Does Credit Affect Deforestation? Evidence from a Rural Credit Policy in the Brazilian Amazon

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Abstract

The concession of rural credit in the Brazilian Amazon became conditional upon stricter legal and environmental requirements in 2008. This paper uses this policy change to investigate the relationship between credit and deforestation. Differences-in-differences estimations based on a panel of municipalities show that the policy change led to a reduction in rural credit, particularly for cattle ranching. The effect is concentrated on medium and large loans. A two-stage estimation shows that the decrease in rural credit has curbed deforestation, specially in municipalities where cattle ranching is the main economic activity. We interpret the positive impact of credit on deforestation as evidence of credit constraints in the region.

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1. Introduction

Deforestation and biomass decay have accounted for almost one fifth of global greenhouse gas emissions (IPCC (2007)). A large share of these emissions originates from the clearing of tropical forests, the planet's most biodiverse environments. In light of this, understanding and combating tropical deforestation, which offers a means to simultaneously tackle the threats of climate change and irreversible loss of biodiversity, has become a topic of global concern (Burgess et al., forthcoming).

Rapid deforestation in tropical forests is typically associated with pressures caused by intense economic growth in developing countries, where the majority of such forest are concentrated. The expansion of agricultural production, in particular, is often done at the expense of forests. Palm oil in Indonesia, cattle ranching in Costa Rica and Brazil, and soybean farming in Brazil are important examples of economic activities whose development resulted in the clearing and conversion of significant areas of native forest. As rural credit is a key financial mechanism to support agricultural production in developing countries (Conning and Udry (2007), Udry (2010)), investigating the relationship between credit and deforestation in these countries contributes to the effort to curb tropical deforestation.

How does the availability of rural credit affect deforestation? Theory alone offers ambiguous answers to this question. On the one hand, should credit be used to increase rural production by incorporating new lands for production, greater availability of credit would likely lead to rising deforestation, as forest areas are cleared and converted into agricultural land. On the other hand, should it be used to fund capital expenditures required to improve agricultural technology and productivity, increases in the availability of rural credit could actually contain forest clearings and curb deforestation.

The aim of this paper is to empirically investigate the relationship between credit and deforestation. We use a rural credit policy change in Brazil to identify the causal effect of rural credit on deforestation. Brazil offers the ideal context in which to conduct this study. The planet's largest rainforest tract, the Brazilian Amazon has also long been the world's most active agricultural frontier in terms of forest loss and CO_2 emissions (FAO (2006), Morton et al. (2006), Santilli et al. (2005)). The conversion of forest areas in the Amazon has contributed nearly half of the country's total net CO_2 emissions (Ministério de Ciência e Tecnologia (2010)). In addition, rural credit in Brazil, which receives significant support from government subsidies, is an important source of funding for agriculture, as well as a key policy instrument. According to MAPA (2003), the official rural credit portfolio covers about a third of the annual financial needs of the agricultural sector in Brazil. As part of these needs are covered by producers' own resources, this portfolio represents an even larger share of external finance in the sector. Thus, any policy measure that affects rural credit also affects one of Brazil's main support mechanisms for agricultural production.

This paper shows that a reduction in rural credit has contributed to reduce deforestation in the Brazilian Amazon. The evidence is provided by the evaluation of Resolution 3,545, introduced in 2008 by the Brazilian National Monetary Council (*Conselho Monetário Nacional*, CMN). This resolution conditioned the concession of rural credit in the Amazon Biome upon proof of compliance with legal and environmental regulations. We investigate several aspects of both the implementation and impact of this novel credit policy, and explore variations in rural credit concessions caused by this new regulation to estimate the effect of credit on deforestation.

We interpret the impact of credit on deforestation as evidence of the existence of credit constraints in the region. Based on Banerjee and Duflo (2012), we argue that the potential rationing in the availability of subsidized credit induced by the policy change may have tightened credit constraints, leading to changes in farmers' production decisions and thereby affecting deforestation. We develop a very stylized economic model that guides the interpretation of our results, showing how a change in the availability of subsidized credit may either increase or decrease forest clearings.

Three key aspects in the policy change helped us design our empirical analysis. First, its conditions applied only to rural credit used in landholdings inside the Amazon Biome. Having access to both contract-level credit concession microdata and deforestation satellite data for all of the Legal Amazon (a larger administrative region), we are able to use Legal Amazon municipalities that are not part of the Amazon Biome as a control group to evaluate the impact of the resolution in the biome. This aspect allows us to use a difference-in-differences approach for the evaluation of the resolution.

