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RURAL SETTLEMENTS AND DEFORESTATION IN THE AMAZON

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Rural Settlements and Deforestation in the Amazon

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Abstract

Since the 1970s, the creation of Rural Settlements with state assistance has been one of several strategies by the Federal Government of Brazil to colonize remote regions with low population. Even though the area dedicated to these settlements remained relatively stable for decades, between 2002 and 2014 Rural Settlements in the Amazon region jumped from 220 thousand square kilometers to 376 thousand square kilometers, an increase of 71%. This paper shows that most part of this increase was located in remote areas with low population and in municipalities with high forest coverage. We also use a fixed-effect model to calculate the impact of the Rural Settlements created between 2002 and 2014 on deforestation. We find that the impact is positive and statistically significant. Rural Settlements are responsible for 30% of total deforestation in the Amazon Biome. We also find that the effect is heterogeneous, and depends on the type of Rural Settlement, with Rural Settlements types located in remote areas being responsible for most part of the impact of Rural Settlements on deforestation.

Keywords: deforestation, Amazon, property size, conservation policy
JEL codes: Q23, Q24, Q28

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1. Introduction

Although in many countries "settlement" is a term used to designate a group of people who establish themselves in an area to live and produce, Rural Settlement in Brazil usually means some portion of land occupied by farmers who receive that land as part of an agrarian reform effort. This land usually comes from a previous owner who had unproductive land or from some public lands that do not have any private owner. The rural settlers who benefit from the agrarian reform usually also receive state assistance to help with their production. This assistance is usually in the form of subsidized financing or technical assistance from the government.

Historically, the literature has presented an important link between Amazon Rural Settlements and deforestation. The creation of Rural Settlements, the literature argues, could increase deforestation for many reasons. First, settlements could increase population density in the areas where they are located. Second, environmental law in the Amazon requires that at least 80% of each rural household's land be preserved with native vegetation. It is usually more difficult for small-scale farmers to keep this percentage of their land intact as native forest and still produce for the market. When the tract of land is larger, it is more likely that farmers can meet this requirement. At the same time, Rural Settlements and agrarian reform in Brazil are usually seen as one of the ways to reduce poverty and inequality, which raises the dichotomy of social development versus environmental conservation (Caviglia-Harris and Harris, 2011; Turner, 2007).

The aim of this paper is to investigate whether state assisted Rural Settlements contributed to an increase in deforestation in the Amazon between 2002 and 2014. Conservation policies targeted large deforestation polygons and, depending on the state, had an impact on large properties; however, there was also a huge increase of settlement project areas in the Amazon Biome, which jumped from 220 thousand square kilometres in 2002 to 376 thousand square kilometres in 2014. These settlements are usually large tracts of land that have been divided into small plots that are distributed to small-scale farmers with state assistance. These plots are used for crop production, cattle beef activities, and milk production.

We intend to identify how these projects expanded in the Amazon region from 2002 to 2014 and whether they were a barrier to the effectiveness of conservation policies. Have the new settlements created a force pushing to the deforestation direction, and thus trending away from conservation? Was this force quantitatively important? This paper intends to address these questions.

From the 1960s to the 1980s, small-scale farmers with state assistance deforested large areas of tropical forest in Southeast Asia and Latin America, including the Amazon. As globalization and urbanization increased during the 1980s, the agents of deforestation changed in Brazil and Indonesia. Well-capitalized ranchers, farmers, and loggers, producing for consumers in distant markets, became more prominent in these places and this globalization weakened the historically strong relationship between local population growth and forest cover (Rudel et al., 2009).

This change was reinforced by Brazilian Federal Government policies. Incentives were created to develop the enterprise agricultural sector, such as: exemptions of agricultural income from income taxation; rules of public land allocation based on claims that are more secure when the land is cleared; a progressive land tax that contains provisions that encourage the conversion of forest to crop land or pasture; a tax credit scheme aimed toward corporate livestock ranches that subsidizes inefficient ranches established on cleared forest land; and subsidized credit available for SUDAM-approved ranches (Binswanger, 1991; Fearnside, 2005).

The result of these changes and policies was that large landholders became responsible for most of Brazilian Amazon deforestation. Pacheco (2012) shows that, in absolute terms, areas dominated by large and medium landowners clear a higher amount of Amazon forest than areas dominated by smallholders. However, smallholders are able to keep a smaller share of their farm as native forest, since they have less land dedicated to agricultural production. Godar et al. (2014) show that while areas dominated by large landowners were responsible for 47% of accumulated deforestation in the Amazon, areas dominated by smallholders were responsible for only 13.9% of Amazon area deforested.

Property-level analyses are confined to small geographical areas, but also confirm these results (Walker et al., 2000; D'Antona et al., 2006; Aldrich et al., 2006; Michalski et al., 2010; Godar et al., 2012). Using data from four different municipalities, Walker et al. (2000) show that the relative participation of large cattle ranching producers depends on the type of activity predominant in the municipality. In areas designed for Rural Settlements, with high in-migration of small-scale producers, the relative participation of large cattle ranchers on deforestation is smaller; however, in areas designed for large ranching initiatives originally undertaken by SUDAM, the relative participation of large cattle ranchers could reach as much as 100%.

These questions became even more important with the introduction of a new set of conservation policies that targeted large deforestation polygons. Amazon deforestation rates escalated in the early 2000s, but after peaking at over 27 thousand square kilometres in 2004, they decreased sharply to about 5 thousand square kilometres in 2014 (INPE (2015)). The strengthening of Amazon monitoring and law enforcement efforts starting in 2004 was one of the main drivers of this deforestation slowdown (Assunção et al., 2013a, 2015a).

Central to these efforts was the implementation of the remote sensing-based Real-

Time System for Detection of Deforestation (DETER). Yet, the satellite used in DETER is only capable of detecting forest clearings where the total contiguous area exceeds 0.25 square kilometres. Because DETER is used to target law enforcement activities in the Amazon, clearings smaller than this threshold are less likely to be caught by law enforcers. The recent change in deforestation composition suggests that the dynamics of Amazon forest clearings may have changed in response to DETER's technical shortcoming.

With this caveat in the monitoring system, Assunção et al. (2015b) show that relative participation of small-scale farmers on total deforestation increased in Pará, the state with higher deforestation rates in the Amazon. Godar et al. (2014) also show that command and control policies implemented in the 2000s reduce deforestation by 81% in areas dominated by large landowners and by only 73% in areas dominated by smallholders. Therefore, the importance of settlements to this change in the small-scale agriculture deforestation become an important research issue.

Many Rural Settlements are created after invasions of unproductive land by rural organizations, such as the Landless Movement (Movimento dos Sem-Terra), which suggests the impact of the judicial insecurity of property rights. In this case, the increase of Rural Settlements could affect deforestation through this judicial insecurity (Araujo et al., 2009; de Janvry et al., 2015).

There is also a literature that links population density and roads to deforestation (Caviglia-Harris and Harris, 2011; Imbernon, 1997; Pfaff et al., 2007; Chomitz and Thomas, 2003). As many of the settlements projects affect the number of people living in these places and also the infrastructure needed to transport agricultural production, the settlements could be causing an increase in deforestation.

Our work also speaks to the literature on the drivers of deforestation. The impact of socioeconomic and geographic factors on deforestation has long been documented. Population, road density, climate, rural credit, and agricultural commodity prices, among others, have been shown to be important drivers of forest clearing activity (Cropper and Griffiths, 1994; Panayotou and Sungsuwan, 1994; Andersen, 1996; Barbier and Burgess, 1996; Chomitz and Gray, 1996; Cropper et al., 1997; Angelsen and Kaimowitz, 1999; Pfaff, 1999; Barbier and Burgess, 2001; Ferraz, 2001; Pfaff et al., 2007; Chomitz and Thomas, 2003; Araujo et al., 2009). More recent works have looked specifically at the 2000s Amazon slowdown, aiming at disentangling the leading causes of the decrease in deforestation (Hargrave and Kis-Katos, 2013; Assunção et al., 2013b,a; Assunção and Rocha, 2014; Assunção et al., 2015a,b).

We contribute to this literature by showing the impact of policies that could create incentives for deforestation, such as the creation of new settlements, and partially offset the impact of conservation policies. We also investigate the heterogeneous effects of Rural

Settlements on deforestation. First, we separate the impact of Rural Settlements, by type of settlement. Second, we investigate heterogeneous effects depending on the location of the settlement.

We use a georreferenced dataset publicized by the National Institute of Colonization and Agrarian Reform (INCRA) with the area occupied by Rural Settlements, by settlement type. We merge this dataset with municipality deforestation data obtained from processed satellite imagery that was made publicly available by the National Institute for Space Research (INPE).

