Property Rights and Deforestation: Evidence from the *Terra Legal* Land Reform in the Brazilian Amazon

Molly Lipscomb
Batten School
University of Virginia

Nividetha Prabakaran
Estonian Business School

Abstract

This paper estimates the early impacts of *Terra Legal*, a large property rights reform, on deforestation and farming in the Brazilian Amazon. Twelve and a half million hectares, more than 2.5% of the Brazilian Amazon, have been registered under this program. The establishment of property rights may increase a farmer's incentive to invest in his land and expand his farm due to a lower risk of expropriation. On the other hand, the enforcement of conservation requirements may be easier when farmers have legal titles to their land. We use county level data from 2007-2012 on farm registrations, deforestation, crop choice and bovine management to test the impact of the *Terra Legal* land reform. While we find no overall impact of the program on deforestation during the period in our sample, we do show that there is substantial heterogeneity in impacts across counties. Counties with the largest area registered do have an increase in the *level* of area deforested, but they also have a decrease in the *rate* of deforestation. We investigate the extent to which changes in deforestation are related to the amount of registration that occurs among small, medium and large farms, and find limited support for less deforestation among counties with more area registered by small farms; more area registered by large farms is associated with a higher level of deforestation, but a decreased deforestation rate. Our results suggest that land tenure reform can create incentives to decelerate deforestation. Farm size has a strong impact on the farm management changes generated by improved property rights; coupling land tenure reforms with incentives to intensify production rather than expand could lead to reduced deforestation, particularly among small farms.

Introduction

Establishing property rights may reduce the over-exploitation of forests by incentivizing agents to intensify use of the land to which they have a title rather than spreading out across larger swaths of land. Federal regulations on land use may be more enforceable in areas where land rights are clear, further reducing deforestation. On the other hand, increased profits in farming, and the potential for future legal claims to other territory, could lead to further expansion in settlements. These conflicting tendencies may generate different responses to titling policies by small versus large farms. Under President Lula da Silva, Brazil began a new land tenure reform, *Terra Legal*, in 2009 aimed at increasing the land tenure rights of farmers in the Amazon. One objective of the program was to enable small farmers to obtain titles. We evaluate the effects of the early stages of the *Terra Legal* program on deforestation in the Amazon using county-level data on registrations, deforestation and crop choice.

The theoretical impact of increased property rights on deforestation may be either positive or negative. One outcome of improved land tenure is that the land can be used more efficiently: resources no longer need to be spent on protecting rights to the land, and there are increased incentives for farmers to invest in the land (Besley, 1995). The Jevons paradox suggests that as farming becomes more efficient and therefore more profitable, farms are likely to expand and convert more land from forest to agriculture to take advantage of the higher returns (Skonhoft, 1998; Ceddia, Bardsley, Gomez-y-Paloma, & Sedlacek, 2014). However, the Borlaug hypothesis suggests that increased productivity may lead to a reduction in forest loss as less land is necessary to produce a given amount of food and resources (Lobell, Baldos, & & Hertel, 2013). Some empirical support has been found for a reduction in land use and deforestation following increased agricultural productivity (Assunção, Lipscomb, Mobarak, &

Szerman, 2018) and the intensification of land use leading to land-sparing (Barretto, Berndes, Sparovek, & Wirsenius, 2013). We provide empirical evidence on the deforestation effects of land tenure reform in the Amazon.

Brazil has a long history of property rights struggles in the Amazon. Land reform policy in the late 1980s and early 1990s created increased incentives for violence among squatters and between squatters and landowners as encroaching on land was a common technique for gaining control over, and eventually a title to, the land (Alston, Mueller, & Libecap, 1999). Deforestation was also a way of establishing ownership; farmers cleared large swaths of land to show that they were under cultivation and that the land had therefore been claimed. This led to both increased levels of forest clearing and violent conflicts (Araujo, Bonjean, Combes, Motel, & Reis, 2009). The *Terra Legal* program was designed to reduce violent conflict over land and enable improved enforcement of environmental regulations by providing households that had been farming a parcel of public land for over five years before 2004 with a legal title to the land.

The *Terra Legal* policy was different from most previous titling efforts in Brazil: the objective of *Terra Legal* was to improve legal access to land for the poor. Small farmers with land holdings below the minimum sustainable farm size[1] obtained the property for free, while those with medium-sized properties paid a discounted price; only those with large properties paid the full market price of the land for the title.[2] Authorities made titling land substantially easier, particularly for small farmers by traveling to sites and inspecting properties. We use the phased rollout of the *Terra Legal* program to compare counties that received the program early on to

[1] The minimum sustainable farm size threshold varied by county, based on population and proximity to cities.
[2] The market price and the discounted price were determined locally and our data does not include payment amounts.

those that received it later. Because the *Terra Legal* program encouraged small farmers to register who may not have registered without the administrative help that was provided, we are able to use *Terra Legal* to compare the impacts in counties with more land registered by small farmers under the program to counties with more land registered by large farmers.

We find no overall effect of the rollout of the *Terra Legal* program, but the effects of the program varied substantially by the amount of registration in a county and by the amount of a county covered by small, medium, and large farms. Deforestation levels increased following registration by larger areas of medium and large farms, but deforestation rates declined suggesting that the deforestation associated with more registration of large farms occurred in counties that started with higher base amounts of forestland. On the other hand, deforestation levels in a county actually weakly declined following increased registrations by small farms (although this is not statistically significant in most specifications).

One concern with our estimates would be if the registration program were correlated with the "prioritization" or "blacklisting" programs that other literature has found to have led to large decreases in deforestation (see, for example, Cisneros, Zhou, & Börner, 2015 or Assunção & Szerman, 2018). We estimate the effect of Terra Legal registrations while controlling for the blacklisted counties, and find that our results remain broadly consistent.

This paper adds to a growing literature on the impacts of forest conservation programs in Brazil. The most related paper to our work is Assunção and Szerman (2018) which also estimates the impact of the Terra Legal program, but evaluates the program at the level of a "gleba" or a parcel of federal public land while our analysis is at the county level. They estimate the impact of the full titling process (in contrast, we estimate the impact of the first step toward titling, registration), and are able to observe the impacts over a longer time horizon. Assunção and

Szerman estimate substantial decreases in deforestation from the titling program (between 9.2 and 11.2 percent), but they also find substantial heterogeneity in impacts–less of a reduction in deforestation in areas with high levels of grazing and in larger parcels. The difference between our small estimated impacts and those of Assunção and Szerman (2018) may result from either the longer time horizon of their data (through 2014) or from the fact that their level of observation is by plot of federal public lands to which the registration and titling program was limited. Our measures include spillover effects to areas that did not qualify for the program.

Other work has also highlighted the variability in impacts of land tenure reform programs on deforestation. Duchelle et al. (2014) points out the importance of formalizing rights to land prior to enacting large payments for environmental services programs such as REDD+ which may create incentives for land-grabbing thereby reducing the effectiveness of the program. Souza-Rodrigues (2015) uses a structural model with variation from transportation costs to evaluate the relative effectiveness of incentives-based programs versus command and control programs and finds that incentives programs are much more cost-effective in generating improved forest conservation. BenYishay, Heuser, Runfola, & Trichler (2017) estimate the effect of formalizing indigenous rights to land in the Brazilian Amazon, and find little impact from formalizing the rights of these communities on forest levels. We investigate the pathways through which registrations may impact deforestation: land management, spatial spillovers, and credit use and highlight how these vary between counties with higher levels of registrations by small, medium, or large farms.

We are not the first to highlight the importance of the distinction between small, medium and large farms. Souza-Rodrigues (2015) shows that there is often very little impact from regulating the smallest farms in the Amazon since they control a relatively small share of the

total land. In the case of *Terra Legal*, the policy was designed to favor small farmers, and so they form a larger share (15% of early registrations) of the land that was treated by the program. The decreases in deforestation among counties with large amounts of registration by small farmers which we measure are similar to the results in (L'Roe, et al, 2016) in response to a program to register properties for environmental enforcement: although the mapping program was aimed at environmental monitoring, many small farmers enrolled in order to increase the strength of their claim on the land. L'Roe, et al. (2016) find that these small farmers decreased deforestation in response to the program–in many cases this may have been a response to the increased enforceability of the environmental regulations when their farms were registered.

While we do not find an impact of the program overall, in counties with the highest area of land registered, we do see increases in the level of deforestation. Deforestation *levels* increase when more land is registered by medium and large farms, but deforestation *rates* also decrease. This suggests that the continued deforestation is occurring primarily in places with high base (2007) levels of forest. These may be the areas that are most difficult to monitor. By contrast, deforestation levels appear to weakly decrease when larger areas are registered by small farms. Registration and titling enable government agencies to better enforce forest code conservation requirements. Land tenure reform provides one policy lever that may help reduce deforestation, particularly in areas where forest cover is already being lost at a high rate.

Background: Land Tenure and the Terra Legal Program

The *Terra Legal* program was formed in 2009 with the objectives of reducing deforestation and ending land disputes and violent land-grabbing. It is a federal program aimed

at public lands in the Legal Amazon region, and rolled out over several years from 2009.[3] The policy was targeted toward farmers and granted squatters who had been farming a particular plot of federal land for at least five years as of 2009 the ability to apply for registration.

This policy differs from previous policies used for land tenure regularization in the Legal Amazon in its depth of registration efforts and pricing. To make registration easier, *Terra Legal* officials traveled to areas of Amazon states close to the federal land to register the squatters rather than requiring them to travel to the bureaucratic headquarters. In the past, many squatters did not take advantage of their rights to titled land, even when guaranteed by the constitution, due to the high costs involved with titling and the bureaucratic backlog (Araujo, Bonjean, Combes, Motel, & Reis, 2009). By reducing travel costs, program administrators expected to increase take-up, particularly among small farmers.

The rollout of the program was not strictly phased (a squatter could travel to a *Terra Legal* regional office to get his land registered at any time), but the extensive registration process made it costly for farmers to register outside of the time period when the administrators were present. Most registrations occurred following the availability of the officials based on the logistics of their visiting the areas that met the criteria for the program. Officials traveled to each county to promote the titling policy and examine the property being registered to ensure that the squatter had been there farming the land for at least five years, as well as to determine the exact border and to geocode it. The registration process for each county typically took about two weeks to a month, depending on the size of the county and the number of people applying for a title, after which the officials moved on to the next county. Since the *Terra Legal* program is a

[3] Registrations are still ongoing, but this data is from the first wave between 2009-2012.

federal program managed by federal employees and officials, the states had little influence over the order of rollout. Officials moved from county to county with the goal of completing the process as quickly as possible while stopping at all counties which had land available for titling under the criteria of the program. The rollout of the program began quickly, with registrations in 114 different counties in 2009 and 205 counties in 2010, but slowed down substantially with registrations in 67 counties in 2011 and 33 in 2012.[4] The phased rollout of the program and its dependence on logistical constraints reduces the potential for endogeneity in rollout of the program based on deforestation rates or farming productivity.