Second, credit takers who were beneficiaries of the National Program for the Strengthening of Family Agriculture (*Programa Nacional de Fortalecimento da Agricultura Familiar*, Pronaf) were subject to far less stringent conditions for credit concession. Pronaf is designed to target small-scale producers, with eligibility for the program being dependent on the producers' farm size. As our data allows us to identify whether credit was contracted through Pronaf or non-Pronaf channels, we evaluate how, for a given municipality, credit concession differed between small and mid-to-large-scale producers after the adoption of Resolution 3,545. We explore this second aspect in an alternative difference-in-differences formulation.

Third, the resolution's conditions were such that borrowers who proved they had the intention to comply with environmental regulation were allowed access to credit. The key requirement behind this was a formal commitment to adapt to environmental rules over time, rather than at the current time. For practical purposes, this made intention to comply equivalent to compliance, helping us validate our strategy for the estimation of the relationship between credit and deforestation. A possible concern for our identification strategy could arise from financially unconstrained farmers changing their current choices about deforestation to prevent future credit restrictions. The way Resolution 3,545 was implemented mitigates the relevance of this issue.

Our analysis is based on a contract-level microdata set compiled by the Central Bank from Common Registry of Rural Operations (*Registro Comum de Operações Rurais*, Recor) data. This data set contains detailed information on all rural credit contracts negotiated by official banks (public and private) and credit cooperatives from 2002 through 2011 in the Legal Amazon states of Acre, Amazonas, Amapá, Maranhão, Mato Grosso, Pará, Rondônia, Roraima, and Tocantins. We use this data to construct a panel of total amount of rural credit at the municipality level. We also take advantage of recent satellite-based deforestation data from the National Institute for Space Research's (*Instituto Nacional de Pesquisas Espaciais*, INPE) Project for Monitoring Deforestation in the Legal Amazon (*Projeto de Monitoramento do Desflorestamento na Amazônia Legal*, PRODES/INPE). Municipality-level deforestation data is merged with rural credit data to form a panel covering the 2002 through 2011 period. To the best of our knowledge, this is the first time that contract-level rural credit and municipality-level deforestation panel-data are combined to investigate the relationship between deforestation and credit.

Our main difference-in-differences results indicate that Resolution 3,545 led to a reduction in the concession of rural credit in the Amazon Biome. In counterfactual simulations, we estimate that approximately BRL 2.9 billion (USD 1.4 billion) were not loaned in the 2008 through 2011 period due to restrictions imposed by the policy change. A reduction in loans specific to cattle ranching activities accounted for 90% of this effect. The policy change also led to a decrease in the concession of non-Pronaf credit, as compared to Pronaf credit, within a given municipality. This is to be expected in light of the legal exemptions that were introduced for small-scale producers. Counterfactual simulations conducted using the Pronaf *vs.* non-Pronaf specifications yield results similar to those obtained using the biome *vs.* non-biome specifications, which is reassuring in terms of support for our identification strategy. Several robustness checks corroborate the use of our main specifications.

We investigate potential heterogeneous effects of Resolution 3,545 by exploring specific elements of municipality and contract-level heterogeneity. First, we test if the policy's impact differed among municipalities with different leading economic activities. Municipalities are categorized as being either cattle or crop-oriented. Our findings suggest that the resolution had a significant negative impact on rural credit concession in both types of municipalities, with a stronger effect on cattle-oriented ones.

Second, we analyze how Resolution 3,545 affected both size and composition of rural credit contracts in the Amazon Biome. Results show that the policy had a distributional effect on cattle-specific contracts. The number of medium and large cattle-specific contracts, as well as the number of medium crop-specific contracts decreased, while the number of small cattle-specific contracts slightly increased. We document no impact on small crop-specific contracts. This effect is likely the consequence of credit agents striving to reallocate resources away from credit takers subject to the resolution's conditions and towards those facing less stringent legal restrictions.

Having shown that Resolution 3,545 caused a reduction in rural credit concession in the Amazon Biome, we move on to test whether this reduction affected deforestation. Results from instrumental variable regressions indicate that the decrease in rural credit helped contain deforestation in the biome. In counterfactual simulations, we estimate that additional 2,700 square kilometers of forest would have been cleared from 2009 through 2011 in the absence of the resolution-induced credit constraint. Considering that deforestation rates in the late 2000s and early 2010s were between 5,000 and 7,000 square kilometers per year, the effect attributed to the resolution is substantial. We also find that the relationship between rural credit and deforestation varies according to the regionally leading economic activity, with municipalities where cattle ranching predominates over crop farming showing a stronger impact of credit on deforestation. Overall, the results suggest that there are relevant credit constraints affecting deforestation activity in the Brazilian Amazon Biome, and that the expansion of agriculture at the extensive margin in the biome - particularly in cattle-oriented municipalities - is financially constrained. Again, several robustness checks corroborate our results.

