean Log(pasture to agriculture cover (%)) - Property Level



This is an indication that the relative decrease in conversion in non-amnestied properties is caused by the enormous increase in conversion in amnestied properties. Thus it speaks for a predominance of the first effect discussed above. Since there was also no evidence of increased deforestation it seems likely that the reaction to changes in the forest code on land use is mainly caused by amnestied properties.

5.4 Overall Robustness of the Property Level Analysis

As we had seen above there exists a limitation of the property data-base which is limited to the year 2018 and does not give information on the creation date of the property. It could be possible that our results are driven by properties which did not even exist before the update of the forest code. In order to remediate this, I perform the following robustness check for the property level analysis: I limit the properties to those which had positive pasture area in the year 2000 or 2001. Since pasture is an indication of deforestation and of human activity, I see this as a valid criterion to determine the existence of the property throughout the sample period. This decreases the total number of properties to 274068, cutting about 60.000 (or ~20% of) properties out. However, it does not change the conclusions of the property level analysis which can be verified in the Annex II.

6. Municipality Level Effects on Productivity

6.1 Estimation Strategy

The differential impact of the forest code is to be assessed using the following model on the municipality level:

$$\gamma_{mt} = \beta_0 + \beta_1 Post2011_t * ShareCompliant2008_m + \lambda * X_{mt} + \alpha_m + \theta_t + \varepsilon_{mt}$$

For each dependent variable γ our variable of interest is ShareCompliant2008. It is calculated for each municipality by summing the area of all properties that are compliant in 2008 and dividing it by the sum of the area of all properties in the municipality. It was multiplied by 100 to obtain the value in percent. It captures the relative importance of compliant properties in the municipality. It is then interacted with a dummy, $Post2011_t$, which indicates years after the expected enactment of the law taking effect. After that, I include the vector X_{mt} of covariates, in this case climate and soil quality data, as well as agricultural prices. Finally, there are fixed effects for each municipality α_m and year θ_t. As before price and climate controls were introduced as lagged values, since farmers are expected to make anticipatory decisions on the municipality level as well.

6.2 Results

In table 4 we can find the results of the estimations regarding agricultural productivity. It should be noted that in table 4 and 5, differences in the number of observations are due to the removal of outliers. In some cases the values provided by MapBiomas were very close to 0 due to measurement errors in the satellite images or in the interpretation algorithms. They inflated the productivity and credit variables unrealistically and had to be dropped.

First, we will take a look at the effect of compliant area on forest cover in hectare. Although the coefficient is not significantly different from 0, we find a marked reduction in forest cover. For each percent more in compliant property area, forest cover decreased by about 36 hectares after 2011.

Our main effect of interest can be found in column (2): Since the dependent variables in columns 2-4 are in natural logarithms, an increase in 1% in the share of the total property area that was compliant in 2008, signifies a decrease of 0.103% in the cattle-stocking rate. This is an economically meaningful quantity, considering a mean cattle number per hectare of 2.574, an decrease of 0.103% would mean an decrease of 0.00265 cattle per hectare. For example the new forest law potentially opened up 30 million hectare of land for agricultural production as we had seen above. If it was purely used for cattle and would be affected by the decrease, then it would mean a decrease in herd-size of 80.000 animals.

Next, the percentage of sustainable capacity that is used also is reduced as a result of the forest code, although this is somewhat lower with a reduction of 0.042% for each percentage more in compliant property area. Given the overall low share of sustainable capacity that is used, this coefficient confirms that the forest code had a negative impact on the efficiency of cattle-ranching in the Amazon. Finally, there is no significant effect of the revision of the forest code on the production value of soy per planted hectare. Notably, by using annual data from Mapbiomas for the area of soy that was planted, I also can exclude any differential increases in double-cropping that would not be captured by data from the IBGE.

Table 4: Results - Municipality Level - Productivity

	Forest cover in ha	cattle per ha	Percentage of sustainable capacity that is used in cattle	Soy - Value per planted ha
Share of compliant property area in 2008:yrafter2011[1]	-36.17176 (17.81079)	-0.00103 * * * (8e-05)	-0.00042 * * * (4e-05)	-5e-05 (0.00204)
Observations	8784	8515	7791	1982
R2	0.99971	0.85272	0.85846	0.64004
Municipality FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Climate variables	Y	Y	Y	Y
Agricultural Prices	Y	Y	Y	Y
Terrain aptitude	Y	Y	Y	Y
Municipality time trend	Y	Y	Y	Y
Number of Municipalities	488	481	447	190
Mean dependent variable	468095.32339998	0.618933150612474	0.25800323208186	1.26769619094131

[1]Note: The dependent variables in columns (2) to (4) are in natural logarithms. The coefficient of interest is the share of total property area of each municipality that was compliant with the forest code in 2008. Standard erors in parentheses are clustered by municipality. Significance: *** p<0.01, ** p<0.05, * p<0.1.

Having described the results on agricultural productivity we now investigate possible effects on credit concessions. We focus only on credit concessions for cattle ranching for two reasons. On the one hand, there was no significant effect of the forest code on the productivity of soy as noted above. Since soy is the most important cultivar in the Amazon, it is not expected that there is any effect on credit concessions for agriculture at all. On the other hand, it is noted in Moffette *et al.* (2019) that the cultivation of crops is much less dependent on the official lines of credit that we are investigating than cattle-ranching. Rather farmers obtain direct financing via their buyers and middlemen. Thus, even if there was an effect of the forest code on agriculture it probably will not be discernible in credit concessions.