We then use a difference-in-difference approach to calculate the impact of the share of municipality area covered by settlements on deforestation. We control for municipality and time-fixed effects, and other variables which could affect deforestation.

We show that the share of municipality covered by settlements positively affects deforestation. Quantitatively, using our preferred specification, Rural Settlements are responsible for 30% of 2014's total deforestation in the Amazon Biome.

To try to understand the mechanism of the effect of Rural Settlements on deforestation we calculate some heterogeneous effects. There are four types of Rural Settlements. The Colonization Rural Settlements (the old ones, with no variation in our sample period), the conventional Rural Settlements (the more common, managed by INCRA, a federal agency that takes care of property rights in Brazil), State and Municipal Rural Settlements, and Special Rural Settlements, which are the ones with some environmental condition. (These are designed to serve families who wish to work with more sustainable production techniques, such as using fewer or no pesticides, or with more sustainable extractive activities, such as sustainable forestry projects).

We find that Special Rural Settlements do have a positive and significant effect on deforestation. Yet, the location of these settlements were very concentrated in areas with very high forest coverage and a low rate of deforestation. The idea is that even with the use of sustainable practices, these settlements cause some deforestation. As these areas had no deforestation before, we identify some increase in deforestation rates in these municipalities. Special Settlements are responsible for 15% of 2014's total deforestation in the Amazon Biome.

Conventional settlements also have a positive but statistically non-significant effect on deforestation. This may be because the increase of this type of settlement between 2002 and 2014 was lower than the increase of special settlements, which implies less statistical power to measure the effect, as we are controlling for fixed effects.

When running OLS estimates we also find that conventional settlements and colonization settlements have higher positive correlation with deforestation. But this correlation is completely spurious. These settlements were located in places where deforestation is higher today, but not necessarily, because they were there. When controlling for fixed effect both types of settlements become statistically non-significant to explain deforestation.

Therefore, Rural Settlements are causing part of deforestation in the Amazon, as have been claimed by literature. Our paper, however, takes a step forward and measures the effect of Rural Settlements on deforestation controlling for many other effects. While Alencar et al. (2016) shows that deforestation within Rural Settlements represents 30% of Amazon deforestation, they were not taking into account that those areas could be deforested even without any Rural Settlement presence. In other words, they were not isolating the effect of Rural Settlements. Yet, part of deforestation outside Rural Settlements could be caused by the settlers.

Our calculation differs from the Alencar et al. (2016) one in two aspects: first, we measure the impact of Rural Settlements on deforestation in the Amazon within or outside Rural Settlements; second, we also isolate the impact of Rural Settlements on deforestation from the impact of other factors on deforestation.

The rest of this paper is organized as follows: Section 2 discusses the institutional context in the time of the implementation of priority municipalities; Section 3 provides a detailed description of the data used in the paper; Section 4 explains the empirical strategy used to calculate the impact of priority municipalities on deforestation; Section 5 discusses the results of the paper; and Section 6 addresses the conclusions and policy implications of our results.

2. Institutional Context

2.1. Land Colonization and Rural Settlements

Since the 1970s, the Brazilian Federal Government has tried to colonize remote areas in the country, especially in North and Center-West regions. These regions cover most of the Brazilian Amazon and have been very important to the discussion about agricultural and conservation policies. In the 1970s and 1980s, many Rural Settlements were implemented by the National Institute of Colonization and Agrarian Reform (INCRA) with state assistance. These settlements received subsidized rates on credit and state technical assistance.

During this period the area where the Rural Settlements would be implemented was chosen by INCRA. However, since the 1990s, the sites of new Rural Settlements have been determined by squattersâĂŹ organizations. For example, the Landless Rural Workers Movement (MST) frequently invades public lands or the Legal Reserve of large rural households to increase pressure for settlement colonization in these areas. Because Brazilian agrarian reform legislation designates "unproductive" land as a priority for takeover for conservation, it stimulates this kind of practice. Public land and legal reserves are usually seen as having no "productive" use. The squatters, then, invade this land, which should instead be conservation areas with native vegetation. However, when the squatters are successful in settling the areas, INCRA legalizes the settlements. When the area of squatted land is located on a large farm, INCRA compensates the owner, usually with a price higher than the market value (Fearnside, 2005).

This scenario provides incentives to large ranchers to stimulate these invasions, especially when they are experiencing financial problems. In this case, the squatters win with the invasion (receive the land), the large farmer wins with the invasion (receives the compensation higher than his land market value), and the commercial bank also wins with the invasion (receives repayment of the loan when the large farmer is in risk of default). Also, with these agreements, squatters and owners avoid land disputes, which usually results in violence in these regions.

Another important aspect of this context is that when squatters receive the land, they have to clear part of it to give as a guarantee for bank loans. INCRA has claimed that Rural Settlements have been created only in areas that have already been deforested. We show in Section 3.2 that this is not really true.

Although the implementation of Rural Settlements in the Amazon has been common since the 1970s, it was in the last decade that it gained momentum. Up to 2002, only 4.8% of the Amazon Biome was covered by Rural Settlements. This number climbed to 8.3% by 2014. The link between the Federal Government party, elected in 2002, and the landless workers movements facilitated the invasions, which were followed by the acquisition of these lands for rural colonization. Therefore, the study of the impact of these settlements on forest conservation became a relevant research question.

The increase in the area covered by Rural Settlements in the 2000s was not homogeneous. It depended on the type of settlement. INCRA divides the Rural Settlements into four types.

First, the Rural Settlements, which were created in the 1970s and 1980s as part of the First National Agrarian Reform Plan (First PNRA) and known as "Colonization Settlements", were part of the Federal Government's efforts to stimulate migration to the country's interior, mainly to North and Center-West regions. This type of Rural Settlement has not seen much variation in the last few decades. Then, as our main strategy control for fixed effect and we use data from 2002 to 2014, we are not measuring the effect of this type of settlement on deforestation.

The second type of rural settlements are the "Conventional Settlements". The Conventional Settlements are those settlement projects that typically serve farmers who wish to work with rural activities in the projects created after the 1st PNRA. They are divided into batches and each family is entitled to a lot for their livelihood, and after some time and the fulfillment of certain conditions, issued a temporary property title with resolving clauses that will later be converted into definitive title.

The third type of Rural Settlements are the "Special Settlements." Special Settlements are projects that have an environmental focus on the aspect of land use. In this "class" there are 3 modes: Extractive Projects (PAE), designed to address families concentrated on extractive activities; Sustainable Development Projects (PDS), designed to address families who wish to work with more sustainable production techniques, such as reduced use of pesticides or their elimination; and Forestry and Settlement Projects (PAF) where the production base of the families is forestry exploitation.

These three types of Rural Settlements projects are created and regulated by INCRA, sometimes encouraged by the Federal Government, and sometimes instituted after the invasion of landless organized groups.

There is one more type of Rural Settlement, which is not regulated by INCRA, but that INCRA recognizes. It is the state and municipal Rural Settlements named "Recognized Settlements." INCRA recognizes the people living in these areas as target for agrarian reform, and the settlements allow them to have financial and technical assistance. INCRA also recognizes the population living at some protected areas created by the Ministry of Environment, named "Recognized Conservation Units", as population target for agrarian reform. However, in this case, the areas are not really Rural Settlements because the initial goal for the area was environmental conservation.

2.2. Conservation Policies

The Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm), the pivotal conservation policy effort of the mid-2000s, marked the beginning of a novel approach towards combating deforestation in the Brazilian Legal Amazon.[1] Launched in 2004, it integrated actions across different government institutions and proposed innovative procedures for monitoring, environmental control, and territorial management. After its introduction, all changes to Brazilian forestry and conservation policy happened within the plan's framework. The operational project for the PPCDAm consisted of a large set of strategic conservation measures to be implemented and executed as part of a new collaborative effort among federal, state, and municipal governments, alongside specialized organizations and civil society.

One of the pillars of the PPCDAm was the strengthening of Amazon monitoring and

[1] The Legal Amazon is a socio-geographic division of Brazil. It is composed of the western territory of the state of Maranhão and the entire territory of the states of Acre, Amapá, Amazonas, Mato Grosso, Pará, Rondônia, Roraima, and Tocantins.

law enforcement. The main driving force behind this was the adoption of DETER in 2004. Developed and operated by the National Institute for Spatial Research (INPE), DETER is a satellite-based system that captures and processes georeferenced imagery on forest cover in 15-day intervals. These images are used to identify deforestation hot spots and target law enforcement efforts. Prior to the activation of the satellite-based system, Amazon monitoring depended on voluntary reports of threatened areas, making it very difficult for law enforcers to identify and access deforestation hot spots in a timely manner. With the adoption of DETER, law enforcers were able to identify more accurately and act upon areas aÂňffected by illegal deforestation more quickly.