Our results yield two key policy implications. First, the evidence shows that conditional rural credit can be an effective policy instrument to combat deforestation. Second, and perhaps more important, our analysis suggests that the financial environment in the Amazon is characterized by significant credit constraints. Thus, policies that increase the availability of financial resources could potentially lead to higher deforestation rates. This issue lies at the core of the recent debate about REDD policies that ultimately involve payments for environmental services (see Alston and Andersson (2011), Angelsen (2010), and Angelsen and Wertz-Kanounnikoff (2008)). Although the implementation of these policies occurs in a context different to the one we assess in this paper - namely, payments are conditional on environmental deliveries - our results highlight the importance of sustained monitoring and enforcement of conditionalities for REDD policies.

The remainder of the paper is structured as follows. Section 2 presents an overview of related literature. Section 3 describes the institutional context of Brazilian rural credit and Resolution 3,545 at the time of policy implementation. Section 4 introduces the model that guides our empirical analysis and defines the role of credit constraints within our framework. Section 5 describes the data and presents stylized facts and trends on credit concession and deforestation. Section 6 details the empirical strategy used to calculate the impact of Resolution 3,545 on credit and deforestation. Section 7 discusses results on policy effectiveness in restricting credit. Section 8 discusses results on the relationship between credit and deforestation. Section 9 closes with final remarks.

2. Related Literature

The literature analyzing the direct link between credit and deforestation is scarce. On the one hand, Binswanger (1991) discusses whether there could be a positive relationship between credit and deforestation. He argues that subsidized rural credit tends to increase the demand for land, leading to a more rapid expansion of crop farmland and pasture, but does not formally test his hypotheses. On the other hand, rural credit policies could also encourage producers to increase productivity within a given area of land. Pfaff (1999) empirically studies the relationship between a proxy for credit supply and deforestation in the Brazilian Amazon. He finds that the number of bank branches is positively correlated with deforestation, thought this result is not significant in all specifications. Hargrave and Kis-Katos (2010) also find positive correlations between credit and deforestation in some regressions, but no such impact in others (including their preferred specification). Unlike previous studies, we explore a policy-induced and exogenous source of variation in rural credit. By using the policy change as an instrumental variable for credit supply, we are able to identify a causal relationship between credit and deforestation. We find a positive and robust effect of rural credit on deforestation.

Our results also provide a better understanding of the determinants of the recent Brazilian Amazon deforestation slowdown. After peaking at over 27,000 square kilometers per year in 2004, the deforestation rate in the Brazilian Legal Amazon sharply decreased in the second half of the 2000s to about 5,000 square kilometers in 2011 (INPE (2012)). There is a substantial stream of literature documenting the impact of long-run socioeconomic drivers of deforestation activity in the Amazon. Examples include, but are no limited to, the effect of population, road density, and agroclimatic characteristics on deforestation (see Chomitz and Thomas (2003), Reis and Guzmán (1994), and Reis and Margulis (1991)). However, there is scarce empirical evidence on the immediate drivers of the recent Amazon deforestation slowdown. This paper complements the findings of Assunção et al. (2011). The authors show that, even when controlling for commodity prices and relevant fixed effects, conservation policies introduced starting in 2004 and 2008 helped avoid half of the forest clearings that would have been observed from 2002 through 2009 should the policies not have been adopted. Our paper isolates the credit channel and specifically tests whether credit constraints have been effective in curbing deforestation vis-a-vis other recent conservation efforts adopted in the Brazilian Amazon.

Finally, our results contribute to a broader literature on rural credit. Previous studies have found beneficial effects of the availability of credit in rural contexts. Credit supply has been positively associated with poverty reduction (Burgess and Pande (2005)), and agricultural investment and consumption smoothing (Rosenzweig and Wolpin (1993), Conning and Udry (2007)). In this paper we unfold a potential negative externality by documenting that greater availability of rural credit may also lead to higher deforestation.