For cattle-ranching the number of credit contracts and their value per hectare of pasture has been disaggregated into credits for operational capital and credits for investment. We find an overall reduction in all categories. Since we are here too using the natural logarithms of the dependent variables, in column (1) we can see that each additional percentage of compliant property area in a municipality decreases the number of credits for operational capital in cattle-ranching by 0.463%. For credits for investment capital, this decrease is even more pronounced with a value of 0.538%. Looking at the value of the cattle-credits per hectare of pasture there is a similar dynamic. For operations we find a decrease of 0.032% while for investment we find a decrease of 0.072% for each percent more in compliant area in the municipality.

Table 5: Results - Municipality Level - Credit for Cattle Ranching

	No of credit contracts (Cattle Ranching - Operations)	Value of credit contracts per ha (Cattle Ranching - Operations)	No of credit contracts (Cattle Ranching - Investment)	Value of credit contracts per ha (Cattle Ranching - Investment)
Share of compliant property area in 2008:yrafter2011[1]	-0.00463 * * *	-0.00032 * * *	-0.00538 * * *	-0.00072 * * *
	(0.00067)	(3e-05)	(0.00089)	(5e-05)
Observations	8784	5585	8748	6724
R2	0.73468	0.56989	0.61577	0.36574
Municipality FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Climate variables	Y	Y	Y	Y
Agricultural Prices	Y	Y	Y	Y
Terrain aptitude	Y	Y	Y	Y
Municipality time trend	Y	Y	Y	Y
Cluster	Municipality	Municipality	Municipality	Municipality
Number of Municipalities	488	457	486	485

[1]Note: All dependent variables are in natural logarithms. The coefficient of interest is the share of total property area of each municipality that was compliant with the forest code in 2008. Standard erors in parentheses are clustered by municipality. Significance: *** p<0.01, ** p<0.05, * p<0.1.

6.3 Robustness

6.3.1 Productivity and Land Use

First of all, evaluating the event study for the change in forest cover, we can find no significant pre-trend and a marked reduction after the introduction of the forest code. If this trend continues, a significant coefficient is to be expected with the inclusion of further years in the analysis. However, until now no further conclusions are possible.

The robustness of our results on productivity can be confirmed for the productivity of cattle-ranching. As we can see, both for cattle-stocking rates and stocking-rates as a percentage of their sustainable capacity, there is no discernible pre-trend before 2012. After that, there is a continuous downwards movement with significant coefficients starting in 2014. We can interpret these results as an indication that both causal effects mentioned above are functioning. On the one hand it is possible that properties that received an amnesty increased their stocking rates. Specifically, this could be a result of an increased conversion of pasture to agricultural areas that was hypothesized in the first part of the empirical investigation. Secondly, as we can see municipalities in which less properties received the amnesty and more properties were compliant with the forest code, cattle-stocking rates decreased. This is probably due to an increase of pasture areas that exceeded the increase in cattle-heads noted by Santanna and Costa (2019). Thus, production was developed at the extensive margin which decreased productivity somewhat. But this did not imply a reduction in output.