The choice of target areas for the program occurred as follows. The *Terra Legal* program is part of a larger plan to geocode and catalogue the lands in the Amazon. At a monthly meeting, heads of the agencies associated with land management in the Amazon, including FUNAI (carries out policies involving the indigenous people), the Environmental Ministry, and *Terra Legal*, gathered and determined which portions of large parcels of federally owned land, called "glebas," fell under the purview of each agency.[5] If the other agencies did not claim any of the parcels in the gleba , *Terra Legal* took over management of the area for titling with no administratively defined order across glebas. The objective of this comprehensive effort was to help with government monitoring efforts; monitors can more easily identify responsibility for the cutting of the trees based on the national catalogue or "Cadastro" of land owners.

[4] Authors' calculations.
[5] *Glebas* were determined around the time when colonists settled Brazil, *gleba* borders are unrelated to present day deforestation concerns.

Pricing in the *Terra Legal* program varies by small, medium, and large farms. Small farms–those with less than one módulo fiscal [6] (on average 70 hectares–less than one square kilometer) are able to title their land for free. States set both the size of a módulo fiscal and the price of land for medium and large sized farms. Farms between one and four módulo fiscais receive a per-hectare price of less than market value with payments phased out over 20 years; above this level, the land owners can get rights to the land, but must pay the state-determined market price, again over a 20 year period.[7] Each county defines the exact size of its módulo fiscal, ranging from 5 to 100 hectares.

Between July 2009 and November 2012, more than 100,000 applicants had registered their land in 390 counties. 463 counties had *glebas* in which farmers were allowed to apply to the program (Brito & Barreto, 2011). Table 1 provides summary statistics on the registered and titled farms. The total area registered is around 125,000 square kilometers (or 12.5 million hectares); approximately 2.58% of the Brazilian Legal Amazon. On average, area registered under *Terra Legal* represented 3% of the area of the county, but varied between 0 and 82%. The average size of a registered farm is 124 hectares (1.24 square kilometers) and 1.76 *módulo fiscais (mfs)*. Each county in the Amazon has an average of 245 registrations, and the average area registered in a county is 305 square kilometers.

About 3% of farmers who registered under the program had already obtained land titles as of 2012; the titled area spans roughly 2,250 square kilometers (about 558,000 acres) and is solely in the Legal Amazon. More than half the registrations are the small farms measuring less

[6] A módulo fiscal is the minimum amount of land that is estimated to be necessary in the county to maintain an income large enough to sustain a family.
[7] The law specifies the sale will be at market value, but the state government determines the price and it varies across counties. Our data does not include transaction prices.

than 1 mf; medium farms make up roughly 30% of the total titles and only 14% of the titles are large farms. By area registered, the percentages are quite different: 15 percent of land area was registered by small farmers, 33 percent was registered by medium sized farmers, and the remaining 53 percent was registered by large farmers. The small farms go through the registration process fairly quickly, which is reflected in the fact that almost 3 in 4 titled properties are small.

Because of the discounted pricing, cattle ranchers, large farms and logging firms have an incentive to increase their land holdings by buying land cheaply. The program prohibits immediate sale of the newly titled lands, but after three years, the land purchased for large farms can be sold on the market. Many of the registered farms are already large: over 7000 registered farms are equal to or larger than 1000 hectares in the registration data.

Figure 1 shows the total area occupied by registered farms in the sample and their location, overlaid on a satellite image of the Brazilian Amazon in 2010. The impact land registration and titling could potentially have on the forest stock is large.

To combat deforestation and promote sustainable forestry, *Terra Legal* has instituted several safeguards. The land title states that the property owners must maintain an 80% legal reserve on the land in accord with the Forest Code, i.e. 80% of their property should consist of forests/trees. Failure to maintain this land in conservation could result in government appropriation of the property. Small farms that can be obtained at no cost are only given a provisional title for 10 years; the final deed is only approved if this legal reserve requirement has

been met.[8] The provisional title is enough to use as collateral, so borrowing for investment is easier for small farmers who go through the *Terra Legal* program. Officials can also arrive unannounced to examine the property at any time within the provisional 10 years. Anecdotal evidence based on conversations with the land management officials in the Amazon suggests that the rule of 80% forest reserves is not strictly followed.

Data

We combined data from four sources in order to estimate the impact of the *Terra Legal* program registrations on county level deforestation, number of bovines, and crop-level production in the Legal Amazon region. More detailed information on our data is included in Appendix B, the Data Appendix.

Registration Data: We obtained farm-level data from *Terra Legal* that includes detailed records of registrations from July 2009 to October 2012 (Terra Legal, 2009-2012). This includes the amount of land registered, the month and year of registration, the location of the farm, and the status of the application as of October, 2012.[9] As of 2012, very few (less than 2%) of applications for title were rejected, and rejections were typically due to administrative formalities such as incorrect completion of the application or duplication. Registrations therefore have a close correspondence to titling, and farmers can view a completed registration as a strong signal that they will receive a formal title to their land. In addition, following registration, the farmers can be held responsible for maintaining the legal conservation requirements, so they may

[8] Medium and large sized farmers do receive the official deed rather than the provisional one following payment of the requisite fees.
[9] We were able to get this data directly from the program by emailing the contact address listed on the program website.

respond by reducing any efforts at deforestation. We therefore use registration as a proxy for land rights. Using this registration information, we construct our explanatory variables at the county-year level.

Total registered area is measured in square kilometers and is a stock variable; it is divided into three subcategories according to the size of the properties: "Small" Farms each have area less than 1 *módulo fiscal (mf)* , approximately 70 hectares. "Medium" properties are of size 1-4 *mf* , while the "Large" Farms are more than 4 módulos fiscais *mfs* .

Deforestation Data: Our deforestation data comes from the PRODES project, a government program which has been monitoring deforestation in the Amazon via satellites since 1988 (Instituto Nacional de Pesquisas Espaciais (INPE), 2007-2012). The program is part of the collaboration between the Environmental Ministry (MMA), the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA), as well as the Ministry of Science, Technology and Innovation (MCTI). The images are collected every two weeks at a resolution of 20-30 meters. The data is aggregated into annual deforestation estimates, after accounting for cloud cover and other sources of error. This dataset spans the years 2000-2012 and includes information on the area deforested in square kilometers and the area forested. We combined the deforestation data with geocoded boundary maps from 2001 from IBGE for the counties in order to measure deforestation in each county in each year. Our two deforestation outcome variables are *Area Deforested*, which is difference between the area forested in each year compared with the year before (cumulative), and *Rate of Deforestation*, which is the change in *Area Deforested* divided by the total forest area in the county as of 2006 (the year before the beginning of our sample).

Farm Productivity Data: Our crop cultivation panel data from 2002-2012 is from IPEA, the Institute of Applied Economic Research, and IBGE, the Brazilian Institute of Geography and Statistics (The Brazilian Institute of Geography and Statistics (IBGE), 2007-2012; The Brazilian Institute of Geography and Statistics (IBGE), 2007-2012; The Brazilian Institute of Geography and Statistics (IBGE), 2007-2012). This data provides information on the area cultivated in a county annually, the quantity produced of various crops and the value of the production at the county-year level.

The total area cultivated, measured in hectares, is a flow variable. Area cultivated by temporary crops are crops that require annual planting, such as wheat, rice, soy, tobacco and corn, while area cultivated by permanent crops can be harvested over multiple years, such as coffee, cocoa and oranges.

Bovine Data: Data on number of bovines owned in a county are from the Municipal Livestock Production data (PPM) from SIDRA (IBGE's Automatic Data Recovery System).

Credit Data: The credit data is from the Annual Statistics of Rural Credit, provided by the Brazilian Central Bank's Common Register of Rural Operations (RECOR). This data includes various sources of rural funding including rural savings, Brazilian Development Bank (BNDES), Constitutional Funds, and the National Program to Strengthen Family Farming (PRONAF), a rural credit program established in the 1990s to improve outcomes of family farms. The data includes information on the number of contracts and the value of the loan for various purposes, such as investment or commercialization or whether it's for agriculture or livestock. For our analysis, we use the number of contracts and value of loans (in Reias) for agricultural investment purposes.

County-Level Economic Data: IPEA provides information on county population estimates annually, as well as county GDP, which is subdivided into agricultural and non-agricultural GDP. For our analysis, we use as controls the annual county population estimates and non-agricultural GDP.

Empirical Specification and Results: The impact of Terra Legal on Deforestation

We estimate the effect of the *Terra Legal* reform allowing increased registrations leading to land titling on deforestation. While we find no overall effect of the reform on deforestation during the period of our sample, we find substantial heterogeneity across the counties involved in the program. Most counties saw a small decrease in deforestation, but those above the 80th percentile for area registered had an increase in deforestation.[10] There is an increase in deforestation associated with larger percentages of the county being registered under the program. In order to investigate mechanisms, we disaggregate the effect by the size of the farms registered in the county. Counties with small farm registrations show a small negative impact (not statistically significant in most specifications), but counties with medium and large farm registrations do appear to generate statistically significant deforestation. The rate of deforestation does decrease for large farms, however, suggesting that the higher levels of deforestation among counties with more are registered by large farms may be focused in counties with higher base levels of forest or those that had higher rates of deforestation prior to the program.

[10] We have tested alternative thresholds including the 70th percentile and the 90th percentile, and we find that the results are robust to the choice of the threshold.

Local Deforestation

We begin by estimating a difference-in-differences model of the impact of the *Terra Legal* program on deforestation in areas where the rollout occurred. This allows us to estimate the impact of a county going from untreated by the *Terra Legal* program to treated by the program. We estimate the model as follows:

$$y_{it} = \alpha + \beta_1 Post\_Rollout_{it} + \Gamma Controls_{it} + \mu_i + \nu_t + \epsilon_{it},$$

where y_{it} is Area Deforested. $Post\_Rollout_{it}$ takes the value 1 in the year of the highest number of registrations that are completed in the county, and all years after, 0 prior to the year of the most registrations.[11] We include county and year fixed effects. The county fixed effects control for anything specific to the county that do not vary over time such as area, land quality, or distance to major transportation. The year fixed effects control for the overall changes across the sample in deforestation over the years. We also control for the inverse hyperbolic sine of population and non-agricultural GDP, as these variables could affect deforestation levels and create more demand for registrations—failing to control for them would leave us with a potential omitted variables bias as we are interested in the impact of registrations on deforestation. We are interested in the sign of β_1, the impact of a county going from outside of the *Terra Legal* program to treated by the *Terra Legal* program.