3. Institutional Context

3.1. Rural Credit

Rural credit is one of Brazil's most traditional ways to support agriculture (MAPA (2003)). It encompasses significant government subsidy. The Ministry of Agriculture (*Ministério da Agricultura, Pecuária e Abastecimento*, MAPA) estimates that approximately 30% of the resources needed in a typical harvest year are funded by rural credit (MAPA (2003)). The remaining 70% come from producers' own resources, as well as from other agents of agribusiness (such as trading companies) and other market mechanisms (such as legal instruments that enable the pre-sale of production). In light of this, any policy measure that affects rural credit also affects one of Brazil's main support mechanisms for agricultural production.

In Brazil, rural credit is loaned according to rules and conditions established in the Central Bank's Manual of Rural Credit (*Manual de Crédito Rural*, MCR). All agents comprising the National System of Rural Credit (*Sistema Nacional de Crédito Rural*, SNCR), which encompasses public banks, private banks, and credit cooperatives, must abide by the MCR's norms. Rural credit is used to finance short-term operating funds, investment, and commercialization of rural production.[1]

One of the key policy instruments for determining the concession of rural credit in Brazil is the annual Crop and Livestock Plan (*Plano Agrícola e Pecuário*, PAP), commonly known as the Harvest Plan (*Plano Safra*). Published in the first semester of each year by the MAPA, the PAP summarizes the directives established for agricultural policy in each harvest year.[2] The document is intended to serve as guidance for producers, informing them about elements central to agricultural production in the country. At the PAP's core are the government's plans regarding amounts of credit to be loaned to both commercial and family production[3], as well as the subsidized interest rates that apply to a large fraction of planned credit loans.

[1]According to MAPA's classification system, short-term operating funds credit is meant to cover the usual expenses of production cycles; investment credit is to be applied to durable goods or services whose benefits last over an extended period of time; and commercialization credit is intended for use in ensuring supply and allowing for storage during periods of falling agricultural output prices. As, in practice, some activities may fall into multiple categories, we restrict our attention to aggregate credit.

[2]In Brazil, a harvest year is the period covering July of a current year through June of the following year.

[3]A family producer is described in Law 11,326/2006 as one who practices rural activities while simultaneously meeting the following criteria: (i) holds no more than four fiscal modules, where a fiscal module is defined as the minimum area needed in each municipality to ensure the economic viability of exploring a rural establishment within that municipality; (ii) uses predominantly own family's labor in the

From a total of BRL 14.7 billion (USD 7.3 billion) in the 2001/2002 harvest year, the amount of credit planned for rural commercial production in the PAP increased to BRL 50.0 billion (USD 24.7 billion) in 2006/2007 and reached BRL 102.7 billion (USD 50.7 billion) in 2011/2012. A large share - typically over half - of these resources were loaned under fixed per year interest rates: 8.75% up to and throughout the 2006/2007 harvest year, and 6.75% thereafter (see MAPA (2001), MAPA (2006), and MAPA (2011)).

Considering the annual SELIC[4] rate of over 18% in the beginning of the 2000s and over 8% in the beginning of the 2010s, the interest rates established in the PAP represented a very significant government subsidy for rural credit. Family production, whose planned amount of credit increased from BRL 2.5 billion (USD 1.2 billion) in the 2001/2002 PAP to BRL 10.0 and 16.0 billion (USD 4.9 and 7.9 billion) in the 2006/2007 and 2011/2012 PAPs respectively, received even greater subsidies, having access to annual interest rates as low as 1% for specific categories of production.

3.2. Conservation Policy Efforts and Central Bank Resolution 3,545

Brazilian conservation policies underwent profound revision in the 2000s. Most of these changes occurred within the framework of the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (*Plano de Ação para a Prevenção e o Controle do Desmatamento na Amazônia Legal*, PPCDAm). Launched in 2004, this plan inaugurated a new form of dealing with deforestation. It integrated action across different government institutions, and introduced innovative procedures for monitoring, environmental control, and territorial management in the Legal Amazon (Ipea et al. (2011), IPAM (2009)). Henceforth, policymakers sought to inhibit forest clearings and promote forest conservation through three main policy efforts: the strengthening of command and control operations, the expansion of protected territory, and the adoption of more restrictive rural credit policies. The remainder of this section focuses on Resolution 3,545, the major rural credit policy change of the late 2000s.