Yet, the monitoring system suffers from an important technical limitation: the satellite used in DETER is only capable of detecting forest clearings that have a total contiguous area of greater than 0.25 km^2. Any clearings smaller than this are, essentially, invisible to the monitoring system, and are therefore less likely to be caught by law enforcers.

In addition to the implementation of the DETER system, the PPCDAm promoted improved qualifications of law enforcement personnel via stricter requirements in the recruitment process for the environmental police and through more specialized training of law enforcers. The new plan also introduced institutional changes that brought greater regulatory stability to the administrative processes for dealing with environmental crimes.

New directives for the investigation and punishment of environmental infractions regulated the use of sanctions including fines, embargoes, and the seizure of production goods, tools, and materials. Law enforcement efforts were also strengthened with the creation of the priority municipalities policy in 2008, which singled out municipalities with intense deforestation activity and took differentiated action towards them. These municipalities, selected based on their recent deforestation history, were classified as in need of priority action to prevent, monitor, and combat illegal deforestation. In addition to being more closely monitored, priority municipalities became subject to a series of other administrative measures that did not necessarily stem from law enforcement policy. Examples include harsher licensing and georeferencing requirements for private landholdings, compromised political reputation for mayors of priority municipalities, and economic sanctions applied by agents of the commodity industry.

Parallel to the PPCDAm's monitoring and law enforcement efforts, the creation of protected areas gained momentum in the mid-2000s. From 2004 through 2009, the area covered by conservation units of integral protection and sustainable use in the Legal Amazon increased by over 520,000 km^2. By the end of the 2000s, nearly half of the Legal Amazon territory was under protection as either conservation units or indigenous lands.

Finally, a novel approach towards the concession of rural credit was adopted to restrict financial resources to those who did not abide by environmental and land titling regulations. Starting in 2008 the concession of rural credit for use in the Amazon biome became conditioned upon presentation of proof of borrowers' compliance with environmental legislation and legitimacy of land claims. Small-scale producers, however, benefited from both partial and complete exemptions to the policy's requirements.

Although the environmental conservation policies have had a broad spectrum of monitoring and incentives, large landowners, in theory, suffered the greatest impact with their implementation. DETER was created to catch large tracts of deforestation hot spots; Priority Municipalities targeted places with very high deforestation rates, which usually were very large municipalities (and consequently, with many large households); and the credit policies leave smallholders exempt of many obligations.

Because conservation policies have had the greatest impact on large landowners, it is even more important to investigate the impact of Rural Settlements on deforestation, which usually divide the land into small plots for small scale farmers. As conservation policies are not targeting these farmers, the increase in the area designated for them and the analysis of their behavior become important research questions.

3. Data, Descriptive Statistics, and Stylized Facts

This section introduces the data used in this paper, presents descriptive statistics, and discusses stylized facts to characterize aggregate trends for our variables of interest.

3.1. Deforestation

Data on deforestation is built from satellite-based images that are processed at the municipality level and publicly released by PRODES/INPE. Because PRODES data is reported annually, we first convert our municipality-by-month settlement panel into a municipality-by-year settlement panel. We define deforestation as the annual deforestation increment, that is, the area in square kilometers of forest cleared over the twelve months leading up to August of a given year.[2]

For any given municipality, cloud coverage during the period of remote sensing may compromise the accuracy of satellite images, requiring images to be produced at a different time. As a result, image records for different years may span from less to more than twelve months. To control for measurement error, variables indicating unobservable areas are included in all regressions. This data is also publicly available at the municipality-by-year level from 2002 to 2014 from PRODES/INPE.

To smooth the cross-sectional variation in deforestation that arises from municipality size heterogeneity, we use a normalized measure of the annual deforestation increment.

[2]More precisely, the annual deforestation increment of year t measures the area in square kilometers deforested between the 1^{st} of August of $t-1$ and the 31^{st} of July of t.

The normalization ensures that our analysis considers relative variations in deforestation increments within municipalities. The variable is constructed by dividing the deforestation increment variable by the size of municipality.

3.2. Rural Settlements

We use data on settlements compiled by the National Institute of Colonization and Agrarian Reform (INCRA), with information about the area occupied by the settlements, by type of settlement. We use this information to calculate the total area of settlement by municipality and build the panel municipality-year from 2002 to 2014.[3].

To make fair comparisons we consider only Rural Settlements located in the Amazon Biome. Brazil has deforestation data also from municipalities outside of the Amazon Biome but within a geopolitical region called Legal Amazon. However, municipalities outside the Amazon Biome have very different vegetation from municipalities within the Amazon Biome and deforestation problems are concentrated on the Amazon Biome. As most part of the new settlements were created within the Amazon Biome, we keep only municipalities in this region.

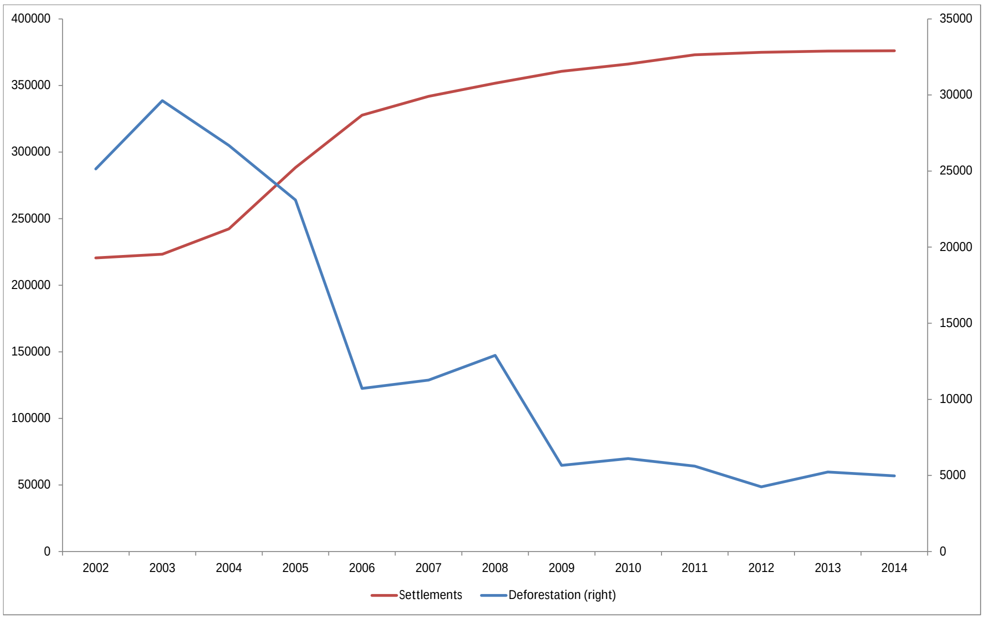
3.3. The Evolution of Rural Settlements and Deforestation in the Amazon

Deforestation rates have declined in the Amazon since 2004 and the area occupied by Rural Settlements has increased. Figure 1 presents the evolution of both deforestation and Rural Settlements in the Amazon Biome from 2002 to 2014. Notice that deforestation was 25 thousand square kilometres in 2002 and decreased to around 5 thousand square kilometres in 2014. At the same time, the area occupied by Rural Settlements increased from 220 thousand square kilometres in 2002 to 376 thousand square kilometres in 2014. Despite the opposite direction of the evolution of these two variables, it is important to verify whether regions where deforestation declined by less were also regions where Rural Settlements increased by more.