Because counties in which there were many *Terra Legal* registrations may behave differently than counties in which *Terra Legal* had fewer people taking up, we also estimate the

[11] While we don't have the actual path followed by the administrative team which ran the Terra Legal program, we estimate the path of the rollout using when the registrations for a county were accomplished. We have tested the robustness of the results to dropping the counties in which the number of registrations was low (ie, these may be self-registration counties where administrative rollout did not actually occur, and we have found that the results remain consistent. Regression available on request.

differential effect of the *Terra Legal* program on counties in which there was more than the 80th percentile of land registrations for the *Terra Legal* program. We use the following specification:

$$y_{it} = \alpha + \beta_1 Post\_Rollout_{it} + \beta_2 Post\_Rollout_{it} * HighRegistrations + \\ + \Gamma Controls_{it} + \mu_i + \nu_t + \epsilon_{it},$$

Again, y_{it} is *Area Deforested*. In addition to an indicator variable for $Post\_Rollout$ defined as described above, we also include an interaction term between $Post\_Rollout_{it}$ and $HighRegistrations$ which is an indicator for a county which had at least as much land area covered by *Terra Legal* registrations as the 80th percentile county. Controls are the same as in the main specification. β_1 is the overall impact of the county undergoing the rollout of *Terra Legal* while β_2 is the differential impact on deforestation of the rollout in counties which had particularly high area (greater than the 80th percentile) registered.

The difference-in-differences specification relies on the assumption that the trend in deforestation for those in the high-registration group *would have been similar* to the trend in deforestation for those with fewer registrations in the absence of the program. To test this, we analyze the difference in pre-trends between the two groups for the years 2007-2009 in Appendix A. We find that the pre-trends are very similar and not statistically different between early rollout counties and late rollout counties. The results are more mixed for high registration counties relative to the other counties, so results using these variables should be interpreted with caution.

Results are shown in table 3. We find no overall impact from the rollout of the program in specifications (1) and (2), but specifications (3) and (4) suggest that there is substantial heterogeneity in the impact across counties. Counties with less area registered had a small reduction in deforestation of approximately 0.5 percentage points (statistically significant at the 1% level). Counties in which the rollout led to the most new registrations saw an overall

increase in deforestation of approximately 0.6 percentage points across all counties to 1 percentage point when the sample is restricted to counties which were eligible for the rollout (statistically significant at the 5% level).

One concern with our specifications may be that the counties with the highest levels of registrations could also be those that are the largest, and larger counties may have a differential trend in cumulative deforestation. We test this in specifications (5) and (6) by adding an interaction between year and county area. If the result were biased by counties with larger areas having a different trend in their deforestation levels, we would see that the coefficient on the interaction term between rollout and high registrations would lose significance. We find that the magnitude of the coefficient decreases somewhat, but that the coefficient is similar to that in the main specification, and the sign and significance are unchanged.

We next estimate the effect of incrementally more area registered under the *Terra Legal* program in a county on five outcomes—deforestation levels and rates, deforestation in nearby areas, crop cultivation, number of bovines, and credit use—using a panel data fixed effects model. The key identification assumption is that the order and location of rollout are determined based on factors unrelated to these outcome variables and that registrations took place as a response to the availability of the program rollout rather than because farmers who were most likely to gain from the program sought out their registrations early and self-registered. If management of the program were at the local level, we would be concerned that counties in which large gains from titling were expected would prioritize the program–pushing the counties with larger impacts from the program to be first to institute the reform, and decreasing the generalizability of the findings. There was little scope for selection by productivity or likelihood of deforestation after controlling for county fixed effects because the rollout of *Terra Legal* was

determined at the federal level and the administrative boundaries of land to be dedicated to the program were determined based on "glebas" which were set during the colonization of Brazil.

In order to further check that results are not biased by cases in which farmers register outside of the rollout period, we calculate the number of registrations that occur in each county before the county had its highest number of registrations (the estimated rollout year). We find that approximately 8% of registrations occurred prior to the highest registration period for the county in which they were registered. We estimate a specification with these observations prior to the rollout occurred and find that our results are robust to omitting these "self registration" observations.[12]

In order to avoid allowing values in the tail of the distributions to skew the coefficient, we apply the inverse hyperbolic sine (IHS) transformation to the outcome variables and independent variables of interest. This is particularly important since county size varies substantially in the Amazon. There is more area to cultivate in larger counties, which means the average effect on area cultivated would be overstated for small counties and understated for larger ones. Transforming the outcome variables results in a distribution closer to the normal distribution.

We fit the following general model:

$$y_{it} = \alpha + \beta_1 Area\_Registered_{it} + \Gamma Controls_{it} + \mu_i + \nu_t + \epsilon_{it},$$

where y_{it} is the total area that has been deforested in county i in year t, $Area\_Registered_{it}$ is the area registered in county i in year t. Controls are the same as the main specification. β_1 measures the response of deforestation to the total area registered and is the elasticity of

[12] Regression results available on request.

deforestation to area registered. In all regressions, we cluster the standard errors at the county level.

We also estimate the effects by farm size: we split the registered area into three size categories:

$$y_{it} = \alpha + \beta_2 Area\_Reg\_Small_{it} + \beta_3 Area\_Reg\_Med_{it} + \beta_4 Area\_Reg\_Large_{it} + \Gamma Controls_{it} + \mu_i + \nu_t + \epsilon_{it},$$

where $Area\_Reg\_Small_{it}$ is the area registered in county i in year t by the smallest farms (less than 1 mf), which obtain the title for free. $Area\_Reg\_Medium_{it}$ is the area registered by medium sized farms (those between 1 and 4 mf), and $Area\_Reg\_Large_{it}$, the area registered by large farms (those above 4 mf) in county i in year t. Controls area the same as the main specification. β_2, β_3 and β_4 are the elasticity of deforestation to area registered by small, medium, and large farms respectively.

Also, as can be seen from the large standard deviations in registered area in table 2, the distribution of area registered is very flat; the median county has 53.5 square kilometers registered as of 2012, but the 25th percentile county has 6.4 and the 75th percentile county has 259. This is also true when we look at the distributions among the different farm sizes: the 25th percentile county for small farm registrations had 0.36 while the 75th percentile had 46.5 square kilometers registered. We therefore discuss the coefficients in the tables in terms of a 100 percent change in the area registered, since the dispersion across counties in registrations is so large.

As may be expected based on the results from specifications (3) and (4) in table 3, in which we see that counties with the highest number of registrations had an increase in deforestation levels, table 4 shows that counties that had more land registered under the *Terra Legal* program had an increase in the cumulative area deforested. Overall, we find that a 100%

increase (i.e. a doubling) in area registered increases cumulative area deforested by 0.1% percent (significant at the 1% level). The impact is larger among counties in which there was land eligible for the rollout at 0.3 percent (significant at the 1% level) and largest for counties in which the largest area was registered at 0.4 percent.

The decomposition of the pooled effect by the size of registered farms shows that registration of the medium and large properties does appear to increase deforestation levels, displayed in table 4. When the effect of registrations is disaggregated by farm size, a 100 percent increase in the area registered by medium or large farms, leads to an increase of 0.3% and 0.2%, respectively in deforestation levels (significant at the 10% and 5% levels respectively). Limiting the sample to the counties eligible for rollout leads to an increase in the magnitude of the overall coefficient, as is to be expected since we expect no impact in counties in which there are no registrations. A 100% increase in the area registered in counties which have registrations leads to a 0.3% increase in total area deforested (significant at the 1% level). Finally, in the counties with the most registrations, the effect of registering more medium sized farms is larger: a 100 percent increase in the area registered by the medium sized properties leads to a 0.5% increase in the cumulative area deforested on average within those counties. The effect of registering small farms is negative, though insignificant in most specifications. We have controlled for county and year fixed effects which remove the average level of deforestation in a county and in the year, so these regressions show the level of deforestation *in comparison with* average levels of deforestation for the county and during that year.

While area deforested is important in that preserving the biomass in the Legal Amazon is important, it is also important to understand whether the *Terra Legal* reform accelerated or decelerated existing deforestation at the county level. The annual deforestation rate provides us

with a measure of changes in the rate of deforestation over time. Our deforestation rate variable is defined as the area deforested in year t divided by the area deforested in the county as of 2006.

Table 5 provides results for the deforestation rate based on the specification in equations (3) and (4), with y_{it} as the deforestation rate rather than the stock of deforestation. The effect of registrations from *Terra Legal* on the deforestation rate is negative overall, and statistically significant at the 5% level in the full sample, but positive (but not statistically significant) when the sample is limited to counties with the largest number of registrations (Column 5). Counties with more area registered by large farms experience the largest decrease in the deforestation rate. A 100 percent increase in the area registered by large farms decreases the rate of deforestation by approximately 6.5% for counties in the full sample, 5.4% in counties in which there were registrations, and 6.4% in counties in which there were the most registrations. As we saw from table 4, these counties with large farms also tended to have higher levels of deforestation. This suggests that the counties with greater areas of large-farm registrations are coming down from relatively high levels of deforestation in the earlier years. The decrease in the rate suggests that large farms may already have deforested quite a bit prior to registration and are slowing their deforestation following applying for the title.

Mechanisms

There are several ways that land tenure reform could impact deforestation. First, potential squatters may see land tenure reform giving current squatters ownership over the land that they have been farming as a signal that they will also receive a title to their land in the future. Therefore, increased registrations could mean increased deforestation in nearby counties. We test whether these spatial spillovers occurred. In addition, farmers with full ownership of their land are more likely to be able to invest in their farms: either because of the improved land

security—in that they know that their long term investments in the land will remain part of their property in the future—or through improved access to credit. We investigate the changes in management decisions that occur when larger percentages of the county have been registered: we analyze changes in crop choices and bovine management at the county level. Finally, increased property rights over the land may lead to increased credit availability. We test whether counties which had more registrations also had an expansion in credit through rural credit programs such as PRONAF.