Figure 7: Event Study - Forest cover in ha - Municipality Level

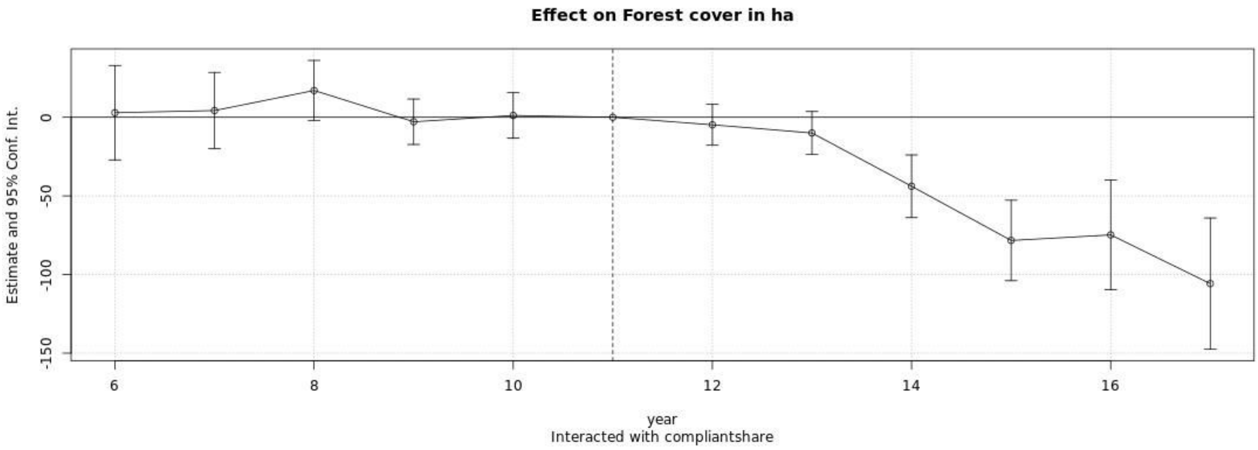


Figure 8: Event Study - Cattle per ha - Municipality Level

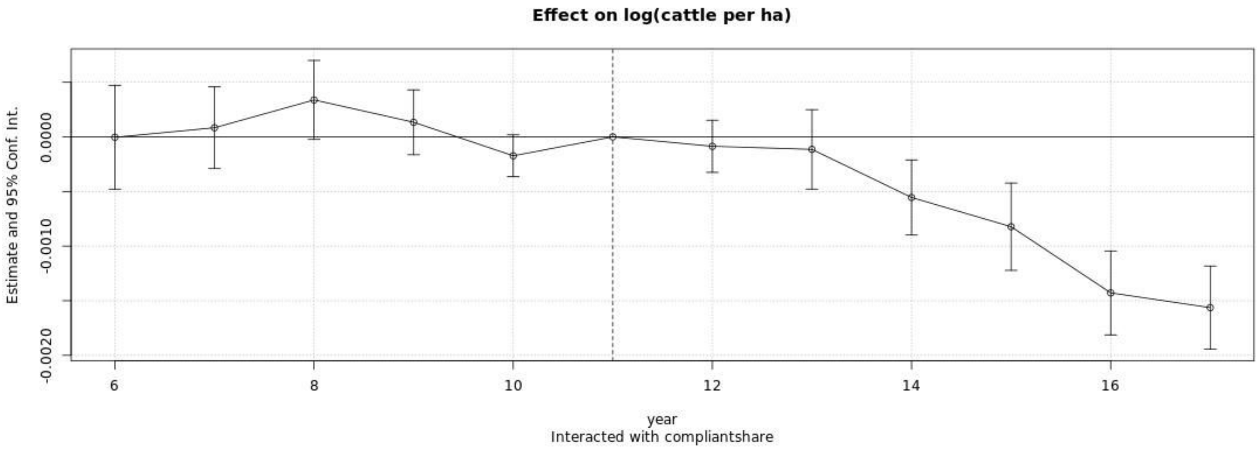
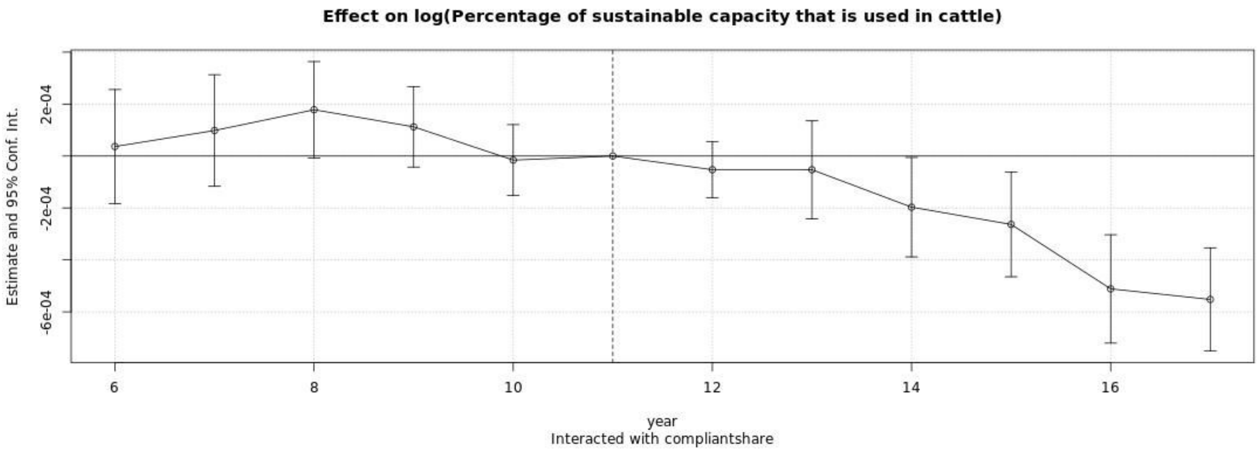
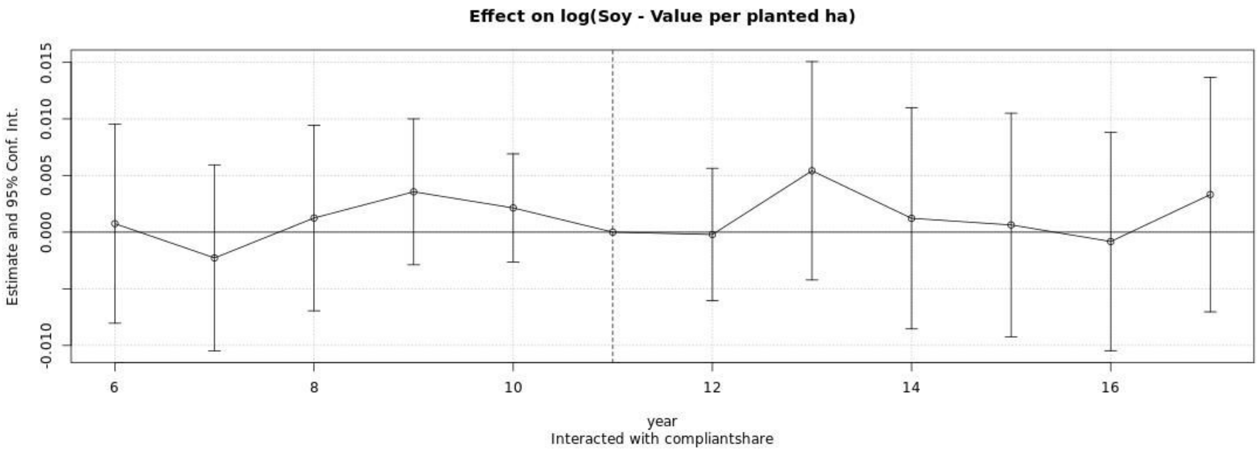


Figure 9: Event Study - Percentage of sustainable capacity used - Municipality Level



As expected, for the productivity of soy, there are no significant coefficients in the event study.