We start measuring the evolution of both deforestation and Rural Settlements by state. Figure 2 shows that deforestation decreased in all states of the Amazon Biome. However, the intensity of the decline varies state to state. While deforestation in Mato Grosso presents a huge decrease between 2002 and 2008, in Pará, the rates were more resistant to the conservation efforts. Assunção et al. (2015a) show that small properties were resistant to conservation efforts at the beginning of the decade. Figure 3 shows that Pará was also the state with the highest increase in settlements area. Although this is

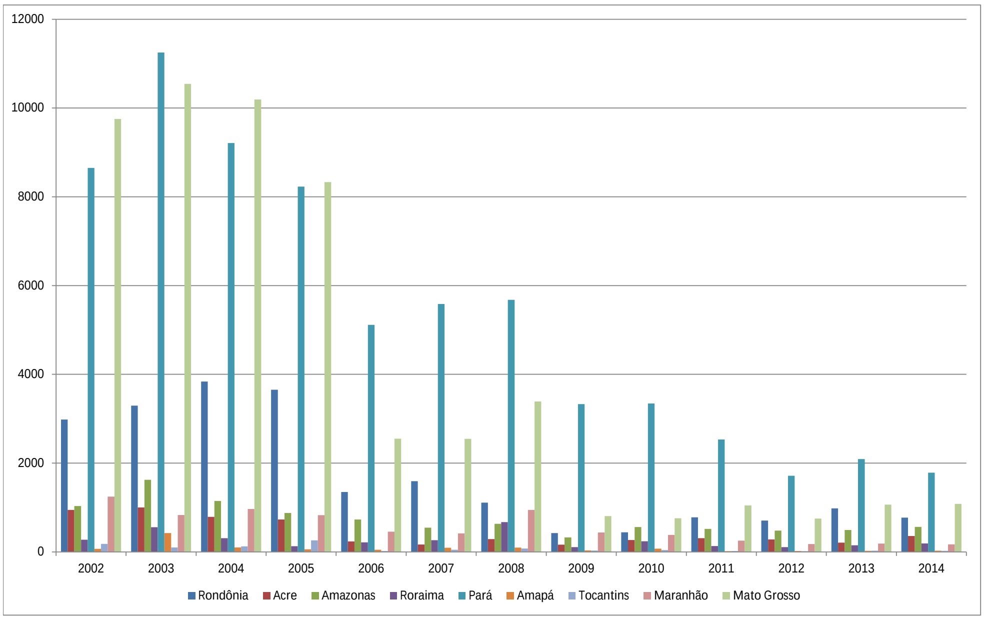
[3] we have data on settlements from 1970 to 2015, but we use in the main calculations only from 2002 to 2014, which are the years we also have deforestation data

Figure 1: Deforestation and Rural Settlements in the Amazon Biome, 2002–2014



Notes: The figure illustrates the total area deforested each year and the total area occupied by Rural Settlements in the Amazon Biome from 2002-2014. These numbers are reported in square kilometres. Data from INPE and INCRA.

Figure 2: Deforestation by State, 2002–2014



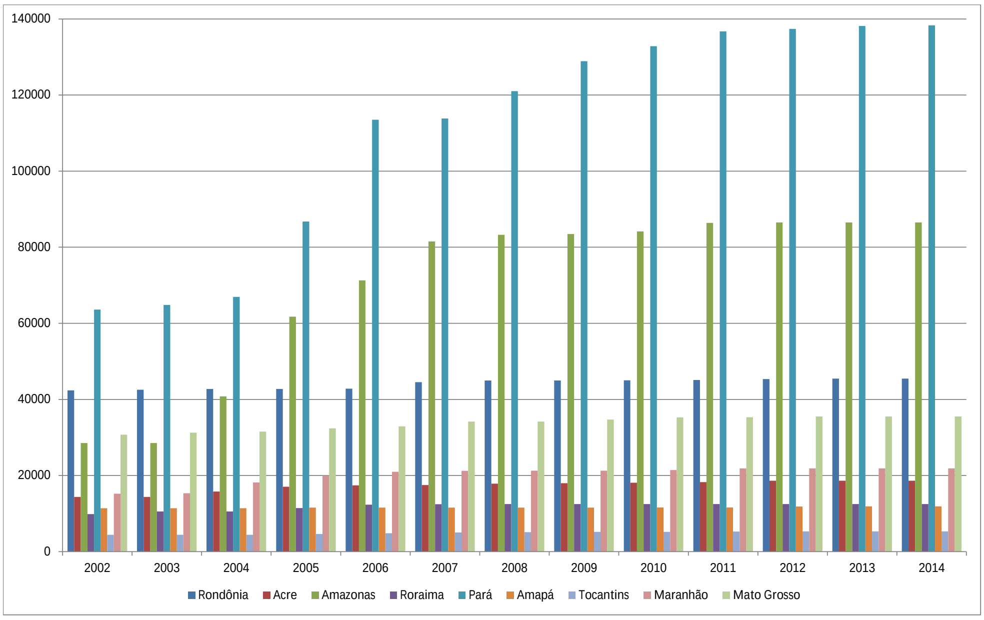
Notes: The figure illustrates the total area deforested each year in square kilometres, by state. Data from INPE.

only a correlation measure (we are not arguing causality here), this trend is already an important finding.

The total area of settlements in the Amazon Biome climbed from 220 thousand square kilometres in 2002 to 376 thousand square kilometres in 2014, an increase of 70%. Figure 3 presents the evolution of the area occupied by settlements in all Amazon states. Among the four states with higher deforestation rates, Pará, Mato Grosso, Maranhão and Rondônia, Pará had the highest increases in area covered by settlements, from 63 thousand square kilometres to 138 thousand square kilometres, a 115% increase. In the other states, the increases in the area covered by settlements were much smaller: Rondônia at 6%, Maranhão at 45%, and Mato Grosso at 15%. However, the most important increase was in the state of Amazonas, where deforestation rates are very low. In this state, the area of Rural Settlements climbed from 28 thousand square kilometres in 2002 to around 86 thousand square kilometres in 2014, an increase of 202%.

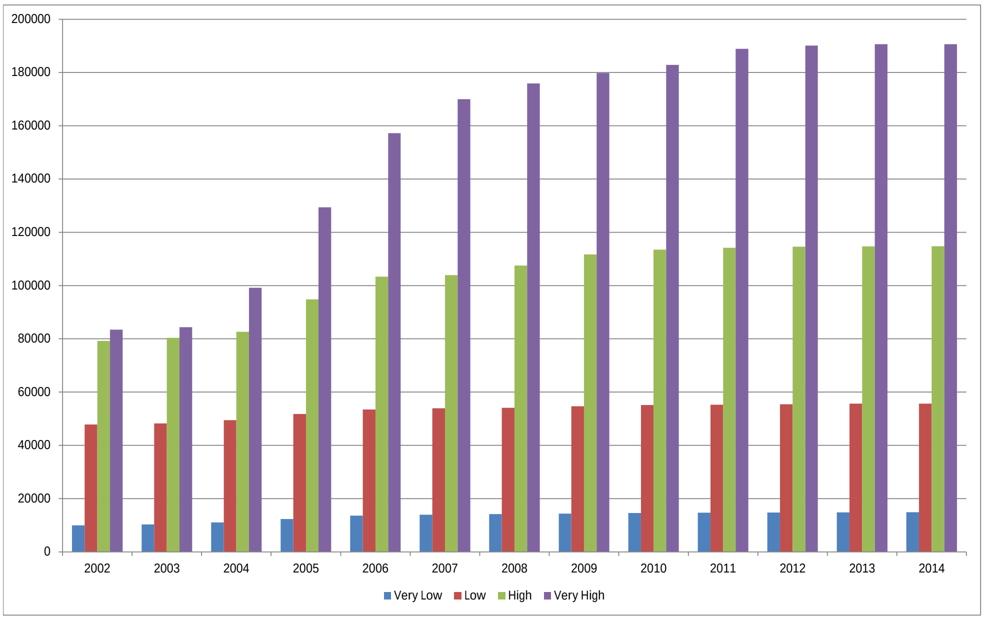
We also investigate the characteristics of the municipalities where the Rural Settlements have been created. The first dimension investigated is the share of municipality territory with native forest in 2002. We divide the Amazon municipalities

Figure 3: Settlements Area, by State, 2002–2014



Notes: The figure illustrates the total settlement area in square kilometres, by state and year. Data from INCRA.

Figure 4: Settlements Area 2002-2014, by 2002 Forest Coverage



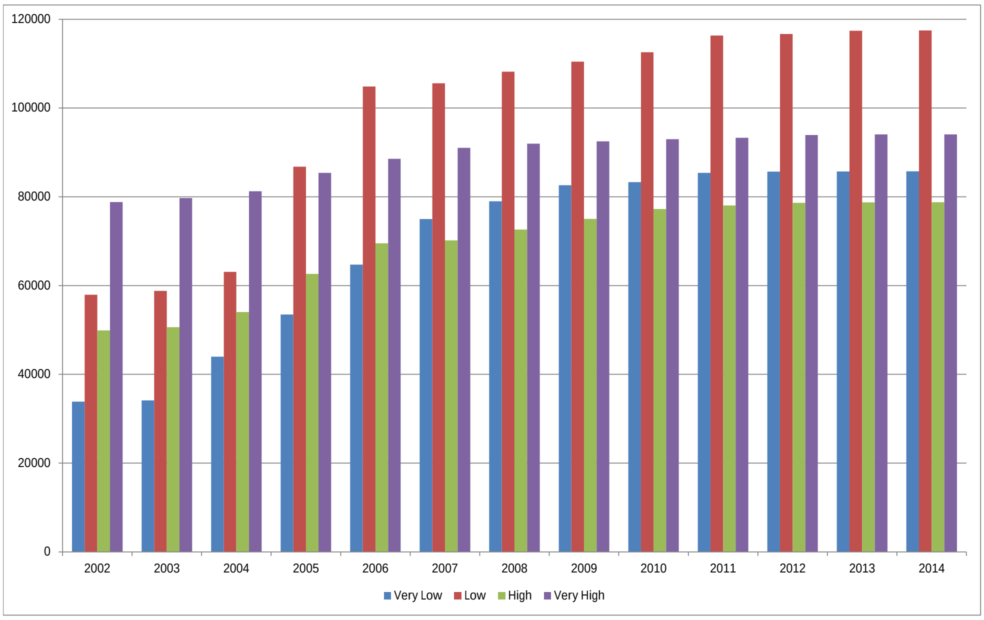
Notes: The figure illustrates the total settlement area in square kilometres, in municipalities where forest coverage was very low (<10%), low (>10% and <32.5%), high (>32.5% and <72%), and very high (>72%) in 2002. Data from INCRA and INPE.

into quartiles of this dimension.