Spatial Spillovers

One of the principal concerns with land tenure reforms is the potential for farmers without current valid claims under the program to expect similar future programs. In response to such programs, they may squat on parcels of land in nearby regions in the hopes of qualifying for future land reforms. It is also common for squatters to try to formalize their claim to land by clearing more land and demonstrating that their land is under cultivation. If the rollout of *Terra Legal* were to create incentives for nearby squatters to try to prove their management of large portions of land, we would expect to see increased deforestation in the counties neighboring those with large areas registered. In addition, there may be local agglomeration in development: increased titles in one county may mean that farmers are able to invest in their land. This may increase the returns to farmers in nearby counties or those who are working in downstream markets, causing others to expand their farms and increase deforestation. We look directly at whether more area registered in neighboring counties affects deforestation (spatial spillover effects).

To estimate spillover effects, we consider whether or not a county is adjacent to any county j that experiences peak registrations in a given year. Specifically, if county j has the greatest area registered in year t, and county i borders county j, then the variable $Neighbor_{it}$ equals 1 for that year and 0 otherwise. Defining the indicator variable in this manner allows us to continue to use the fixed effects estimation strategy. An alternate specification we consider is to lag the variable, i.e. $Neighbor_{it}$ equals 1 in year t if it borders county j, and county j has the greatest area registered in year $t-1$. We find no evidence of spillover effects in either case. Table 6 shows the results of both specifications.

There is no evidence of spillover effects increasing deforestation for either specification on any subset of the sample, although specification (1) suggests that there may be negative spillover effects–that is a 100% larger quantity of land registered in a neighboring county actually reduces deforestation in the own-county by 0.3%. *Terra Legal* registers only the land that was deforested before 2004, 5 years prior to the beginning of the program. Spillovers may have been minimized through maintaining strong restrictions on which farms were able to acquire titles—the rules left no space for farmers wanting more land to expand their holdings through the policy. The lack of spillovers resulting from expanding development following the registration program suggests that in the short term spatial spillovers are minimal, although more research remains to be done into the long term effects of the program and the impacts on local development and deforestation.

This conforms with the findings of Cisneros, Zhou, & Börner, (2015) who find that there were no spatial spillovers from the "blacklisting" of counties which heavily deforested in the Brazilian Amazon. While we may expect spillover effects across counties from these programs, the counties are large, and any spillovers may occur within county.

Crop Choice

Given the impact of the *Terra Legal* program on deforestation, it is important to investigate how farms change their production in response to access to improved land tenure. We may expect farms to invest in more long-term assets following land tenure reform. With more security in their land rights, agents can invest in their farms and cultivate more crops per acre, or to cultivate more lucrative permanent crops. In accordance with a basic model of investment and property rights such as Besley (1995), we find that counties with more registrations have an overall decrease in cultivation, an increase in permanent crop cultivation, and a decrease in temporary crop cultivation.

Table 7 presents the effect of registrations from *Terra Legal* as well as the effect by farm size. The differences-in-differences specification suggests that the rollout had a relatively large negative effect on total cultivation. When a county received the rollout, the total cultivation decreased by 10%. The decrease in cultivation was largest among counties that did not have high rates of registration: the coefficient on the overall post-rollout term is 14.4% (significant at the 1% level) while the interaction term shows that those with high levels of registration had a smaller decrease in cultivation of approximately 7% (significant at the 10% level).

We investigate the incremental impact of a larger area registered on land cultivated within the county in specifications (3), (5) and (7). Specification (3) shows that when the amount of land registered increases by 100% (doubles), total area cultivated decreases by 0.8% (statistically significant at the 10% level). This is matched by a similar decrease in temporary crop cultivation of 0.9% (significant at the 5% level) but the decrease in temporary crops is offset by an increase in permanent crops of 1 percent (significant at the 10% level).

Across the full sample in specification (4), we find that counties with more area registered by small and medium sized farms decrease total cultivation by 1.7 percent and 1.3 percent (significant at the 5 and 10% levels) respectively. However, counties with more area registered by large farms increase their overall cultivation by 1.9 percent. This seems to be led by an increase in cultivation of temporary crops among counties with more area registered by large farms (specification 6): counties with twice as much area registered by large farms increase temporary crop cultivation by 1.9% (significant at the 1% level). Conversely, counties with more area registered by small farms decrease their cultivation of temporary crops when registrations increase: a doubling of area registered by small farms leads to a 2.2% decrease in temporary crop cultivation. There are several potential reasons for this, which we are unable to distinguish in the data: temporary crops may be less profitable particularly at small scale, but allow squatters to maintain their claim on the land; removing the threat of expropriation may allow the farmer to pursue more profitable crop choices. Alternatively, farmers, particularly the small farmers who have only a provisional title to their land, may be more likely to follow the conservation requirements for maintaining 80% forest on their land when they know that they could lose the title if they fail to meet all *Terra Legal* requirements.

Livestock Management

Bovines are widely blamed for a large proportion of deforestation in the Amazon; ranchers burn large swaths of land for pasture to allow the to wander for grazing purposes, making the management of bovines highly land-intensive (Walker, Moran, & Anselin, 2000). Bovines may be particularly attractive to farmers without formal titles to their land as they can be moved if the land is expropriated. We test whether the number of bovines owned changes in a county when a larger area of the county is registered through the *Terra Legal* program.

Results are shown in table 8. We find that there is no overall impact of increased registrations through the program on bovine herds, but that there is a negative association with more area registered by small farms (although the effect is not significant at conventional levels). On the other hand, a larger area registered by medium sized farms in a county leads to an increase in bovines owned: a doubling of the area registered by medium sized farms leads to a 1.8 percent increase in the bovine herd in the county. This result is significant at the 5% level for both the full sample and the sample of counties with any registrations, but is not statistically significant when estimated only on the sample with the highest registrations.

Credit Use

Farmers without a legal title to their land may not be able to procure financing in order to invest in improvements to increase their level of productivity. Rural credit programs are in large part focused on small and medium sized farmers.[13] We estimate the effect of the *Terra Legal* program on the number of contracts issued for agricultural investment purposes in a county, as well as the overall financing amount (the value of the loans) in the county. We restrict the registrations in these specifications to only small and medium sized farms as the largest rural credit programs are targeted toward family farmers and small/medium farmers.

Table 9 presents the results of the effect of overall registrations on access to rural credit. The *Terra Legal* program increased access to rural credit for investment purposes, both on the intensive margin (amount of financing) by 2% for a doubling in area registered by small

[13]One key rural credit program in Brazil is The National Program for Strengthening Family Agriculture (PRONAF). PRONAF targets family farmers: those who use more family labor than wage-based labor in their production (Guanziroli and Basco, 2010).

and medium farms, and on the extensive (number of contracts) margin by 6% for a doubling in area registered by small and medium farms.

Robustness: Blacklisted counties

One potential issue with our estimates is the possibility of confounding the effect of *Terra Legal* with other policies that were offered in the Amazon at the same time. Brazil's Ministry of Environment blacklisted several counties in the period that *Terra Legal* took place because the counties were allowing too much deforestation. Agricultural producers in blacklisted counties who violated conservation requirements could not receive agricultural credit and faced other prohibitions related to their production until they registered a large proportion of the property and reduced deforestation (Duchelle et al., 2014). Forty-three of these blacklisted counties formed the pilot counties for the *Terra Legal* program. In order to check that blacklisting is not driving our main results, we estimate our main specification while controlling for the counties listed in the blacklist program (*Priority* counties), (Massoca, 2018). Priority counties take the value of 1 in the year that they are blacklisted and each year after that, until the year they exit the blacklist. We are interested in the impact of the *Terra Legal* program when the priority counties have been separately controlled for, and the effects by farm size when these counties have been controlled for. Estimates are shown in table 10.

Including controls for blacklisted counties does not have an important impact on the findings from our main regressions–results for overall registered area are consistent with our main results, although the magnitude of the coefficients does decrease somewhat. The most interesting differences arising from the priority controls are in the registrations of small and medium farms. Across all of the sample, when the registered area of small farms doubles, the

area deforested decreases by 0.2% (significant at the 10% level). This is consistent with the main results, but precision increases when controlling separately for priority counties. In priority counties there is a differential positive effect of 1.5%. That is, when the area of registration doubles for small farms in priority counties, the area deforested *increases* by 1.3% (significant at the 5% level). On the other hand, the effect for medium sized farms is the opposite: when the area registered by medium sized farms doubles, deforestation increases by 0.3% (significant at the 5% level). The effect for priority counties is large and in the other direction: there is a differential -1.1 percent effect when the priority counties have a doubling of registered area by medium sized farms, i.e. the doubling of medium sized farm area registered in priority counties reduces deforestation by 0.8%. While the effect is consistent for small farms in the sample of counties in which there have been registrations and the sample with the most registrations, standard errors increase for medium sized farms in priority counties in these smaller samples, leading to an effect that is not statistically significant. It is important to note that these regressions should not be taken as predictive of the impact of the blacklisting program. Blacklisted counties were different from non-blacklisted counties, and to have a comparable sample we would have to constrain the sample to those that were geographically close as pointed out in Assunção et al (2014). We expect this difference in comparability between the counties to be the main reason for the positive coefficient in our blacklisted results relative to that of Assunção et al (2014) and Cisneros et al (2015).[14] These regressions do demonstrate, however, that our main results are robust to controlling for the "blacklisting" program.

[14] Cisneros et al, 2015 used matching techniques to pair blacklisted counties with comparable counties that were not blacklisted.

Conclusion

We analyze the initial impact of an important land tenure reform, *Terra Legal*, in Brazil on land use, crop choice and bovine management. The rollout of the program had little impact on the total level of deforestation, but the impacts were very heterogeneous across counties. Counties below the 80th percentile of registrations saw a decrease in the total level of deforestation when they received the rollout, but counties with the highest levels of registrations had an increase in deforestation. More research is necessary to better understand why deforestation decreased in counties with less area registered while increasing in counties over the 80th percentile in registrations. It is important to highlight that our results are from the early stages of the program: we estimate the impact of increased registrations on deforestation, cultivation, bovines owned, and credit use. Over the longer term, as the registrations are converted into titles, these results may change.