Published by the CMN on February 29th, 2008, Resolution 3,545 conditioned the concession of rural credit for use in agricultural activities in the Amazon Biome upon presentation of proof of borrowers' compliance with environmental legislation, as well as of the legitimacy of their land claims and the regularity of their rural establishments. The measure, aimed at restricting credit for those who infringed environmental regulations, applied to all establishments in municipalities located entirely within the Amazon Biome. Resolution 3,583, published on July 1st, 2008, determined that in frontier municipalities, whose territory is only partially located within the biome, the conditions applied solely

property's economic activities; (iii) meets a minimum of family income originating from the property's economic activities; and (iv) manages the property alongside own family.

[4]The SELIC rate is the Brazilian Central Bank's overnight rate.

to establishments located entirely or partially inside the biome. As the Amazon Biome is contained within the Legal Amazon, all biome municipalities are necessarily located in the Legal Amazon, but not all Legal Amazon municipalities are part of the Amazon Biome (see Figure 1).

Since all agents comprising the SNCR - public banks, private banks, and credit cooperatives - were obligated to abide by the new rules, the resolution represented a potential restriction on official rural credit, and thereby on the fraction of it that is largely subsidized via lower interest rates. However, other sources of financing for agricultural activity, such as traders and supplier's credit, suffered no such restriction.

As determined in Resolution 3,545, to prove eligibility for taking credit, the borrower had to present: (i) the Certificate of Registry of the Rural Establishment (*Certificado de Cadastro de Imóvel Rural*, CCIR); (ii) a declaration stating the absence of current embargoes caused by economic use of illegally deforested areas; and (iii) a state-issued document attesting the environmental regularity of the establishment hosting the project to be financed, or, in the absence of such document, a state-issued certificate indicating that the documentation necessary for regularization had been received. The resolution's requirements applied not only to landowners, but also to associates, sharecroppers and tenants. Implementation of Resolution 3,545 terms by all credit agents was optional as of May 1st, 2008, and obligatory as of July 1st, 2008.

Although seemingly restrictive at first, the conditioning measures of Resolution 3,545 were subject to a series of qualifications that loosened the severity of the new credit constraints. This was particularly relevant for small-scale producers. In its original text, Resolution 3,545 already established exemptions for three groups of small credit takers. The first group, composed of Pronaf beneficiaries and rural producers operating in areas smaller than or equal to four fiscal modules[5], was still required to present the CCIR, but could replace the rest of the documentation by an individual declaration attesting the existence of the required legal reserve and area of permanent protection, and the absence of current embargoes caused by the economic use of illegally deforested areas within the credit taker's establishment.

The second group, encompassing beneficiaries of the National Program of Land Reform (*Programa Nacional de Reforma Agrária*, PNRA) who fit into Pronaf groups A[6]

[5] The actual size of a fiscal module varies according to municipality. It depends mainly on the conditions of production in each municipality including, but not limited to, market dynamics, installed infrastructure, technological availability, and natural features such as soil quality and water availability.

[6] Pronaf group A refers to family producers settled into PNRA land reform settlements, as well as to beneficiaries of the National Program of Land Credit (*Programa Nacional de Crédito Fundiário*, PNCF) who have not yet taken investment credit under the Program of Special Credit for Land Reform (*Programa de Crédito Especial para a Reforma Agrária*, Procera) or that have not yet reached the maximum credit limit for structural investment within Pronaf. The group also includes family producers who were relocated due to the construction of dams for use in hydroelectric power generation or for the provision of water to land reform settlements.

and A/C[7], could replace all documentation by a declaration issued by the National Institute of Colonization and Land Reform (*Instituto Nacional de Colonização e Reforma Agrária*, Incra) either attesting the land reform settlement's environmental regularity, or indicating that a term on the regularization of the settlement had been agreed upon. An annex with a list of all land reform settlement beneficiaries had to be included in the documentation.

The third group, restricted to family producers fitting into Pronaf group B[8], was not required to present any documentation. As the three groups referred to small-scale producers, these exemptions implied that Resolution 3,545 established less restrictive conditions for small producers.

Soon after the compulsory adoption of the resolution, new CMN measures further loosened the requirements for the concession of rural credit to small producers. With the passing of Resolution 3,599 on August 29th, 2008, borrowers from the first group could present a declaration attesting not the existence, but the recomposition or regeneration of the required legal reserve and area of permanent protection within their establishments. Similarly, instead of attesting the land reform settlement's environmental regularity, the Incra declaration presented by borrowers from the second group could attest that the land reform settlement had an environmental license or that the process for obtaining such license had already been started. Resolution 3,599 and Resolution 3,618 from September 30th, 2008, also included the following in the list of Pronaf beneficiaries exempted from presenting any documentation: indigenous people, *quilombolas*,[9], small-scale fishermen, inhabitants or users of conservation units of sustainable use, and regular inhabitants of river margins.