Figure 4 shows the evolution of settlement area in municipalities with very low, low (1st and 2nd quartiles), high, and very high (3rd and 4rd quartiles) native forest coverage. The municipalities with high and very high native forest coverage had a huge increase in the area covered by settlements. In municipalities with very high native forest coverage, the area of Rural Settlements increased by 125% (from 83 thousand in 2002 to 190 thousand square kilometres in 2014), while in municipalities with very low native forest coverage the area of Rural Settlements increased by only 50% (from 10 thousand to 15 thousand square kilometres).

We repeat the exercise taking into account the annual deforestation rate in 2002. The idea here is that municipalities where deforestation rates were high in 2002 are very different from municipalities where deforestation rates were low in 2002. In this case, in the category of very low deforestation, for example, are included the municipalities that deforested less than 0.05% of their territory in 2002. In the category very high are included municipalities that deforested more than 1.23% of their territory in 2002. The

Figure 5: Settlements Area 2002-2014, by 2002 Deforestation Rates



Notes: The figure illustrates the total settlement area in square kilometres, in municipalities where deforestation share was very low (<0.05%), low (>0.05% and <0.37%), high (>0.37% and <1.23%) and very high (>1.23%) in 2002. Data from INCRA and INPE.

other two categories are defined in a similar way, with each category having 25% of the municipalities.

Figure 5 shows that the area of settlements increased more in municipalities where deforestation rates were low or very low in 2002. In municipalities with very low deforestation in 2002 the area of Rural Settlements increased by 153% from 2002 to 2014. In municipalities with very high deforestation in 2002, the Rural Settlements area increased by only 19% in the same period. This means that we have to take care with some endogeneity possibility. We present how we deal with this problem in the empirical strategy section and also in the results.

We repeat the same exercise again, now dividing the Rural Settlements by type. Results are very similar. Except for the conventional settlements, the increase in the area of the other settlement types was higher in municipalities with high and very high native forest coverage.

We present in Figure 6 maps that show the evolution of Rural Settlements over the forest coverage in the Amazon in 2002 and 2011 by settlement type. We present in the figure only the types with some variation. The area of Colonization Settlements become stable, and then, we keep them out of the figure. The green area of the map is the forest coverage. The visual evidence is very impressive for Special Settlements. It is possible to notice that the area of these settlement types (in red) increases mainly over the area covered by native forest (in green) between 2002 and 2011. For conventional settlements the increase in the area is less visible, and it was more uniformly distributed among municipalities with low and high forest coverage.

In summary, the data presented shows that most of INCRA and states and municipal Rural Settlements created in the 2000s were placed in areas highly covered by rainforests, in opposition to INCRA claims. As the usual economic activities of producers in these settlement projects are agricultural activities (usually planted crops and livestock), deforesting part of the land is inherent to their activities and, therefore, more than expected. At the same time, these areas are far from the agricultural expansion frontier, which could mitigate the impact of the creation of settlements on deforestation.

In the next sections we present evidence that, in fact, INCRA settlements as a whole have had impact on deforestation. When we divide the impact by settlements types, the Special Settlements types have had a positive impact on deforestation, while the impact of the other types are statistically non-significant.

3.4. Other Policies

We also use data with information about other conservation policies put into practice by the Federal Government in the studied period. First, we use the information about the Priority Municipalities. In 2008, the Federal Government created a list of municipalities in priority need of prevention and combat to deforestation, named Priority Municipalities. Secondly, we use data from IBAMA with information about the number of areas embargoed by IBAMA in each municipality. We use, then, the total number of embargoes in each municipality as a measure of the intensity of monitoring and law enforcement at the municipality level.

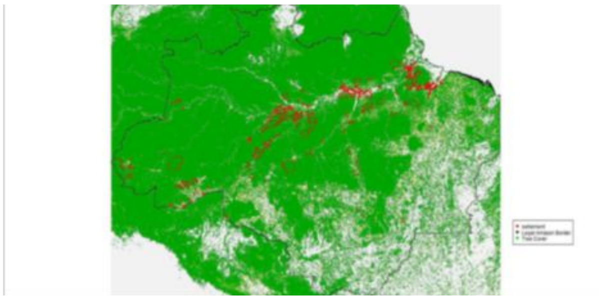
These embargoes are often accompanied by other sanctioning instruments, such as seizure and destruction of production goods, tools and materials, and fines. Because panel data for the use of these instruments are not available, we use the number of embargoes as a proxy for command and control efforts as a whole. Essentially, we are interested in exploring embargoes as a means of capturing the effect of environmental police (IBAMA) presence, not of the sanctioning instrument itself on deforestation.

To maintain consistency across our panel data, we consider the PRODES year – August 1st, $t-1$ through July 31st, t – as the relevant unit of time in our sample. Thus, for each municipality, the total number of embargoes in a given year captures all fines applied in that municipality in the twelve months leading up to August of that year. We

Figure 6: Settlement Area in the Amazon

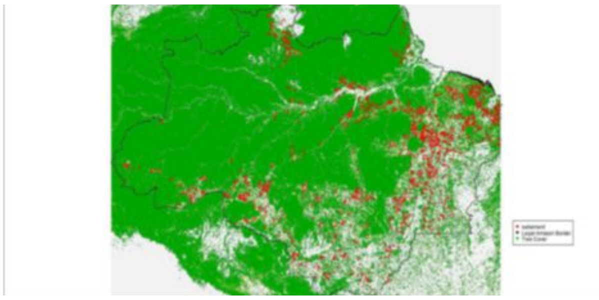
(a) Special Settlements 2002

(b) Special Settlements 2011

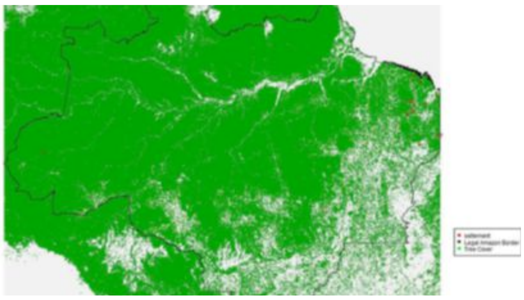


(c) Conventional Settlements 2002

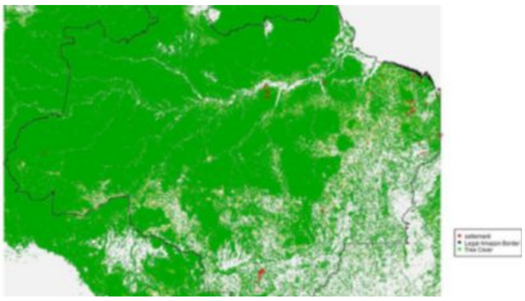
(d) Conventional Settlements 2011



(e) State and Municipal Settlements 2002



(f) State and Municipal Settlements 2011



Notes: The figure illustrates the evolution of settlements by type in relation to the forest coverage in the legal Amazon between 2002 and 2011.

Source: INCRA.

use, then, the lag of the number of embargoes to avoid endogeneity problems. We have information on the lag of embargoes from 2002 to 2014.

3.5. Agricultural Output Prices

Agricultural prices are endogenous to local agricultural production. Thus, to control for fluctuations pressuring deforestation at the municipality level, we must construct output price series that capture exogenous variations in the demand for agricultural commodities produced locally. As argued in Assunção et al. (2015a), agricultural commodity prices recorded in the southern Brazilian state of Paraná are highly correlated with average local crop prices calculated for the Legal Amazon sample municipalities. Hence, we use the Paraná agricultural commodity price series as exogenous indicators of local market conditions within our empirical context. Prices for beef cattle, soybean, cassava, rice, corn, and sugarcane were collected at the Agriculture and Supply Secretariat of the State of Paraná (*Secretaria de Agricultura e do Abastecimento do Estado do Paraná*, SEAB-PR). Soybean, cassava, rice, and corn are predominant crops in the Legal Amazon in terms of harvested area. Although not a predominant crop in the region, sugarcane is also included to take into consideration the recent expansion of Brazilian ethanol biofuel production. Together, the five crops account for approximately 70% of total harvested area averaged across sample years.