Figure 10: Event Study - Value per planted ha Soy - Municipality Level



6.3.2 Credit

Finally we will consider the robustness of our investigation of rural credit for cattle-ranching in the Amazon and its trajectory in reaction to the new forest code of 2012. Broadly, investment credits can serve for the intensification of production, whereas operational credits are used for feedstock, fertilizer and additional cows (MOFFETTE *et al.*, 2019). First, we can find no significant effect of the treatment on the number of credits for operations. Rather, the negative sign of the coefficient seems to be driven by the combination of negative coefficients before and negative coefficients after the treatment, albeit none of them significant. Next, the number of credits for investment purposes shows no significant pre-trend but both positive and negative coefficients after the introduction of the forest code. There is no clear reason for this phenomenon, this is why I regard the coefficient as invalid.

Ultimately, when considering value per hectare we find a robust reduction in the value of the credits for operational purposes. This results is expected, as the amount of money that is needed for operational items such as feed and fertilizer is probably more or less constant per cow. So when stocking rates decrease, this measure ought to decrease as well. When considering the value of investment contracts per hectare of pasture, we can identify a significant, positive pre-trend which invalidates any possible effect of the forest code. This is actually a sign that stocking rates are in general very low since farmers can intensify their production without needing to raise more capital. As we had seen, on average over the whole sample, only about 35% of the sustainable capacity was used, thus there seems to be ample room for improvement without the need to substantially improve the quality of pasture.

Figure 11: Event Study - No of credit contracts - Cattle Ranching Operations - Municipality Level

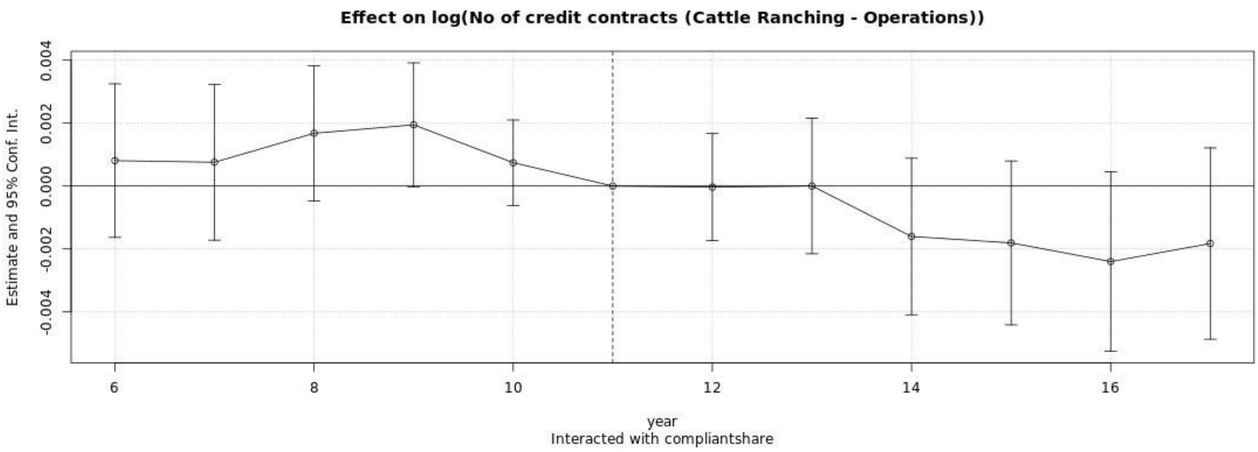


Figure 12: Event Study - Credit Value per ha - Cattle Ranching Operations - Municipality Level

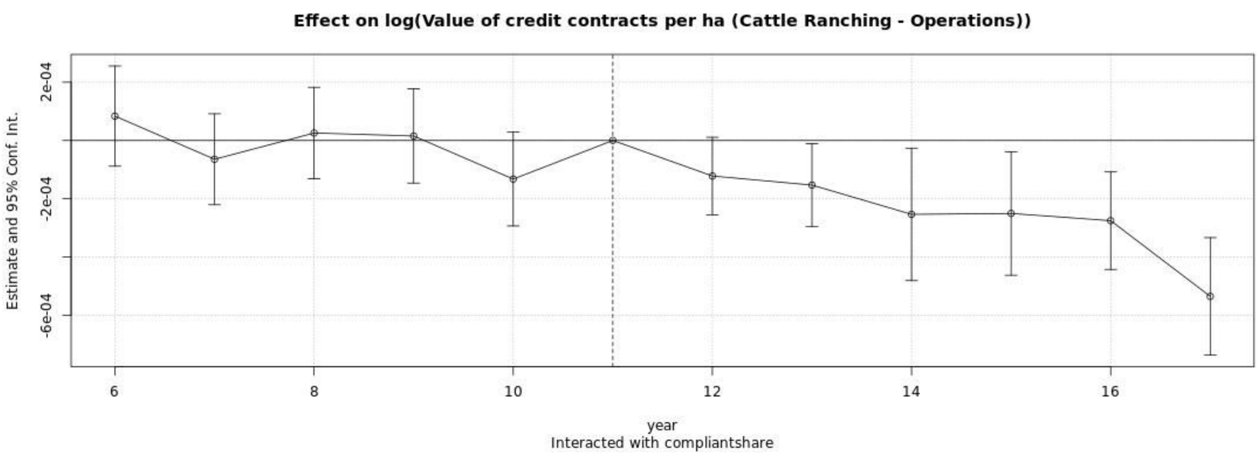


Figure 13: Event Study - No of credit contracts - Cattle Ranching Investment - Municipality Level