Small producers also benefitted from several exceptions introduced for specific harvest years. The CMN determined that the CCIR could be substituted either by the DAP (a document held strictly by eligible Pronaf beneficiaries) for program beneficiaries, or by a CCIR request for all other rural producers operating in areas no greater than four fiscal modules. Resolution 3,618 introduced this new rule for the 2008/2009 harvest year, and Resolution 3,735, published on June 17th, 2009, extended it to the 2009/2010 harvest year.

[7]Pronaf group A/C refers to family producers settled into PNRA land reform settlements, as well as to beneficiaries of the PNCF who not only possess the group A/C Declaration of Eligibility for Pronaf (*Declaração de Aptidão ao Programa*, DAP), but who have also already contracted a first operation in group A, and have not obtained financing for working capital in a Pronaf group other than A/C.

[8]Pronaf group B refers to family producers that meet all of following criteria: (i) explore a fraction of land as owner, land reform settler, tenant or associate; (ii) live in or near the property; (iii) have access to an area no greater than four fiscal modules; (iv) derive at least 30% of family income from both the agricultural and non-agricultural exploration of the property; (v) base exploration of the property on family labor; and (vi) have total family income of up to BRL 6,000 (USD 2,962.20), excluding social benefits. This group is known as Pronaf's rural microcredit group.

[9]*Quilombolas* are inhabitants of *quilombos* settlements traditionally founded by escaped slaves.

3.3. Heterogeneity

Resolution 3,545 established the same restrictions and exceptions in all municipalities to which it applied and, thus, represented a homogeneous policy change across Amazon Biome municipalities. Yet, its impact on rural credit concession and, consequently, on deforestation may have differed across economic sectors due to structural heterogeneity. A key structural difference we take into account is the composition of sources used to meet financial requirements for crop and cattle production. According to FAO (2007), the relative participation of official rural credit contracts has decreased, as agricultural financing, particularly for soybean production, has increasingly been obtained through contracts with traders, input and processing industries, and retailers and market operators. Government credit meets an estimated 30% of the financial requirements of the soybean production sector in Brazil, but the remaining funds are provided by traders and the processing industry (40%), the input industry (15%), and farmers' own resources (10%), with the remaining 5% being attributed to other sources, such as manufacturers of agricultural machinery (FAO (2007)). A crop farming sector that is not heavily dependent on official rural credit, as appears to be the case in Brazil, could compensate the decrease in official rural credit imposed by Resolution 3,545 with alternative sources of financing. Producers operating in this sector would thus be able to sustain investment and deforestation at the same levels as before the credit policy intervention.

Crop production in Brazil also experienced relevant technological advances starting in the early 1990s, particularly with the widespread adoption of direct seeding (FAO (2007)). No such pattern was observed for livestock farming, which remains a low-productivity practice in the country. Crop farmers likely invest a larger share of rural credit loans in the intensification of production, instead of expanding production by operating in the extensive margin as cattle ranchers do. In this case, a decrease in rural credit for crop farmers might not lead to a decrease in forest clearings, since resources were not originally being used to push agricultural production into forest areas.

Although Resolution 3,545 constituted an institutional change at the federal level, regional heterogeneities may have influenced the way in which the resolution impacted local access to credit and, thus, affected deforestation. It is therefore likely that Resolution 3,545's effects differed among different segments of producers and regions. We explore this idea in the empirical analysis described in the remainder of this paper.

4. Model

This section presents the theoretical model that guides our empirical analysis. The model, inspired by Banerjee and Duflo (2012), focuses on how credit constraints can influence deforestation when different production technologies are available to the producer.

Suppose a farmer operates in a forest area and chooses one among two agricultural production technologies - traditional or modern. With the traditional technology, the farmer produces agricultural output using labor and land inputs. This traditional technology is described by:

$$f(L,T) \tag{1}$$

where L is labor employed and T is area used for production. With the modern technology, in addition to labor and land, the farmer also uses other inputs, K, such as tractors and fertilizers. This modern technology is described by:

$$F(K,L,T) = A(K)f(L,T) \tag{2}$$

Assume that labor can be paid at the end of the harvest period, but that expenditures with non-labor inputs must be paid in advance. Taking M as total working capital available to the farmer, working capital constraints are given by $p_T T \leq M$ and $p_K K + p_T T \leq M$ for the traditional and modern technologies, respectively. These constraints allow for the possibility of existing binding credit financing as in Feder (1985) and Udry (2010). A farmer using the traditional technology therefore faces the following decision problem:

$$\begin{aligned} \pi_{traditional}(M) &= \max_{L,T} f(L,T) - p_L L - p_T T \\ &\quad \text{subject to } \; p_T T \leq M \end{aligned} \tag{3}$$