We estimate that the registrations do not cause an increase in deforestation in neighboring counties—in fact, we find limited evidence of a reduction in deforestation in the same period in neighboring counties. This is important, because a primary concern about titling programs is that they may create dynamic incentives for other farmers to locate nearby. Spillovers could occur either because of agglomeration benefits of being near more productive farms, or because of the prospect of future political pressures to again enact a related reform, thereby providing these newer farmers with the opportunity to register and title their lands. However, it is important to note that we are estimating very short-term impacts of the program (within the same year or the year after). Spillover impacts may take much longer to develop, and this should be an avenue for future research to explore.

We disaggregate the effects by farm size, and show that increased area registered by the smallest farms results in decreased deforestation within a county on average, while increased area registered by medium and large farms leads to increased deforestation. The reform only provided small farmers with a provisional title which could be revoked if they failed to meet the requirements of the program, including the Forest Code requirement of conservation of 80% of the land. Therefore, in the short term as farmers wait for their titles, they may be more likely to abide by the requirements of the program and forgo deforestation. Counties with more large farms had an increase in the area deforested when more registrations were awarded, but the rates of deforestation actually declined in counties with more large farms that were registered. Understanding the dynamics of deforestation over time as farmers receive more and more formal claims to their land is important, as policies which appear to reduce deforestation in the short-run may look very different over a longer period.

We are estimating only the impacts of the earliest components of the program; the registrations were the first step to titling the land. Registrations are important for two reasons: first, few applications for land titles were rejected during the period, so registrations were a strong signal to farmers that they were likely to receive a title and the full rights to their land. Second, there are related policies, such as the "CAR" program aimed at registering properties for environmental enforcement purposes. Our findings are similar to the existing findings for that program: similar to our findings that the counties with more registrations by small farms have reduced deforestation, L'Roe, et al. (2016) find that smallholder properties do reduce deforestation practices in response to the availability of the registration program in the state of Para. Further research on the long-term impacts of the program is important in that it will help to elucidate the overall effects of land tenure reform on deforestation and land management.

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Appendix A: Parallel Trends Assumption

The key identifying assumption in our estimation strategy (difference-in-differences) is that treated counties (those with registrations early in the program) and control counties (those with registrations toward the end of our sample or which do not have registrations during our sample) would have had similar trajectories in terms of deforestation and cultivation in the absence of registration. We test this assumption by checking that the trend in the key outcome variables pre-rollout is similar. A parallel trend pre-rollout suggests that the counties would have seen similar changes in deforestation in the absence of the land reform and allows us to attribute the changes that occur after the Terra Legal reform to the intervention. To test this assumption, we plot the county level of cultivation and deforestation from 2000 until 2008, eight years before the implementation of the program. We divide the counties into counties with registrations primarily in 2009-2010 and those with registrations after 2010.

Results for deforestation are shown in table A1. The trends in deforestation prior to rollout are very similar for those with early versus late rollout periods (specifications (3), (4) and (5). The p value for the F stat testing the equality of the trends for early and late rollout is between 0.67 and 0.80 in all cases, meaning that we are unable to reject the null that the coefficients are equal. When we inspect the trends for the high registration areas relative to the rest of the counties, we find that the pre-trends in deforestation are less clean: the p-values for the F-test that the trends are equal are between 0.01 and 0.04 meaning that we are able to reject the null that they are equal with 5% certainty. This means that we should interpret the differences in differences estimates which include high registrations with care: given that the trend in deforestation for the high registration counties was already somewhat higher, the larger levels of deforestation for these counties post-rollout could be an artefact of the continuation of the pre-trend.

Results for pre-trends in agriculture are shown in tables A2 and A3. We find that the pre-trends in agriculture for counties with early registrations versus late registrations are not statistically significantly different (the p-values are between 0.47 and 0.73) across the three dependent variables of interest: area cultivated, permanent crops, and temporary crops. This suggests that the pre-trends in the agriculture variables for early and late registrations are similar, and so we can assume that absent the Terra Legal program, they would have remained on similar paths, and therefore the difference-in-differences specification should accurately estimate the impact of the Terra Legal program and the differential impact on counties as the program is rolled out.

In table A3 we find that the pre-trends in agriculture for counties with high registrations versus all other levels of registrations are also not statistically significantly different (the p-values are between 0.09 and 0.99) across the three dependent variables of interest: area cultivated, permanent crops, and temporary crops. This suggests that the pre-trends in the agriculture variables for high levels and moderate levels of registrations are similar, and so we can assume that absent the Terra Legal program, they would have remained on similar paths, and therefore the difference-in-differences specification should accurately estimate the impact of the Terra Legal program for high versus moderate level registration counties on these agriculture variables as the program is rolled out.

Appendix B: Data Appendix

We combined datasets made available by the various ministries of Brazil in order to perform our analysis at the county level.

Deforestation Data: PRODES

Our main outcome variable, cumulative deforestation, comes from the PRODES project, operated by the National Institute of Space Research (INPE) in conjunction with the Ministry of Environment (MMA) and the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA). While the project started in 1988 to monitor clear cut deforestation in the 760 counties of Brazil's Legal Amazon, the methodology was considerably improved in 2005 to include the images of the rainforest from a variety of satellites (Landsat 5, 7 and 8, CBERS-2, CBERS-2B, Resourcesat-1, and UK2-DMC), in part due to the Terra Amazon GIS platform developed by INPE for all forest monitoring purposes. [15] Images are captured every two weeks at a resolution of 20 – 30 meters.

The PRODES project uses a selection criterion to weed out images with considerable cloud coverage and other data errors before aggregating the images annually to come with the annual cumulative deforestation. PRODES makes available the spatial data[16] and various geographical boundaries for analysis. In addition, PRODES also includes the county data, where the annual area deforested within a county is already calculated using 2001 county boundaries. It is this dataset that we use.[17] The original spatial resolution of 60 square meters is converted to 120 square meters; the amount of pixels in a county were then converted to an area is square kilometers using the formula: $AreaKm^2 = (NrPixel * (1202))/1000000$.[18] Thus, all the variables in the dataset are in square kilometers, comprising of cumulative area deforested, the incremental area deforested in a given year, as well as forested area, non-forested area, cloud cover, hydrography and unobserved. Attributes of the county include its name, state, geocode, as well as longitude and latitude. The geocode uniquely identifies each county and allows us to merge it to the other datasets.

There are 760 observations per year in this dataset, one for each of the counties in the Legal Amazon. We include all 760 counties for our analysis for the years 2007-2012. The variables that we consider in this paper are the cumulative area deforested (Desmatado in the dataset), as well as the incremental area deforested (Incremento in the dataset). To calculate the variable "deforestation rate" we divide the incremental area deforested by the total area forested in the year 2007 (the first year of our sample). The unique geocode identifies each county and allows us to merge it to the other datasets.

[15] $http://www.obt.inpe.br/OBT/assuntos/programas/amazonia/prodes$
[16] available at: $http://www.dpi.inpe.br/prodesdigital/dadosn/mosaicos/$
[17] available at: $http://www.dpi.inpe.br/prodesdigital/prodesmunicipal.php$.
[18] $http://www.dpi.inpe.br/prodesdigital/municipios.html$

Farming data

Crop cultivation

We obtain our crop cultivation data from the online portal of The Institute for Applied Economic Research (IPEA) for the years 2007-2010 and then from the Brazilian Institute of Geography and Statistics (IBGE) for the years 2011 and 2012. IPEA consolidates the data provided by IBGE's County Agricultural Production (PAM) and makes it available in a form more conducive to analysis; for example, all the data is available in one CSV file, with the geocode that uniquely identifies each county always included. The data made available by IBGE requires more time to process, particularly when the geocode is excluded. In this case, we merge the geocode to the data using both the state and the name of county (without any spaces or special characters) to ensure a precise merge.

In the IPEA data,[19] we downloaded 3 files: the total area cultivated in hectares (Área colhida – total), area cultivated with temporary crops (Área colhida – lavoura temporária) and area cultivated with permanent crops (Área colhida – lavoura permanente). The portal allows one to download the data according to the geographic area of interest, in our case at the smallest level by county. To maintain uniformity, we convert the hectares to square kilometres by dividing the variables by 100.

The Municipal Agricultural Data by IBGE[20] is a large, comprehensive dataset, which includes 34 temporary crops and 39 permanent crops. For the years 2011 and 2012, we aggregate the area cultivated across all 34 temporary crops to arrive at the variable "Area cultivated by Temporary Crops" and across all 39 permanent crops to arrive at "Area cultivated by permanent crops." The sum of these two created variables is the total area cultivated in a county. As mentioned earlier, to merge this dataset back to the IPEA dataset and then eventually to the master data, we add the geocode to the data by merging on the state and name of the county.

Livestock Production

We obtain our Municipal Livestock Production data (PPM) from SIDRA (IBGE's Automatic Recovery System); like in IPEA, the data available in SIDRA is in a format better suited for analysis, with all the variables in one file with the geocode of each county included. In the PPM data, we use Table 73, which provides the information on the total number of livestock in each county.[21] The comprehensive list of animals consists of bovines, buffalos, horses, donkeys, mules, pigs, goats, sheep, roosters, chickens, quail and rabbits. The IBGE classifies bovines, buffalos, horses, donkeys and mules as "Large Animals;" pigs, goats and sheep as "Medium Animals," and roosters, chickens, quail and rabbits as "Small Animals." We downloaded the data for all relevant years (2007-2012) from this portal.

[19] available at: $http://www.ipeadata.gov.br/Default.aspx$
[20] available at: $https://ww2.ibge.gov.br/english/estatistica/economia/pam/2015/default.shtm$
[21] available at: $https://sidra.ibge.gov.br/tabela/73$

Credit for Investment

Our credit data is from the Annual Statistics of Rural Credit (Table 5.1.7), published in the Common Register of Rural Operations (RECOR) by the Brazilian Central Bank (BCB).[22] This comprehensive dataset includes various sources of rural credit, including funds from rural savings, the Brazilian Development Bank (BNDES), Constitutional Funds, and PRONAF (National Program to Strengthen Family Farming). Our data is aggregated at the county level, and provides information on the number of contracts and the value of the loans (in Reias). This is further broken down into the types of loans—Funding (Custeio), Investment (Investimento) and Commercial (Comercialização)—and whether the loan was for Agriculture or Livestock. We specifically consider the agricultural investment loans in our analysis for the years of our sample (2007-2012).