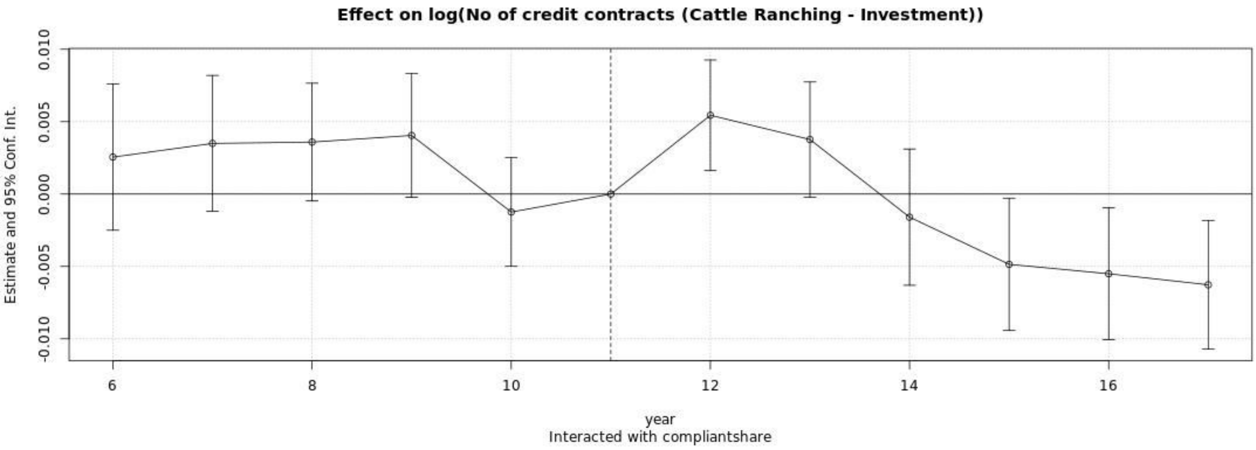
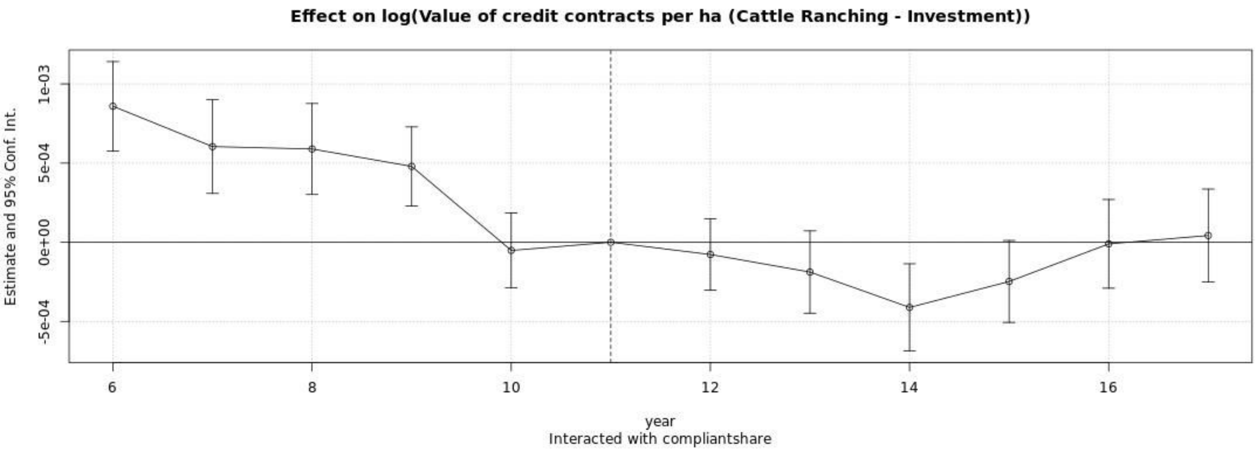


Figure 14: Event Study - Credit Value per ha - Cattle Ranching Investment - Municipality Level