The Paraná price series are used to build two variables of interest. The first of these variables, an annual index of crop prices, is constructed in three steps. First, we calculate nominal monthly price series for each calendar year-month and culture. Annual prices are deflated to year 2014 BRL and are expressed as an index with base year 2014.

Second, we calculate a weighted real price for each of the crops according to the following expression:

$$PPA_{itc} = PP_{tc} * A_{ic,2000-2001} \tag{1}$$

where PPA_{itc} is the weighted real price of crop c in municipality i and year t; PP_{tc} is the Paraná-based real price of crop c in year t expressed as an index with base year 2000; and $A_{ic,2000-2001}$ is the share of municipal area used as farmland for production of crop c in municipality i averaged over the 2000 through 2001 period.[4] This latter term captures the relative importance of crop c within municipality i's agricultural production in the years immediately preceding the sample periods. It thus serves as a municipality-specific weight that introduces cross-sectional variation in the commodity price series.

[4] Variables on annual municipality crop production (harvested area, *quantum*, or value in current prices) are based on data originally from the Municipal Crop Survey of the Brazilian Institute for Geography and Statistics (*Pesquisa Agrícola Municipal do Instituto Brasileiro de Geografia e Estatística*, PAM/IBGE).

Third, we use principal component analysis on the weighted real crop prices to derive the annual index of crop prices. This technique allows the price variations that are common to the five selected crops to be represented in one single measure. The resulting index of crop prices captures the first principal component of the five weighted real prices. As the index maximizes the price variance, it represents a more comprehensive measure of the agricultural output price scenario for this analysis than the individual prices themselves. Moreover, by using the index of crop prices, which absorbs both cross-sectional and time-specific trends at the municipality level plausibly correlated with credit demand, we overcome an important empirical limitation.

The second variable of interest is an annual index of cattle prices, which is derived analogously to PPA_{itc}. However, as land pasture is not observable, in this case $A_{ci,2000-2001}$ is the ratio of heads-of-cattle to municipal area in municipality i averaged over the 2000 through 2001 period.

4. Empirical Strategy

In this section we discuss the empirical strategy used in this paper to identify the effect of Rural Settlements on deforestation. In the Subsection 4.1 we discuss the main strategy used. In Subsection 4.2 we discuss the econometric problems with our estimation and possible solutions for them.

4.1. Main Strategy

The challenge faced in this paper is how to adequately measure the impact of Rural Settlements on deforestation. We have the percentage of the municipality territory covered by settlements and the percentage of municipality territory deforested each year, from 2002 to 2014. We, then, use this information to run a difference-in-difference approach with municipality and year fixed-effects to get the impact of settlement on deforestation.

The strategy has several drawbacks. First, there are many other variables that could affect the location of Rural Settlements and deforestation at the same time. For example, many policies created by the Ministry of Environment were active in the Amazon in the studied period. These policies could also affect both the location of Rural Settlements and deforestation at the same time.

Second, another possible problem may be the relationship between agricultural prices and Rural Settlements. It is well known that agricultural prices affect deforestation (Assunção et al., 2015a). It is also possible that the way in which prices have affected local production impacts the choice for Rural Settlements location. For example, farmers could choose locations that are good for planting products if the price is high at the moment of settlement establishment.

Finally, our dependent variable is measured with some error because there are some years that the satellite cannot see the whole Amazon territory and because there are some parts of the area covered by clouds.

Fortunately, we have data information and some strategies that allow us to deal with some of these challenges. First, we have data about other environmental policies, such as the priority status of each municipality, the number of embargoes per municipality, and the share of municipality territory covered by protected areas. Second, we have information on prices. As explained in Section 3.5 we have information about how commodity prices affect each municipality. Therefore, we can control for price variation and get the impact of Rural Settlements on deforestation orthogonal to price variation. Finally, we also have information on the parts of the Amazon that are not observed by the satellite. Then, we can control for this to mitigate the measurement error.

However, even controlling for these variables, we still have some concerns about the exogeneity of the variable. There are many unobservable or even only partially observed characteristics of the locations that could affect both the establishment of Rural Settlements and deforestation at the same time. For example, the extension of paved roads (Cropper et al., 1997), the intensity of other policies, the quality of the soil for crop production, and the quality of soil for raising cattle. Also, there are some factors that affect deforestation in all municipalities at the same way, and we could confound the effect of these factors with the effect of rural settlements on deforestation. We deal with these problems in three ways.

First, we control for municipality and year fixed effects. Controlling for year fixed effect, we ensure that we are getting the effect isolated from macroeconomic and social changes. Controlling for municipality fixed effects, we solve the problem of the fixed unobservable variables that are affecting Rural Settlements and deforestation, i.e. we ensure that at least the unobservable variables that are not changing with time are not also driving our results.

Therefore, our strategy is based in the following equation:

$$Deforest_{it} = \alpha_i + \phi_t + \beta_1 Settlements_{it} + \beta_2 Prices_{it} + \beta_3 Climate_{it} + \epsilon_{it} \tag{2}$$

where $Deforest_{it}$ is the share of municipality territory deforested in municipality i and year t. Our variable of interest, $Settlements_{it}$, is the share of municipality territory i covered by Rural Settlements in year t.

The term α_i represents municipality fixed effects, which absorb initial conditions and persistent municipality characteristics, such as geography and transport infrastructure. The term ϕ_t represents year fixed effects to control for common time trends, such as seasonal fluctuations in agricultural activity, macroeconomic conditions, common rural policies, and the political cycle. The term $Prices_{it}$ proxies for municipality-specific demand for credit, as it includes annual cattle and crop price indices (current and lagged) varying over time at the municipality level. Finally, the term $Climate_{it}$ controls for climate variables, such as rain and temperature. In all specifications, standard errors are robust to arbitrary forms of heteroscedasticity and are clustered at the municipality level to allow for correlation at a given time, as well as across time within municipalities.

4.2. Econometric Issues

In the last subsection we explain how we deal with the unobservable problems related to omitted variables that are fixed in time. In this section we explain how we mitigate the problems related to omitted variables that vary with time. This problem is more difficult to address.

In Section 3.2 we show that the area covered by Rural Settlements has increased more in municipalities where the share of the territory annually deforested is not very large and where the territory is highly covered by native forests. Therefore, there is an endogeneity source in our estimation. For example, municipalities highly covered by native forests could have different deforestation trends compared with municipalities with little forest coverage. Then, our Rural Settlement coefficient could be biased by the fact that the areas where Rural Settlements have been placed are also areas in which deforestation is expected to increase more, even without the Rural Settlements establishment.

Also, the impact of Rural Settlements on deforestation may be heterogeneous. It is possible that Rural Settlements in the agricultural frontier region impact deforestation differently from Rural Settlements in the middle of the Amazon, which are far from urban markets, for example.

We deal with these issues by completing several robustness exercises and also by allowing impact heterogeneity. First, we run the same regression as in equation 2, but now we control for an interaction between the share of municipality covered by rainforest in 2002 and a time trend. This means that we are controlling for a time trend which depends on the initial levels of native forests in municipalities in our sample. Second we do the same exercise controlling for a time trend that depends on the initial levels of the municipality annual deforestation in 2002. The first measure is a stock measure: it is possible that the deforestation trend in municipalities with highest percentage of territory already deforested is different from the trend in municipalities that was not deforested too much. The second measure is a flow measure: deforestation trends in municipalities where economic activities have been intense with high deforestation rates in 2002 could be different from deforestation trends in municipalities where deforestation rates were low in 2002. Controlling for these interactions of deforestation measures with time trends ensures that our results have not been driven by these different trends.

Also, to ensure that we are not getting the effect of any other omitted variable we run placebo tests including leads and lags of the share of municipality covered by settlements. The leads and lags have different interpretation. If the lags of this share is statistically significant, this means that the impact of an increase in the settlements area in some municipality is lasting more than one year, i.e. the increase in settlements area affects deforestation in the year of the increase, and also in the following years. In the case of the leads, the exercise works as a placebo test. The leads of the share of municipality covered by settlements should not impact deforestation. Unless the case in which farmers are clearing the area before invade the land, increasing they chance to get the land title according to Brazilian rules. However, preliminary analysis in descriptive statistics shows that settlements have been created in areas with a lot of forest and few deforestation, not the opposite. In any case, if the leads are statistically significant, this means that either we have an endogeneity problem in our estimation or farmers have deforested the area before settlements creation.