Control Variables

In all of our analysis, we include two control variables: Population Estimates and Non-agricultural GDP. We downloaded the annual population estimates by county for the years 2007-2012 from IPEA's portal; the name of the dataset is: "População residente - 1º de julho – estimativas."[23]

To create our other control variable, non-agricultural GDP, we downloaded the annual county gross domestic product dataset from SIDRA (Table 5938)[24] for the years 2007-2012. We downloaded the variables: total GDP in current prices (Produto Interno Bruto a preços correntes (Mil Reais)), as well as the gross value added by agricultural activities (Valor adicionado bruto a preços correntes da agropecuária (Mil Reais)). To obtain nonagricultural GDP, we subtracted the value added by agricultural activities from the total GDP.

Terra Legal

The registration data provided by Terra Legal consists of information on the date the application for registration was filed, the location of the property registered, its size in hectares as well as in módulos fiscais, the size of the county in módulos fiscais, and the status of the application as of July 2012. We exclude applications which have already been denied titling from our analysis, as well as those that require further approval from CDN, these properties being too close to military interests.

The application date allows us to determine the month and year of the registration. Using this, we collapse the data by county and year to create our explanatory variables of interest: the number of registrations in a county in a given year and the total area registered in the county. To determine when rollout occurred, we look at the maximum number of registrations in a county and the year in which that number coincides with the number registered. This is designated as the year treatment occurred. To account for self-registrations, we exclude those counties whose per

[22] Available at: *https://www.bcb.gov.br/estabilidadefinanceira/micrrural*
[23] available at: $http://www.ipeadata.gov.br/Default.aspx$.
[24] available at: $https://sidra.ibge.gov.br/tabela/5938$

capita number of registrations in the year 2009 (obtained by dividing the number of registrations in year 2009 by the population estimate) is below the 10th percentile. Finally, we sum up the number of registrations and the total area registered within a county over time so that all variables are stock variables. Thus, the total number of registrations in a county over the entire period of registrations is the same as the total number of registrations in year 2012. Further, using the size of the property registered in módulos fiscais(mfs), we are able to create the various size variables. The area registered by small farms in a county in a given year is calculated by only considering the properties registered with area below 1 modulo fiscal; similarly, the area registered by medium and large farms consider only the properties with area between 1 and 4 mfs and more than 4 mf, respectively. As with the other variables, these are aggregated over time so that they are stock variables as well.

Because the deforestation variable from PRODES is in square kilometers and 1 square kilometer is equal to 100 hectares, we divide all area registered variables by 100 to obtain the same unit (square kilometers) across our sample. Finally, to merge this dataset to the master data, we affix the unique geocode as detailed before based on the state and name of the county. Area variables are all inverse hyperbolic sine transformed in order to avoid over-weighting the tails before being included in our regressions.

Figures:

Figure 1: Brazilian Amazon as of 2010 overlaid with the sample of farms registered 2009-2012

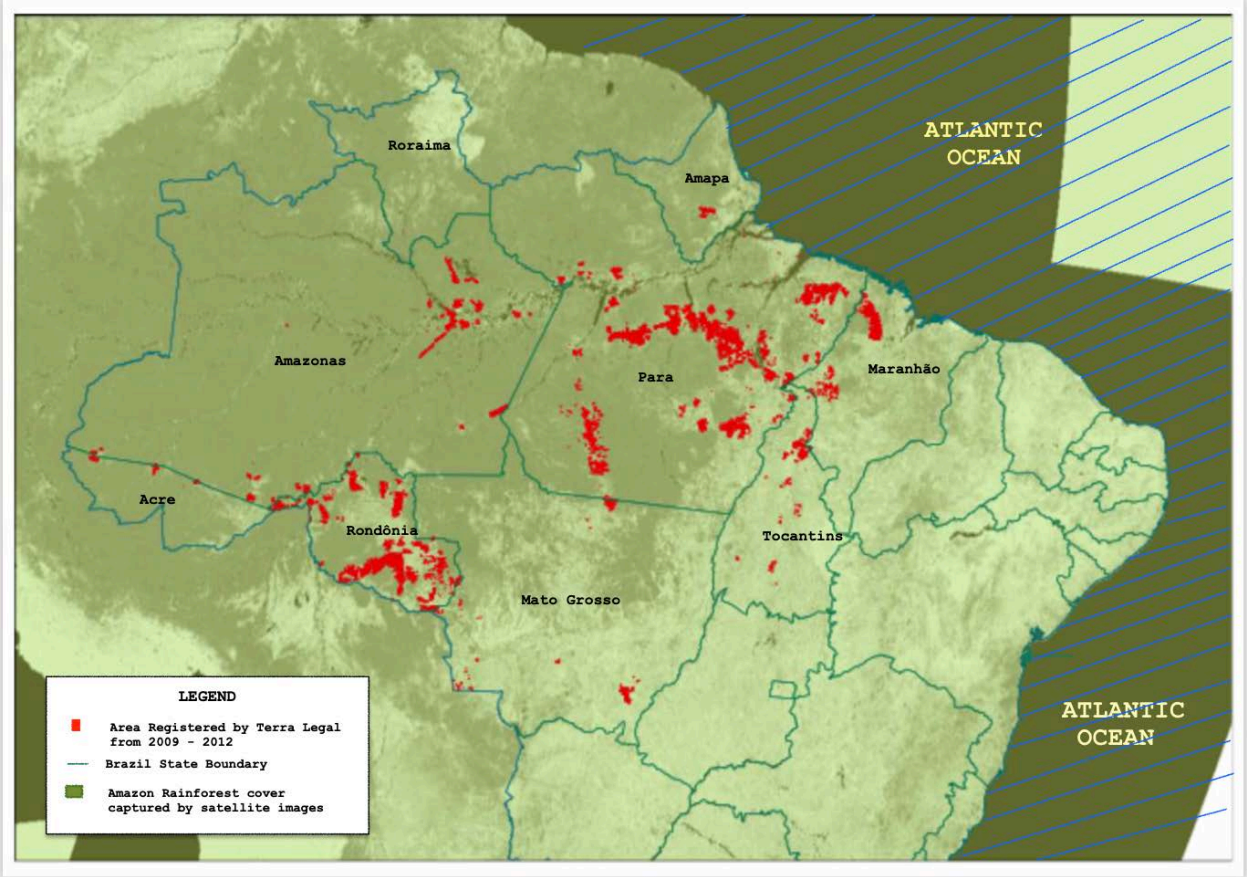

Table 1: *Terra Legal* - Program Statistics as of 2012

	Number of Registrations	Area Registered (in sqkm)	Number of Titles	Area Titled (in sqkm)
All	101,786	125,628	3,015	2,257
....by Small Farms	60,493	18,272	2,184	681
....by Medium Farms	31,382	40,968	710	79.5
....by Large Farms	9,911	66,387	121	534
Share of Registered Properties with Titles				3%
Share of Registered Area that is titled				1.8%
Average Number of Registrations (within a municipality)				245
Average Area Registered				305 sqkm
Average Size of Registered Property				1.24 sqkm (1.76 *mf*)
Average size of 1 *modulo fiscal (mf)*				0.8 sqkm

Table 2: Terra Legal Registrations, Deforestation, and Farm Production in the Legal Amazon

Variables	Full Sample		Post Rollout	
	(1)	(2)	(3)	(4)
Total Area Registered (in sqkm)	84.51	1.30	163.31	2.51
	(408.94)	(2.34)	(557.10)	(2.75)
.....by Small Farms	12.11	0.75	23.40	1.45
	(48.73)	(1.63)	(65.77)	(2.04)
.....by Medium Farms	27.14	0.97	52.45	1.88
	(132.82)	(1.91)	(181.02)	(2.31)
.....by Large Farms	44.86	0.91	86.68	1.76
	(262.48)	(1.98)	(359.90)	(2.46)
Area Deforested (in sqkm)	970.83	6.04	1,305.15	6.56
	(1,387.57)	(2.72)	(1,625.87)	(2.62)
Deforestation Rate (percent)	10.49	1.48	15.42	1.83
	(35.07)	(1.59)	(45.88)	(1.71)
Total Area Cultivated (in sqkm)	172.99	4.99	186.81	5.16
	(600.82)	(1.68)	(712.68)	(1.59)
.....with Permanent Crops	7.61	1.86	11.91	2.25
	(22.23)	(1.62)	(29.19)	(1.79)
.....with Temporary Crops	165.38	4.82	174.89	4.96
	(600.98)	(1.71)	(713.51)	(1.60)
Number of Bovine	98,810	11.12	129,165	11.72
	(147,460)	(1.71)	(168,001)	(1.41)
Investment Contracts	59	3.27	60	3.27
	(127)	(1.97)	(131)	(1.97)
Value of Investment Loans (in Reias)	1,748,297	11.45	1,802,701	11.56
	(7,058,797)	(4.91)	(7,364,074)	(4.95)
Population Estimates	30,295	10.21	32,151	10.31
	(100,115)	(1.14)	(104,769)	(1.25)
Non-agricultural GDP (in thousands of Reias)	344,424	11.90	142,120	12.11
	(2,129,846)	(1.30)	(887,983)	(1.39)
Observations	4,547	4,547	2,353	2,353

Note: Observations are at the county-year level. Standard deviations in parentheses. The sample consists of 760 counties in Brazilian Amazon and spans 2007 - 2012. Columns (1) and (3) are the untransformed variables, while Columns (2) and (4) are inverse hyperbolic sine transformations of the variables. Column (3-4) limit the sample to the years 2009-2012, when registrations take place. Registrations are broken down by size, defined as follows: "Small" Farms - less than 1 mf; "Medium" - between 1-4 mf; "Large" Farms - more than 4 mf.

Table 3: Effect of Terra Legal on Deforestation in the Amazon

	Cumulative Area Deforested					
	(1)	(2)	(3)	(4)	(5)	(6)
Post Rollout	-0.001	0.001	-0.008***	-0.005***	-0.007***	-0.003**
	(0.002)	(0.001)	(0.002)	(0.001)	(0.002)	(0.001)
Int Post Rollout × High Regs			0.014***	0.015***	0.010***	0.010***
			(0.003)	(0.003)	(0.003)	(0.003)
Int Country Area × Year					0.0002***	0.0003***
					(0.00004)	(0.00004)
Constant	5.63***	6.28***	5.67***	6.36***	2.84***	2.28***
	(0.12)	(0.14)	(0.11)	(0.13)	(0.50)	(0.62)
Observations	4,547	2,353	4,547	2,353	4,547	2,353
R-squared	0.293	0.314	0.302	0.336	0.342	0.418
Number of counties	760	393	760	393	760	393
County and Year FE	YES	YES	YES	YES	YES	YES
Received Registrations		YES		YES		YES

*** p<0.01, ** p<0.05, * p<0.1

Note: Robust standard errors clustered at the county level in parenthesis. Sample consists of 760 counties in the Brazilian Legal Amazon from 2007-2012. All variables except binary are inverse-hyberbolic-sine transformed. 'Post Rollout' is 1 during the year rollout occurs and remains 1 thereafter. 'Int Post Rollout × High Regs' is the interaction of the dummy 'High Reg'—1 for counties with area registered above the 80th percentile—and 'Post-Rollout.' 'Int County Area × Year' is the interaction of the area of a county (in thousands of square kilometers) and year. Columns (1,3,5) consider the entire sample, while columns (2,4,6) restrict the sample only to the counties that received any registrations. We also control for annual nonagricultural GDP and population in a county, in addition to county fixed effects and year fixed effects, in all regressions. Registrations data provided by *Terra Legal*; deforestation data from the PRODES project.