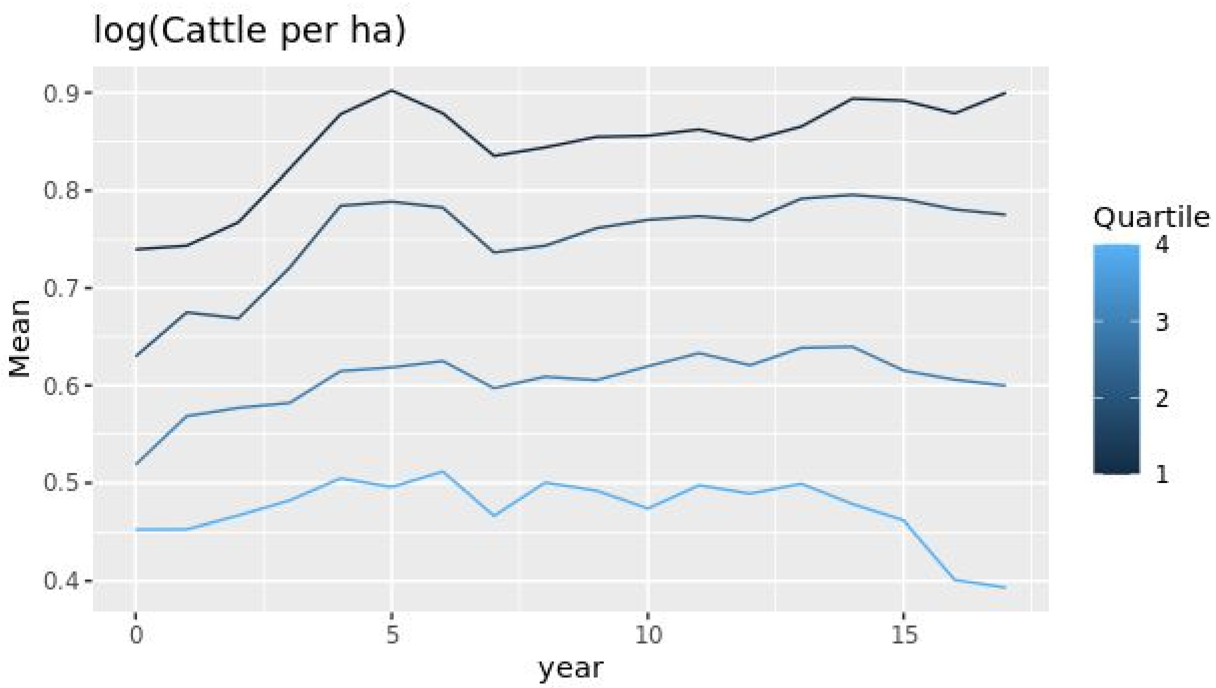


6.4 Direction of the Effect on Cattle per Hectare

To finalize the discussion of the results on the municipality-level, I want to focus on the direction of the productivity impact on cattle-ranching, as I believe it is the result with the most relevant policy implications. As we can identify in the plot below, the reduction in cattle per hectare of pasture is probably driven by both effects, although the second effect (on deforestation) is stronger. On the one hand, municipalities with comparatively less compliant properties increased their stocking rates from 2012 onwards. This can be seen the strongest in the first quartile and very slightly in the second quartile. Both an increase in herd-size as well as a comparatively smaller increase in pasture area due to increased conversion of pasture area to agriculture can be responsible for this.

On the other hand, municipalities with comparatively more compliant properties decreased their stocking rates. This can be seen in the third and fourth quartiles. The probable cause is that they extended their production on the extensive margin, by increasing deforestation. The evidence on stocking rates thus supports both possible effects that were mentioned above.

Figure 15: Mean Log(Cattle per ha) - Municipality Level



7. Discussion of the Results

To conclude this text I want to put my results into context. As we have seen in the property level analysis there was a major increase in productivity caused by a switch in non-compliant properties. In reaction to the forest code they changed from pasture to agriculture to capture the increased value of their properties. On the other hand, on the municipality level we found evidence of this first effect and of the second effect: properties which did not gain an amnesty increased their pasture areas, probably by deforestation, in reaction to the new forest code, as they were expecting another amnesty. In terms of financing, we could identify an accompanying movement in the value of operational credit per hectare which was to be expected. The lack of an increase in the value of investment credits per hectare shows the ample potential to improve cattle productivity at low costs.

In terms of policy implications, my analysis allows two conclusions. First, if given the right incentives, farmers have room to improve both the productivity of cattle-ranching and make a switch to agriculture to be able to profit more. This means that in as much as it aimed to increase productivity on compliant areas, the forest code was a success. Politicians which advocated for the alleviation of burdens of small farmers can thus be seen as correct. Secondly, there was a decrease in productivity for cattle-ranching in farms that did not receive the amnesty. Here the largest problem of the forest code becomes apparent: the lack of enforcement and the expectation of another amnesty gives property owners that had not yet deforested illegally ample reasons to start doing so. Specifically, the lack of enforcement exposes a weakness in the argumentation of politicians who were in favor of the forest code. Certainly, previous environmental rules were at times complicated and confusing, that is why a fresh start can be actually justified. But a condition of the fresh start would be that property owners actually start to respect the rules afterwards or could be reasonably expected to do so. However, if the rules are not sufficiently enforced and landowners do not respect them anyway, then the amnesty in itself does not seem justified.

To conclude the discussion of the results, I want to briefly touch upon the delays in the implementation of the forest code that were explained above. In general, the fact that I found an effect of the forest code is an indication that property owners already responded to the enactment of the law. Specifically, those which were given the amnesty did not wait for its confirmation by the supreme court in 2018. In fact, the productivity losses that we observed might even be influenced by the delays in the deadlines for the inscription in the CAR and the missing analysis of its entries. This made it easier for compliant properties that did not receive an amnesty to increase deforestation and pasture area.

8. Directions for Further Research

First, it is possible to investigate the differential sizes of the amnesty since smaller properties were substantially more benefitted like we had seen in the explanation of the forest code. Santanna and Costa (2019) do this for deforestation. However in terms of agricultural productivity and land-cover conversion, a major caveat could be that smaller properties undergo a different dynamic than larger properties, since they generally lack capital and access to technology. Thus it needed to be explored whether the impact of the different amnesty sizes could be differentiated well from the different underlying dynamics of properties of different sizes.

Secondly, as we had seen above the forest code is part of a selection of private-sector and public policies that target land use in the Amazon. While this study was limited in scope it is conceivable to study their interaction with the forest code in an analysis similar to mine which could improve our understanding of its impacts. Especially the changing of the soy moratorium in 2016 to equate the cut-off of the amnesty of the forest code could have an impact on those properties that had received an amnesty by the forest code in 2012. Notably this study was limited to data until 2017 and thus did not include enough data to reliably determine an effect of this change.