To calculate the heterogeneity of the impact, we also run the main regression considering alternative samples. First we keep only municipalities within a distance of 200, 300, and 400 kilometres from the Amazon Biome border, which is the area known as deforestation arc, or the agricultural expansion frontier. That means, we keep only municipalities near to agricultural expansion frontier. Second, we also do the opposite, and keep only municipalities far from the agricultural expansion frontier. In this case, we keep only municipalities with a minimum distance of 200 kilometres from the Biome border.

These tests with alternative samples serve also as robustness checks. Our results may have been driven by the fact that Rural Settlements increased more in municipalities where deforestation was always very small in our sample. When comparing this municipalities with other municipalities where deforestation was always very high we could be comparing apples with oranges. Then, restrict our samples could help us to compare similar municipalities, some of them with high increase of Rural Settlements coverage and some of them with low increase in Rural Settlements coverage.

Finally, the impact is also probably different depending on the type of Rural Settlements. "Conventional Rural Settlements" are different from "Special Rural Settlements," which are also different from "State and Municipal Rural Settlements." We present estimation separating the effect of each type of Rural Settlement on deforestation.

Table 1: Deforestation and Rural Settlements, by type, 2002-2014, in km2

	Deforestation	Settlements	Colonization Settlements	Conventional Settlements	Special Settlements	State and Municipal Settlements	Amazon Biome Area
2002	25136	220503	37774	156737	23504	2488	4515696
2003	29626	223286	37774	159326	23697	2490	4515696
2004	26682	242342	37774	163615	38461	2492	4515696
2005	23095	288304	37774	175911	72030	2589	4515696
2006	10716	327644	37774	186963	99752	3154	4515696
2007	11263	341795	37774	189166	111701	3154	4515696
2008	12888	351746	37774	190128	120689	3154	4515696
2009	5662	360572	37774	190902	127871	4025	4515696
2010	6103	366108	37774	191330	131581	5423	4515696
2011	5608	373070	37774	191580	138248	5467	4515696
2012	4247	374933	37774	192340	139352	5467	4515696
2013	5222	375873	37774	192679	139952	5467	4515696
2014	4970	376045	37774	192813	139991	5467	4515696

Notes: The table describes the evolution of deforestation and the evolution of Rural Settlements (total and by type), from 2002 to 2014 in square kilometres. Data from INPE and INCRA.

5. Results

This section describes the estimation of the impact of Rural Settlements on deforestation. The first part of the section discusses the main estimation, the second part the robustness exercises, and the third part separates the analysis by type of settlements and discusses heterogeneous effects.

5.1. The Impact of Rural Settlements on Deforestation

Rural Settlements are expected to have a positive relationship with deforestation. In Section 2 we show that Rural Settlements were created in municipalities with a higher share of territory covered by native forests. Then, when the settlement is created, we suppose farmers deforesting part of their land for agricultural production (crop plantation, cattle activities, or both) and forestry activities.

We start our analysis by presenting the numbers of the evolution of Rural Settlements by type and by repeating the numbers of settlements and deforestation in Table 1. It is possible to see that the area of special settlements increased more relative to the other settlement types. We also use these numbers to interpret quantitatively the coefficient of our regressions in the following tables.

Table 2 presents the results of the estimation of Equation 2. Column 1 shows the results of the regression of deforestation on Rural Settlements by OLS, controlling only for time fixed effect. In Column 2, we control for municipality fixed effects. In Column 3, we also control for prices and policies. In Column 4, we add an interaction of time trends

Table 2: Impact of Rural Settlements on Deforestation

VARIABLES	(1) OLS	(2) Fixed Effect	(3) Prices and Policies	(4) Trends	(5) Lead and Lag
Settlements	0.0056	0.0107	0.0080	0.0040	0.0020
	(0.0012)***	(0.0031)***	(0.0030)***	(0.0022)*	(0.0046)
Settlements in t-1					0.0059
					(0.0020)***
Settlements in t+1					-0.0047
					(0.0065)
Observations	7,059	7,059	7,059	7,059	7,059
Year FE	Yes	Yes	Yes	Yes	Yes
Municipality FE	No	No	No	No	No
Prices and Policies	No	No	No	No	No
Trends	No	No	No	Yes	Yes
Number of municipalities		543	543	543	543

Notes: Dependent variable is the share of municipality deforested, by municipality-year. In Column 1, we run OLS regression, controlling only for time fixed effect. In Column 2, we control for municipality fixed effect. In Column 3, we control for prices and policies. In Column 4, we add an interaction of time trends with initial forest coverage and with initial annual deforestation. In Column 5, we test the effects of the lead and the lag of Rural Settlement variable. Significance: *** p<0.01, ** p<0.05, * p<0.1.

with initial forest coverage and with initial annual deforestation. In Column 5, we test the effects of the lead and the lag of Rural Settlement variable

Initial analysis of Columns 1, 2, and 3 point to a positive relationship between Rural Settlements and deforestation. In Column 1 we run an OLS regression. The positive coefficient means that municipalities where the presence of Rural Settlements is higher are also municipalities with higher deforestation rates. However, when we control for municipality fixed effects, the coefficient is even higher. This means that municipalities where the area of Rural Settlements increased more were also the areas where deforestation increased more during our sample period. In Column 3 we control for prices and policies and the coefficient decreases but remains positive and statistically significant.

However, we did not account for the possible endogeneity problem yet. Could deforestation in these municipalities be higher even if Rural Settlements were not there? We attempt to answer this question by analyzing columns 4 and 5. We showed in Section 3 data that most of the new Rural Settlements created between 2002 and 2011 were located in municipalities where forest coverage was very high and deforestation was very low in 2002. Therefore, these municipalities could have trends very different from municipalities with low forest coverage and high deforestation rates. For example, conservation policies against deforestation targeted places with high deforestation rates. Therefore, municipalities with lower deforestation rates in 2002 could being reducing less deforestation because they were not targeted by policy as much as municipalities with higher deforestation rates that year.

To deal with these problems we run the same regressions, but now we control for two kind of trends. First, we include a time trend interacted with the initial level of forest coverage. The idea here is that municipalities with higher initial levels of forest coverage would reduce deforestation by less than municipalities with lower levels of forest coverage. Second, we control for a time trend interacted with initial levels of annual deforestation. The idea here is that municipalities with high deforestation rates may reduce more deforestation than municipalities with low deforestation rates, especially in a period where policies become tougher and commodity prices become less attractive. Because the increase in Rural Settlements was concentrated in these areas (with high initial forest coverage and high initial annual deforestation), we may be confounding the effect of these trends with the effect of Rural Settlements.

Our preferred specification then is, in Column 4, where we control for municipality fixed effects, for prices, policies, and the trends. The coefficient remains positive and statistically significant. Quantitatively, an increase of 1 p.p. in the municipality territory covered by Rural Settlements increases 0.004 p.p. in the share of municipality territory annual deforested. In other words, considering that Rural Settlements occupied 8.32% of Amazon Biome in 2014, our results mean that Rural Settlements are responsible for 30% of deforestation in the Amazon Biome in 2014.

We interpret these results as a sign that Rural Settlements are causing deforestation. In the next section we separate the effect of each kind of Rural Settlement on deforestation and shed light on what is happening in previous table.

5.2. Different Rural Settlement Types

In this section we measure the effect of each kind of Rural Settlement on deforestation. In the last section we showed that Rural Settlements have a positive effect on deforestation. In this subsection we investigate which type of Rural Settlement is causing more deforestation. It is possible that some types of Rural Settlements have an effect on deforestation and other types do not. In this section we investigate this possibility.

Table 3 presents regressions analyzing this question. In Column 1 we run deforestation on types of Rural Settlements by OLS, controlling for time fixed effect as in previous table, but not controlling for municipality fixed effect. The results are as expected, according to the description in Section 2. The "old" Rural Settlements, that means, the types of Rural Settlements more frequently in the past (Colonization and Conventional Rural Settlements), have positive correlation with deforestation. Municipalities in the frontier of agricultural expansion with high deforestation rates are the municipalities where these two types of Rural Settlements occupy a higher area. The "new" Rural Settlements, which

Table 3: The Impact of Rural Settlments, by type

VARIABLES	(1) OLS	(2) Fixed Effect	(3) Prices and Policies	(4) Trends	(5) Lead and Lag
Special Settlements	-0.0012	0.0147	0.0110	0.0056	0.0014
	(0.0011)	(0.0027)***	(0.0025)***	(0.0021)***	(0.0023)
Special Settlements in t-1					0.0026
					(0.0015)*
Special Settlements in t+1					0.0022
					(0.0030)
Conventional Settlements	0.0101	0.0006	0.0003	0.0004	0.0004
	(0.0020)***	(0.0061)	(0.0062)	(0.0038)	(0.0038)
State and Municipal Settlements	-0.0057	0.0108	0.0094	-0.0002	-0.0003
	(0.0059)	(0.0204)	(0.0204)	(0.0217)	(0.0217)
Colonization Settlements	0.0031				
	(0.0015)**				
Observations	7,059	7,059	7,059	7,059	7,059
Year FE	Yes	Yes	Yes	Yes	Yes
Municipality FE	No	Yes	Yes	Yes	No
Prices and Policies	No	No	Yes	Yes	No
Trends	No	No	No	Yes	Yes
Trends	No	No	No	Yes	Yes
Number of municipalities		543	543	543	543

Notes: Dependent variable is the share of municipality deforested, by municipality-year. In this case, the regressors are the share of municipality occupied by Rural Settlements, by type. In Column 1, we run OLS regression, controlling only for time fixed effect. In Column 2, we control for municipality fixed effect. In Column 3, we control for prices and policies. In Column 4, we add an interaction of time trends with initial forest coverage and with initial annual deforestation. In Column 5, we test the effects of the lead and the lag of a special Rural Settlement variable. Significance: *** p<0.01, ** p<0.05, * p<0.1.

means the Rural Settlements that become more frequently established more recently, such as special settlements, have a negative correlation with deforestation. This means they were created in municipalities with lower deforestation rates, although the coefficient is not significant.