Table 4: Effect of Registrations on Deforestation Levels in the Amazon

	Cumulative Area Deforested					
	(1)	(2)	(3)	(4)	(5)	(6)
Total Area Registered	0.001**		0.003***		0.004***	
	(0.000)		(0.000)		(0.001)	
...by Small Farms		-0.002		-0.002		-0.004*
		(0.001)		(0.001)		(0.002)
...by Medium Farms		0.003*		0.003**		0.005**
		(0.001)		(0.001)		(0.002)
...by Large Farms		0.002**		0.002**		0.002**
		(0.001)		(0.001)		(0.001)
Constant	5.577***	5.122***	6.298***	6.310***	7.046***	7.044***
	(0.115)	(0.123)	(0.128)	(0.125)	(0.236)	(0.228)
Observations	4,547	4,547	2,353	2,353	1,111	1,111
R-squared	0.296	0.262	0.340	0.351	0.480	0.494
Number of counties	760	760	393	393	186	186
County and year FE	YES	YES	YES	YES	YES	YES
Received registrations			YES	YES		
Highly Registered					YES	YES

*** p<0.01, ** p<0.05, * p<0.1

Note: Robust standard errors clustered at the county level in parenthesis. Sample consists of 760 counties in the Brazilian Legal Amazon from 2007-2012. All variables are inverse-hyberbolic-sine transformed. In addition, 'Area' variables are stock variables. Columns (1, 3, 5) estimate the effect of total registered area, while columns (2, 4, 6) decompose the effect by size. Registered properties sized less than 1 *mf* are "Small" farms, between 1-4 *mf*—"Medium", and greater than 4 *mf*— "Large". Columns (1,2) consider the entire sample, while columns (3,4) restrict the sample only to the counties that received registrations, and columns (5,6) restrict the sample to the counties with registered area above the 80th percentile. We control for annual nonagricultural GDP and population in a county, in addition to county fixed effects and year fixed effects, in all regressions. Registrations data provided by *Terra Legal*; deforestation data from the PRODES project.

Table 5: Effect of Registrations on the Deforestation Rate in the Amazon

	Rate of Deforestation					
	(1)	(2)	(3)	(4)	(5)	(6)
Total Area Registered	-0.037***		-0.017		0.021	
	(0.008)		(0.011)		(0.018)	
...by Small Farms		0.001		-0.005		-0.016
		(0.028)		(0.028)		(0.037)
...by Medium Farms		-0.016		0.039		0.010**
		(0.030)		(0.030)		(0.042)
...by Large Farms		-0.065***		-0.054***		-0.064**
		(0.018)		(0.017)		(0.026)
Constant	1.133	8.508***	2.914	2.229	1.835	2.404
	(1.650)	(1.464)	(2.215)	(2.273)	(3.775)	(3.859)
Observations	4,547	4,547	2,353	2,353	1,111	1,111
R-squared	0.169	0.108	0.215	0.220	0.246	0.256
Number of Counties	760	760	393	393	186	186
County and Year FE	YES	YES	YES	YES	YES	YES
Receive Registrations			YES	YES		
Highly Registered					YES	YES

*** p<0.01, ** p<0.05, * p<0.1

Note: Robust standard errors clustered at the county level in parenthesis. Sample consists of 760 counties in the Brazilian Legal Amazon from 2007-2012. All variables are inverse-hyberbolic-sine transformed. 'Deforestation rate' is the annual change in total area deforested. Columns (1, 3, 5) estimate the effect of total registered area, while (2, 4, 6) decompose the effect by size. Registered properties sized less than 1 *mf* are "Small" farms, between 1-4 *mf*—"Medium", and greater than 4 *mf*— "Large". Columns (1,2) consider the entire sample, while columns (3,4) restrict the sample only to the counties that received any registrations, and columns (5,6) restrict the sample further to the counties with the highest registrations (in the 80th percentile). We also control for annual nonagricultural GDP and population in a county, in addition to county fixed effects and year fixed effects, in all regressions. Registrations data provided by *Terra Legal*; deforestation data from the PRODES project.

Table 6: Spillover Effect of Registrations on Cumulative Deforestation in the Amazon

	Cumulative Area Deforested					
	(1)	(2)	(3)	(4)	(5)	(6)
Total Area Registered	0.001**	0.003***	0.004***	0.001**	0.003***	0.004***
	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)
Neighboring county						
...Registered in year t	-0.003***	-0.001	-0.001			
	(0.001)	(0.001)	(0.001)			
...Registered in year $t-1$				-0.001	0.001	0.000
				(0.001)	(0.002)	(0.002)
Constant	5.567***	6.300***	7.040***	5.561***	5.938***	7.046***
	(0.114)	(0.129)	(0.236)	(0.114)	(0.545)	(0.237)
Observations	4,547	2,353	1,111	4,547	2,353	1,111
R-squared	0.298	0.341	0.480	0.297	0.340	0.480
Number of counties	760	760	393	393	186	186
County and Year FE	YES	YES	YES	YES	YES	YES
Received Registrations		YES			YES	
Highly Registered			YES			YES

*** p<0.01, ** p<0.05, * p<0.1

Note: Robust standard errors clustered at the county level in parenthesis. Sample consists of 760 counties in the Brazilian Amazon from 2007-2012. All variables are inverse hyberbolic sine transformed. In addition, 'Total Area Registered' is a stock variable. 'Neighboring County Registered in year t' is an indicator variable that equals 1 if any neighboring county experiences peak registrations in year t, while 'Neighboring County Registered in year $t-1$ equals 1 if a neighboring county experiences peak registrations in year $t-1$. Columns (1,4) estimate the model on the full sample, while columns (2,5) restrict the sample only to the counties that have any registrations, and columns (3,6) restrict the sample to the counties that are in the 80th percentile of registered area. We also control for annual nonagricultural GDP and population in a county, in addition to county fixed effects and year fixed effects, in all regressions. Registrations data provided by *Terra Legal*; deforestation data from the PRODES project.

Table 7: The Effect of Area Registered on Crop Cultivation

	Area Cultivated							
	Total Cultivated				Temporary Crops		Permanent Crops	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post Rollout	-0.109***	-0.144***						
	(0.0392)	(0.0447)						
Int Post Rollout × High Regs		0.074*						
		(0.043)						
Total Area Registered			-0.008*		-0.009**		0.010*	
			(0.004)		(0.004)		(0.005)	
...by Small Farms				-0.017**		-0.022***		-0.004
				(0.007)		(0.008)		(0.013)
...by Medium Farms				-0.013*		-0.010		0.021*
				(0.008)		(0.009)		(0.012)
...by Large Farms				0.019***		0.019***		-0.005
				(0.005)		(0.005)		(0.010)
Constant	6.107***	6.380***	5.111**	5.023**	3.942*	3.803	7.172***	7.173***
	(1.687)	(1.693)	(2.213)	(2.237)	(2.298)	(2.320)	(2.515)	(2.527)
Observations	4,542	4,542	4,547	4,547	4,547	4,547	4,547	4,547
R-squared	0.014	0.015	0.012	0.013	0.017	0.021	0.036	0.038
Number of counties	760	760	760	760	760	760	760	760
County and Year FE	YES	YES	YES	YES	YES	YES	YES	YES

*** p<0.01, ** p<0.05, * p<0.1

Note: Robust standard errors clustered at the county level in parentheses. Sample consists of 760 counties in the Brazilian Amazon monitored by PRODES from 2007-2012. All variables except binary ones are inverse-hyberbolic-sine transformed. 'Post Rollout' is 1 during the year rollout occurs and remains 1 thereafter. 'In Post Rollout × High Regs' is the interaction of the dummy 'High Reg'—1 for counties with area registered above the 80th percentile—and 'Post-Rollout.' Columns (1,2) report the difference in difference estimates of counties who have gone through the registration program, and in (2) counties which have had high registrations in the registration program on total area cultivated. Columns (3,4) show the effect (in decimal terms) of an additional 1% of land registered through the program on the area cultivated in the county. The impact of registrations on area cultivated is then divided into its two subsamples: area cultivated with temporary crops (Column 5,6) and permanent crops (7,8). We control for annual nonagricultural GDP and population in a county, in addition to county fixed effects and year fixed effects, in all regressions. Registrations data provided by *Terra Legal*; crop data from IBGE.

Table 8: The Effect of Area Registered on Number of Bovines

	Number of Bovines					
	(1)	(2)	(3)	(4)	(5)	(6)
Total Area Registered	0.00295		0.00343		0.00144	
	(0.00341)		(0.00398)		(0.00669)	
...by Small Farms		-0.0134		-0.0144		-0.0169
		(0.0112)		(0.0113)		(0.0155)
...by Medium Farms		0.0177**		0.0181**		0.0193
		(0.00896)		(0.00906)		(0.0132)
...by Large Farms		-0.00374		-0.00342		-0.00331
		(0.00516)		(0.00529)		(0.00871)
Constant	9.249***	9.239***	8.952***	8.994***	12.41***	12.36***
	(1.556)	(1.566)	(2.208)	(2.250)	(1.552)	(1.562)
Observations	4,547	4,547	2,353	2,353	1,111	1,111
R-squared	0.048	0.049	0.075	0.078	0.075	0.078
Number of counties	760	760	393	393	186	186
County and Year FE	YES	YES	YES	YES	YES	YES
Receive Registrations			YES	YES		
Highly Registered					YES	YES

*** p<0.01, ** p<0.05, * p<0.1

Note: Robust standard errors clustered at the county level in parenthesis. Sample consists of 760 counties in the Brazilian Legal Amazon from 2007-2012. All variables are inverse-hyberbolic-sine transformed. Columns (1, 3, 5) estimate the effect of total registered area, while (2, 4, 6) decompose the effect by size. Registered properties sized less than 1 *mf* are "Small" farms, between 1-4 *mf*—"Medium", and greater than 4 *mf*— "Large". Columns (1,2) consider the entire sample, while columns (3,4) restrict the sample only to the counties that received any registrations, and columns (5,6) restrict the sample further to the counties with the highest registrations (in the 80th percentile). We also control for annual nonagricultural GDP and population in a county, in addition to county fixed effects and year fixed effects, in all regressions. Registrations data provided by *Terra Legal*; bovine data from the SIDRA.