Similarly, the decision problem for a farmer using the modern technology can be described as:

$$\begin{aligned} \pi_{modern}(M) &= \max_{K,L,T} A(K)f(L,T) - p_K K - p_L L - p_T T \\ &\quad \text{subject to } \; p_K K + p_T T \leq M \end{aligned} \tag{4}$$

Thus, a farmer with available working capital M chooses the modern technology if, and only if, $\pi_{modern}(M) \geq \pi_{traditional}(M)$. Define M_0 such that $\pi_{modern}(M_0) = \pi_{traditional}(M_0)$. We assume that p_k and $A(K)$ are such that all farmers with $M \geq M_0$ choose the modern technology. In summary:

$$\pi(M) = \begin{cases} \pi_{traditional}(M) & \text{if} M < M_0 \\ \pi_{modern}(M) & \text{if} M \geq M_0 \end{cases} \tag{5}$$

Within this framework, with the farmer operating in a forest area, the choice of area to be used for production is equivalent to deforestation. We are therefore particularly interested in how optimal farmland size is affected by the availability of capital when the farmer is allowed a choice of production technology.

To simplify the analysis, we consider specific functional forms for the production functions, assuming that $f(L,T) = L^{\beta}T^{\gamma}$ and $A(K) = K^{\alpha}$, where $\alpha > 0$, $\beta > 0$, $\gamma > 0$ and $\alpha+\beta+\gamma < 1$. The assumption of decreasing returns to scale helps determine a finite optimal farmland size. We focus on the characterization of the optimal land input. For the traditional technology, the optimal choice of farmland is given by:

$$T_{traditional}(M) = \begin{cases} \dfrac{M}{p_T}, & \text{if} M < \overline{M} \\ T^*_{traditional} & \text{if} M \geq \overline{M} \end{cases} \tag{6}$$

$$\tag{7}$$

where $T^*_{traditional} \equiv \left(\dfrac{\gamma}{p_T}\right)^{\frac{1-\beta}{1-\beta-\gamma}} \left(\dfrac{\beta}{p_L}\right)^{\frac{\beta}{1-\beta-\gamma}}$ and $\overline{M} = p_T T^*_{traditional}$. For the modern technology, the optimal choice of farmland is given by:

$$T_{modern}(M) = \begin{cases} \dfrac{\gamma}{\alpha+\gamma}\dfrac{M}{p_T} & \text{if} M < \overline{\overline{M}} \\ T^*_{modern} & \text{if} M \geq \overline{\overline{M}} \end{cases} \tag{8}$$

where $T^*_{modern} \equiv \left(\dfrac{\alpha}{p_K}\right)^{\frac{\alpha}{1-\alpha-\beta-\gamma}} \left(\dfrac{\beta}{p_L}\right)^{\frac{\beta}{1-\alpha-\beta-\gamma}} \left(\dfrac{\gamma}{p_T}\right)^{\frac{1-\alpha-\beta}{1-\alpha-\beta-\gamma}}$ and $\overline{\overline{M}} = p_K K^*_{modern} + p_T T^*_{modern}$.

The relative values of M_0, $\overline{M}$ and $\overline{\overline{M}}$ define different possible cases. For example, a configuration such that $M_0 < \overline{M} < \overline{\overline{M}}$ implies in the optimal farmland size graph shown in Figure 2.

Define M^* as the farm's total investment if the farmer can borrow as much as he wants at the interest rate r. Thus,

$$M^*(r) = \arg\max_{M} \Pi(M) - (1+r)M \tag{9}$$

represents the first-best investment level.

We assume that a typical farmer can be financed by two different sources and ignore, for the sake of simplicity, the possibility of self-financing. A subsidized rural credit line is available at cost r_b, which is below the market interest rate r_m, $r_b < r_m$. Denoting the amounts of subsidized rural credit and market credit as M_b and M_m, respectively, total investment is given by $M = M_b + M_m$. Following Banerjee and Duflo (2012), we say that a farmer is *credit rationed* at the subsidized interest rate if $M_b < M^*(r_b)$, and that a farmer is *credit constrained* if $M < M^*(r_m)$.