Thirdly there is the issue of leakages or spillovers. On a local level it could be investigated whether there occurred spillover from amnestied properties to adjacent, non-amnestied properties. This means whether a change from pasture to agriculture in an amnestied property occurs concurrently with a change from forest to pasture in nearby, non-amnestied properties. An example for this can be found in Gollnow *et al.* (2018). The same could also be true on a more distant level (ARIMA *et al.*, 2011; DOU *et al.*, 2018). To further investigate it, the different rules of the forest code for the Cerrado biome could be used, as in Moffette and Gibbs (2018).

9. Conclusion

This work intended to find the causal effect of the new Brazilian forest code of 2012 on land use and agricultural productivity. By using a difference-in-difference framework, it was possible to conclude that the forest code led to a relative decrease in conversion of pasture to agricultural areas in properties that did not receive an amnesty in the forest code of 2012. Our theoretical considerations predicted that this could happen as a consequence of the forest code, based on more conversion in amnestied and less conversion in non-amnestied properties. Empirically it seemed more likely that the first effect, more conversion in amnestied properties was decisive in this case.

On the municipality level we investigated the effect of the forest code on productivity, both of cattle and agriculture. Broadly our results were in line with those obtained on the property level. A higher share of compliant properties in 2008, resulted in a lesser focus on agricultural productivity: cattle stocking rates were smaller and there were less credits conceded for operational purposes.

In conclusion, these results paint a mixed picture regarding the efficiency of the new forest code. While the increases in productivity are certainly something desirable, it is not clear whether they outweigh the decreases in productivity in more compliant areas. However, it needs to be considered that this analysis was based on the first years of the implementation of the new forest code. It is possible that the situation will still become better, as more and more local governmental structures are built up to enforce compliance and more properties are registered in the CAR.

On the other hand, given the current political scenario in Brazil, it could also become worse. Since the combat against deforestation depends crucially on the support of the federal government, we could very well see more adverse developments in the future.

For the future, one suggestion to limit deforestation further would be to implement a public monitoring system, similar to the cattle and soy moratoria but transparent and encompassing all rural properties. In a recent article Rajão *et al.* (2020) demonstrate the technical possibility of such a system. They use some of its proposed data sources to confirm that the private sector initiatives are not sufficient as beef and soy from illegally deforested properties in the Amazon and Cerrado biomes enter the export market. Rather, the forest code and specifically the CAR should be taken as the basis to implement a comprehensive and public monitoring system for supply chains.

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Appendix

I Data Sources

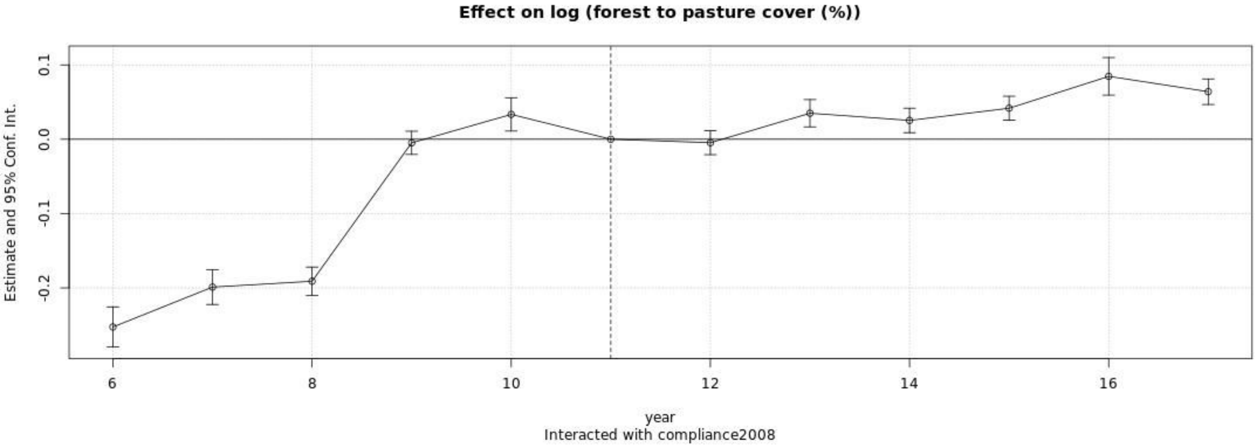
Data	Source	Link
Land cover	MapBiomas	https://mapbiomas.org/
Temperature and Precipitation	Matsuura and Willmott (2018)	http://climate.geog.udel.edu/~climate/html_pages/download.html
Agricultural prices	Secretary for Agriculture - State of Paraná	http://www.agricultura.pr.gov.br/deral/precos
Soil aptitude	Soares-Filho et al. (2014)	http://www.csr.ufmg.br/forestcode/
Agricultural production	IBGE	https://www.ibge.gov.br/estatisticas/economicas/agricultura-e-pecua