Table 9: Effect of Area Registered on Procurement of PRONAF Credit for Investment

VARIABLES	(1) Number of Contracts	(2) Value of Loans
Area Registered by	0.0212**	0.0622**
Small/Medium Farms	(0.0104)	(0.0270)
Constant	0.0828	-9.901
	(4.674)	(11.26)
Observations	4,341	4,341
R-squared	0.036	0.040
Number of counties	753	753
County and Year FE	YES	YES

*** p<0.01, ** p<0.05, * p<0.1

Note: Robust standard errors clustered at the county level in parenthesis. Sample consists of 753 counties in the Brazilian Legal Amazon from 2007-2012. All variables are inverse-hyberbolic-sine transformed. We specifically consider loans obtained through PRONAF for investment purposes. Column 1 is the effect on the number of contracts and column 2 on the value of the loans. 'Area Registered by Small/Medium Farms' is a stock variable of area registered in counties by properties sized less than 4 *mf*. We exclude area registered by properties with area above 4 *mf* because they would be ineligible for the loan. We also control for annual nonagricultural GDP and population in a county, in addition to county fixed effects and year fixed effects, in all regressions.

Table 10: Testing Robustness for Blacklisted County Controls

	Area Deforested					
	(1)	(2)	(3)	(4)	(5)	(6)
Total Area Registered	0.000		0.001***		0.002***	
	(0.000)		(0.000)		(0.001)	
...by Small Farms		-0.002*		-0.002*		-0.005**
		(0.001)		(0.001)		(0.002)
...by Medium Farms		0.003**		0.003**		0.005**
		(0.001)		(0.001)		(0.002)
...by Large Farms		0.001		0.001		0.001
		(0.001)		(0.001)		(0.001)
Priority County	0.030***	0.036***	0.023***	0.024***	0.021***	0.020**
	(0.008)	(0.008)	(0.006)	(0.006)	(0.007)	(0.008)
Int Priority × Reg Area	0.003***		0.004***		0.003***	
	(0.001)		(0.001)		(0.001)	
Int Priority × Reg Small		0.015**		0.014*		0.016
		(0.007)		(0.008)		(0.011)
Int Priority × Reg Medium		-0.011*		-0.008		-0.011
		(0.007)		(0.007)		(0.014)
Int Priority × Reg Large		0.002		0.001		0.002
		(0.002)		(0.003)		(0.007)
Constant	5.594***	5.130***	6.315***	6.319***	7.095***	7.089***
	(0.113)	(0.122)	(0.123)	(0.121)	(0.229)	(0.225)
Observations	4,547	4,547	2,353	2,353	1,111	1,111
R-squared	0.319	0.285	0.379	0.389	0.532	0.549
Number of counties	760	760	393	393	186	186
County and Year FE	YES	YES	YES	YES	YES	YES
Receive Registrations			YES	YES		
Highly Registered					YES	YES

*** p<0.01, ** p<0.05, * p<0.1

Note: Robust standard errors clustered at the county level in parenthesis. Sample consists of 760 counties in the Brazilian Legal Amazon from 2007-2012. All variables are inverse-hyberbolic-sine transformed. 'Priority County' is 1 during the year a county becomes blacklisted and remains so until the year it is removed. 'Int Priority × Registered area' is the interaction of the priority county indicator with the IHS transformation of total area registered. Columns (1, 3, 5) estimate the effect of total registered area after controlling for priority counties, while (2, 4, 6) decompose the effect by size. Registered properties sized less than 1 *mf* are "Small" farms, between 1-4 *mf*—"Medium", and greater than 4 *mf*— "Large". Columns (1,2) consider the entire sample, while columns (3,4) restrict the sample only to the counties that received any registrations, and columns (5,6) restrict the sample further to the counties with the highest registrations (in the 80th percentile). We also control for annual nonagricultural GDP and population in a county, in addition to county fixed effects and year fixed effects, in all regressions.

Table A1: Testing for Parallel Trends: Cumulative Area Deforested

	Cumulative Area Deforested				
	(1)	(2)	(3)	(4)	(5)
Int Low Reg × year	0.007***	0.004			
	(0.002)	(0.003)			
Int High Reg × year	0.011***	0.011***			
	(0.002)	(0.002)			
Int Early Rollout × year			0.002	0.005***	0.013***
			(0.002)	(0.002)	(0.003)
Int Late Rollout × year			0.003	0.007*	0.014**
			(0.004)	(0.004)	(0.006)
Constant	-13.85***	-11.96***	-1.270	-9.421**	-21.33***
	(3.628)	(4.211)	(1.395)	(3.679)	(5.075)
Observations	1,518	784	1,518	784	370
R-squared	0.232	0.288	0.216	0.271	0.413
Number of Counties	760	393	759	392	185
F-stat	4.04	7.5	0.18	0.13	0.06
Prob > F	0.04	0.007	0.67	0.72	0.80
County FE	YES	YES	YES	YES	YES
Receives Registrations		YES		YES	
Highly Registered					YES

*** p<0.01, ** p<0.05, * p<0.1

Note: Robust standard errors clustered at the county level in parenthesis. Sample consists of 760 counties in the Brazilian Legal Amazon from 2007-2012. Columns (1,2) tests for the parallel trend in low vs highly registered areas, and (2) further restricts the sample to those counties that have any registrations. 'Int Low Reg × year' is the interaction of year with the indication variable 'Low Reg' which is 1 for counties below the 80th percentile of area registered. 'Int High Reg × year' is the interaction of year with highly registered counties with area registered above the 80th percentile. Columns (3-5) test for trends between early vs late rollout, with (4) limiting the sample to those with any registrations and (5) to those with the highest registrations (in the 80th percentile). 'Int Early Rollout × year' is the interaction of year with the indication variable 'Early Rollout,' which is 1 if the county received rollout in 2009 or 2010. 'Int Late Rollout × year' is the interaction of year with counties that received rollout after 2010. We also control for annual nonagricultural GDP and population in a county, in addition to county fixed effects, in all regressions.

Table A2: Testing for Parallel Trends in Early vs Late Rollout: Area Cultivated

	Area Cultivated					
	Total	Temporary	Permanent	Total	Temporary	Permanent
	(1)	(2)	(3)	(4)	(5)	(6)
Int Early Rollout × year	-0.033	-0.039	0.050	-0.099	-0.091	0.005
	(0.049)	(0.049)	(0.056)	(0.068)	(0.069)	(0.080)
Int Late Rollout × year	-0.088	-0.096	-0.026	-0.141	-0.139	-0.065
	(0.107)	(0.108)	(0.095)	(0.109)	(0.111)	(0.106)
Constant	72.88*	79.85*	-42.94	219.2*	212.7*	-0.384
	(42.26)	(42.73)	(53.62)	(115.5)	(118.0)	(154.3)
Observations	1,518	1,518	1,518	784	784	784
R-squared	0.006	0.007	0.014	0.007	0.008	0.012
Number of Counties	760	760	760	393	393	393
F-stat	0.20	0.22	0.52	0.12	0.15	0.46
Prob > F	0.65	0.63	0.47	0.73	0.69	0.50
County FE	YES	YES	YES	YES	YES	YES
Receives Registrations				YES	YES	YES

*** p<0.01, ** p<0.05, * p<0.1

Note: Robust standard errors clustered at the county level in parenthesis. Sample consists of 760 counties in the Brazilian Legal Amazon from 2007-2012. 'Int Early Rollout × year' is the interaction of year with the indication variable 'Early Rollout,' which is 1 if the county received rollout in 2009 or 2010. 'Int Late Rollout × year' is the interaction of year with counties that received rollout after 2010. Columns (1-3) tests for the parallel trend in the full sample for total area cultivated (1), area cultivated by temporary crops (2) and area cultivated by permanent crops (3). Columns (4-6) restrict the sample to those counties that have any registrations. We also control for annual nonagricultural GDP and population in a county, in addition to county fixed effects, in all regressions.

Table A3: Testing for Parallel Trends in High vs Low Regs: Area Cultivated

	Total	Temporary	Permanent	Total	Temporary	Permanent
	(1)	(2)	(3)	(4)	(5)	(6)
Int Low Reg × year	-0.112**	-0.102**	-0.086	-0.145*	-0.139	-0.042
	(0.047)	(0.048)	(0.080)	(0.088)	(0.089)	(0.101)
Int High Reg × year	-0.120	-0.137*	0.020	-0.146	-0.164*	0.038
	(0.077)	(0.077)	(0.083)	(0.090)	(0.090)	(0.083)
Constant	230.6***	224.8**	94.45	275.0**	288.7**	-13.55
	(86.58)	(87.58)	(139.5)	(139.9)	(141.6)	(162.8)
Observations	1,518	1,518	1,518	784	784	784
R-squared	0.010	0.010	0.016	0.009	0.010	0.013
Number of Counties	760	760	760	393	393	393
F-stat	0.02	0.28	2.84	0.00	0.09	0.97
Prob > F	0.90	0.59	0.09	0.99	0.77	0.32
County FE	YES	YES	YES	YES	YES	YES
Receives Registrations				YES	YES	YES

*** p<0.01, ** p<0.05, * p<0.1

Note: Robust standard errors clustered at the county level in parenthesis. Sample consists of 760 counties in the Brazilian Legal Amazon from 2007-2012. 'Int Low Reg × year' is the interaction of year with the indication variable 'Low Reg' which is 1 for counties below the 80th percentile of area registered. 'Int High Reg × year' is the interaction of year with highly registered counties with area registered above the 80th percentile. Columns (1-3) tests for the parallel trend in the full sample for total area cultivated (1), area cultivated by temporary crops (2) and area cultivated by permanent crops (3). Columns (4-6) restrict the sample to those counties that have any registrations. We also control for annual nonagricultural GDP and population in a county, in addition to county fixed effects, in all regressions.