In Column 2, we control for municipality fixed effect. The results change completely. In this case, we cannot have the coefficient of Colonization Settlements because there was no variation of this type of settlement during our sample period. The coefficient of Conventional Rural Settlements is not significant anymore. We interpret this result in the following way. Usually, the literature has pointed to a correlation between Rural Settlements and deforestation; our results show that, considering the old types of Rural Settlements (Colonization and Conventional), this relationship is really only a correlation. There is more deforestation in areas where these Rural Settlements are placed only because they were placed in areas that today are on the agricultural expansion frontier. When controlling for fixed effects, we show that the increase in conventional Rural Settlements has no significant effect on deforestation.

However, the coefficients on special Rural Settlements are positive and significant. That means municipalities where the area covered by these Rural Settlements increased were also the municipalities where deforestation increased more (or decreased less). To ensure that we are not attributing the effect of other factors to settlements, we again control for prices and policies (column 3), and for trends depending on initial forest coverage and on initial annual deforestation (Column 4). The results in Column 4 are similar to the results in Column 2.

Quantitatively interpreting this coefficient, we can say that only the Special Settlements are responsible for 15% of deforestation in the Amazon Biome in 2014.

As a robustness check, we also test if our result is coming from some Special Settlements deforestation pre-trend. It is possible that deforestation was already increasing (or decreasing less) in municipalities where special settlements have been created. Then, we run the same regression as in Column 4, adding a lead and a lag of the share of municipality territory covered by special settlements. The results are presented in Column 5. It's possible to see that the variable representing the lead of special settlements coverage is not significant to explain deforestation. That means, there is no pre-trends explaining the coefficient of special settlements. At the same time, when including a lead and a lag of Special Settlements, is possible to see that they only have some effect on deforestation one year after their creation.

Summarizing, the only type of Rural Settlements in which the effect on deforestation survives the robustness checks is the Special Settlements, which are settlements with a focus on some environmental condition. The result is a puzzle. What is the mechanism behind these results? How could Rural Settlements with environmental conditions be the only type to have an effect on deforestation?

Table 4 helps to shed light on this question. To test the heterogeneity of the effect we restrict our sample in four ways to try to understand what is really happening with deforestation rates in places where Rural Settlements have increased. In Columns 1 and 2 we restrict our sample to the region closest to the Amazon Biome border. This region is the one known as the deforestation arc, the agricultural expansion frontier. In Column 1 we keep only municipalities within 200 kilometres of distance to the Biome border and in Column 2 we keep municipalities within 300 kilometres of distance to the Amazon Biome border. In Columns 3 and 4 we do the opposite. In Column 3 we keep only municipalities with a distance higher than 200 kilometres to the Biome Border, and in Column 4 we keep only municipalities with more than 300 kilometres of distance from the Biome border. These municipalities are the ones located more in the interior of the Amazon, far from the main marketplaces for agricultural products.

All the results show a positive and significant effect of Special Rural Settlements on deforestation. Quantitatively, the results could be interpreted in the following way: while one more square kilometre of a Special Rural Settlement in municipalities near to the Amazon Biome border causes more deforestation than one more square kilometre

Table 4: Alternative Samples

VARIABLES	(1) <200km	(2) <300km	(3) >200km	(4) >300km
Special Settlements	0.0212	0.0362	0.0040	0.0036
	(0.0082)***	(0.0091)***	(0.0020)**	(0.0019)*
Conventional Settlements	0.0013	0.0030	-0.0113	-0.0155
	(0.0033)	(0.0035)	(0.0146)	(0.0165)
State and Municipal Settlements	0.0066	0.0073	-0.0018	-0.0070
	(0.0314)	(0.0307)	(0.0117)	(0.0134)
Observations	3,770	4,329	3,224	2,665
Number of municipalities	290	333	248	205
Year and Municipality FE	Yes	Yes	Yes	Yes
Prices and Policies	Yes	Yes	Yes	Yes
Trends	Yes	Yes	Yes	Yes
Sample	<200 km	<300 km	>200 km	>300 km

Notes: Dependent variable is the share of municipality deforested, by municipality-year. In this case, the regressors are the share of municipality occupied by Rural Settlements, by type. All regressions use the same specification as in Column 4, Table 3. In Column 1, we keep municipalities less than 200 km of distance from the biome border. In Column 2, we expand to municipalities less than 300 km of distance. In Column 3, we invert and keep municipalities more than 200 km of distance from the biome border. In Column 4, we keep municipalities more than 300 km of distance from the biome border. Significance: *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

in municipalities far from the border, very few Special Settlements were created in this region. Then, Special Rural Settlements are responsible for only 4% of deforestation in the region known as the deforestation arc, the region closer to the Biome border (result from Column 1).

In the other hand, in regions far from the Amazon Biome Border one more square kilometres of Special Settlements have a smaller impact on deforestation. However, the area occupied by Special Rural Settlements in this region is very large. Therefore, Special Rural Settlements are responsible for around 20% of the deforestation in this region (results from Columns 2, 3 and 4).

The interpretation of this results is that INCRA has created settlements in regions far from the deforestation arc, regions with very few deforestation and with a lot of forest coverage. Then, even the impact of each square kilometre of these settlements on deforestation in this regions being small, the increase in the Rural Settlement area was so large that the impact represents an important fraction of deforestation in the region. To establish agricultural activities in this region, even with sustainable practices, farmers need a tract of cleared land to produce, unless they are engaged only in extractive activities.

Summarizing this finding, the only type of Rural Settlement with significant effect on deforestation is the Special Settlement. The effect is present mainly in municipalities far from the marketplaces and the agricultural expansion frontier. Traditional Rural Settlements (Conventional Settlements and state and municipal Rural Settlements) seem to have no effect on deforestation. The correlation that the literature has identified between conventional settlements and deforestation seems to be related to omitted variables that affect deforestation and also the creation of these Rural Settlements. However, we find an important effect of Special Rural settlements on deforestation. Quantitatively, we find that the whole set of Rural Settlements are responsible for 30% of deforestation on the Amazon Biome, a number very closed to the number found by the literature.

6. Conclusion

The new composition of deforestation in the Amazon, with a higher relative participation of small-scale deforested polygons, has concerned environmental specialists and policy makers. Policies that affect these small-scale farmers and related institutions have, therefore, been an important issue under consideration by policy makers and researchers.

Since the 1970s, Rural Settlements with state assistance have been one of the several strategies of the Federal Government in Brazil to colonize remote regions with low population. However, it was between 2002 and 2014 that the greatest increase in Rural Settlements area occurs in the Amazon region, jumping from 220 thousand square kilometres in 2002 to 376 thousand square kilometres in 2014, an increase of 70

This paper shows that most part of this increase in Rural Settlements area in the Amazon Region was located in remote areas with low population, such as the state of Amazonas, and in municipalities with high forest coverage. Yet, usually, the settlements were created in municipalities where conservation efforts have not arrived, possibly because they are municipalities with few deforestation activities.

The paper also shows that the newly created Rural Settlements had a positive and statistically significant effect on deforestation. Quantitatively, we present evidence that Rural Settlements are responsible for 30% of current deforestation in the Amazon Biome. However, separating the effect by settlement type, the Special Settlement, which is a type of settlement with some environmental condition was the only type with a positive and significant effect on deforestation.

In light of this, our analysis has important implications for the design of public policy in Brazil. It has shown that the new set of Rural Settlements created between 2002 and 2014 has an important impact on deforestation, and our analysis isolated this impact from other variables to show that the Special Settlements possibly affect deforestation the most.

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