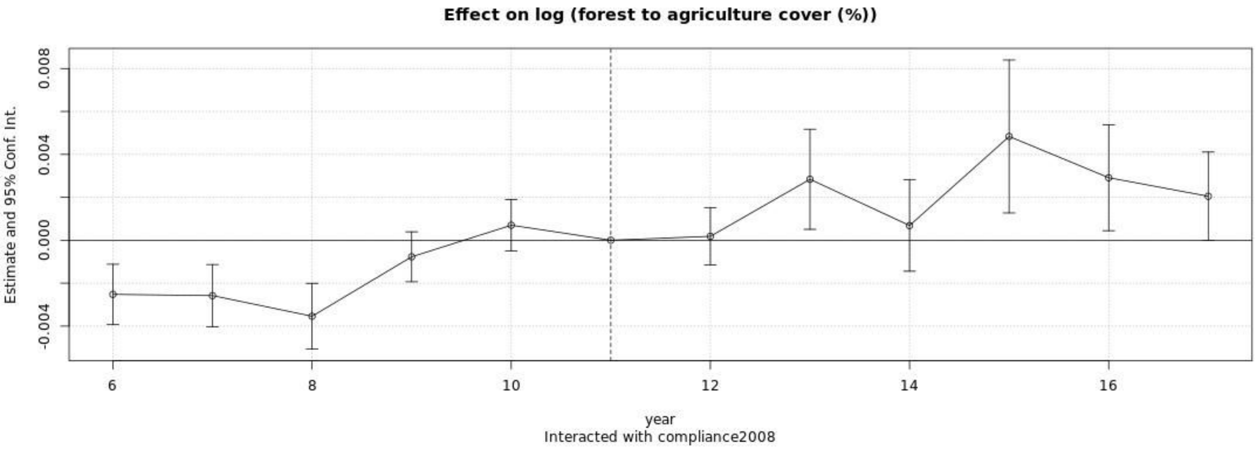
		ria/9117-producao-agricola-municipal-culturas-temporarias-e-permanentes.html
Cattle production	IBGE	https://www.ibge.gov.br/estatisticas/economicas/agricultura-e-pecuaria/9107-producao-da-pecuaria-municipal.html?=&t=o-que-e
Pasture quality	LAPIG/UFG	https://pastagem.org/
Rural credit	Brazilian Central Bank	https://olinda.bcb.gov.br/olinda/servico/SICOR/versao/v2/aplicacao#!/recursos

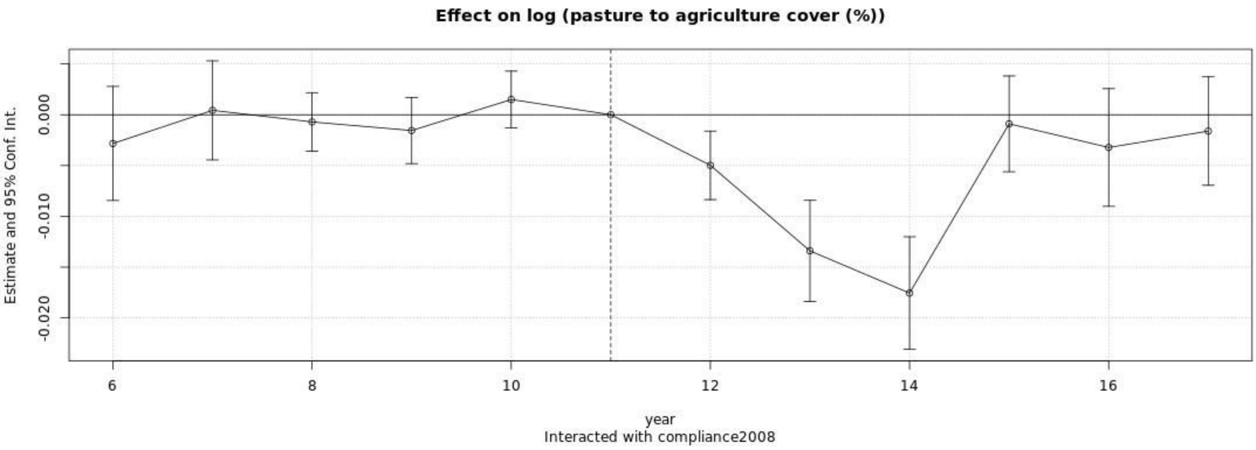
II Additional Robustness Check

	(1)	(2)	(3)
Dependent variable[1]	forest to pasture cover (%)	forest to agriculture cover (%)	pasture to agriculture cover (%)
compliance2008:yrafter2011	0.266 * * *	0.006 * * *	-0.005 * * *
	(0.00155)	(0.00024)	(5e-04)
Observations	4933224	4933224	4933224
R2	0.239	0.137	0.23
Property FE	Y	Y	Y
Year FE	Y	Y	Y
Climate variables	Y	Y	Y
Agricultural Prices	Y	Y	Y
Terrain aptitude	Y	Y	Y
Property time trend	Y	Y	Y
Cluster	Grid	Grid	Grid
Number of properties	1058	1058	1058

[1]Note: Each column represents an individual regression. The dependent variable is always the the natural logarithm of the relative transition area of respective land cover in property i from year t-1 to year t. For each column, the coefficient of interest is the interaction of compliance2008 with a dummy indicating the years 2012-2017, so that the treatment begins in 2012. Standard errors in parentheses are clustered by grids of 0.5 x 0.5 degrees, as in Santanna and Costa (2019). Significance: *** p<0.01, ** p<0.05, * p<0.1.


Effect on log (forest to pasture cover (%))
Estimate and 95% Conf. Int.
0.1
0.0
-0.1
-0.2
6
8
10
12
14
16
year
Interacted with compliance2008


Effect on log (forest to agriculture cover (%))
Estimate and 95% Conf. Int.
0.008
0.004
0.000
-0.004
6
8
10
12
14
16
year
Interacted with compliance2008


Effect on log (pasture to agriculture cover (%))
Estimate and 95% Conf. Int.
0.000
-0.010
-0.020
6
8
10
12
14
16
year
Interacted with compliance2008