As argued in Section 3, Resolution 3,545 may have reduced the availability of subsidized rural credit for some farmers in the Amazon Biome. Yet, the supply of credit supplied at the market rate by agents other than official banks (private and public) and credit cooperatives was not directly affected by the resolution. Our theoretical model offers intuition on how farmers are expected to react to this change in the supply of credit, and thereby potentially affect deforestation, under different assumptions about the availability of financial resources.

To restrict the analysis to a simple, yet interesting, situation, consider the case depicted in Figure 2, where $M_0 < \overline{M} < \overline{\overline{M}}$. Other configurations can be considered analogously. Start with the region where total investment lies below $\overline{\overline{M}}$. Increases in the availability of resources within each technology region - $(0, M_0)$ or $(M_0, \overline{\overline{M}})$ - affect land size positively. If there is no change in the choice of production technology, a reduction in credit leads to a decrease in optimal farmland size and thereby reduces deforestation. However, changes in the availability of resources that cause farmers to switch between technology regions - from $(0, M_0)$ to $(M_0, \overline{\overline{M}})$ or vice-versa - have an ambiguous effect on land size. A reduction in credit may lead the farmer to substitute the modern technology for the traditional one, potentially leading to an increase in optimal farmland size and deforestation. In the region where total investment lies above $\overline{\overline{M}}$, farmers are not credit constrained, so changes within this region do not affect optimal farmland size. Thus, a reduction in M_b that keeps the farmer in the unconstrained region does not affect deforestation, but a reduction in the availability of resources that pushes the farmer into the $(M_0, \overline{\overline{M}})$ interval will reduce optimal farmland size and deforestation. An even stronger reduction in the availability of resources that further pushes the farmer into the $(0, M_0)$ interval has an ambiguous impact on deforestation. Propositions 1-3 summarize these results in the context of the credit reduction implied by Resolution 3,545.

Proposition 1: If the reduction in the availability of subsidized rural credit causes a reduction in deforestation, we can conclude that: (i) farmers are credit constrained; and (ii) credit and deforestation have a positive relationship within technology regions.

Proposition 2: If the reduction in the availability of subsidized rural credit does not affect the amount of cleared land, we can conclude that: (i) either farmers are not credit constrained (they could simply be substituting subsidized rural credit by market credit); or (ii) farmers are credit constrained, but are changing from the modern to the traditional technology.

Proposition 3: If the reduction in the availability of subsidized rural credit implies an increase in deforestation, we can conclude that: (i) farmers are credit constrained; and (ii) they are changing from the modern to the traditional technology.

In summary, a subsidized credit policy restriction can: (i) serve as evidence of credit constraints if we observe an impact on deforestation; and (ii) reveal whether the relevant margin is change in optimal farmland size for a given technology (decreasing deforestation) or change across production technologies (increasing deforestation).

5. Data, Descriptive Statistics, and Stylized Facts

This section introduces the data used in our empirical evaluation of Resolution 3,545, presents descriptive statistics, and discusses stylized facts to characterize aggregate trends for our variables of interest.

5.1. Data on Rural Credit

Our analysis is based on two panels of municipality-level data covering the 2002 through 2011 period. The first panel is constructed from a contract-level microdata set of rural credit loan contracts compiled by the Central Bank from Recor data. This is an administrative microdata set encompassing all rural contract records negotiated by official banks - both public and private - and credit cooperatives in the Legal Amazon states of Acre, Amazonas, Amapá, Maranhão, Mato Grosso, Pará, Rondônia, Roraima and Tocantins.[10] It contains detailed information about each contract, such as the exact day on which it was signed, its value in BRL, the contracted interest rate and maturation date, its intended use by agricultural activity, and the category under which credit was loaned (short-term operating funds, investment, or commercialization). The data set also contains information about the official source of funding for each contract, allowing us to identify whether loans fit into Pronaf or non-Pronaf credit lines. All contracts are linked to a code identifying the municipality in which the borrower's landholding is located. We add up the value of the contract loans across all days in each month and each municipality to convert the microdata panel into a municipality-by-month panel.

We merge our panel of municipality-by-month credit loans data with a geocoded map containing information on the biome's geographic limits and municipalities' location, and use this to identify, for each sample municipality, whether it is entirely located inside the Amazon Biome. We also construct variables indicating the shortest linear distance, in kilometers, between each municipality's border and the biome frontier. Using this variable, we can create subsamples of municipalities, both inside and outside the Amazon Biome, located within specific distances to the biome frontier.

To smoothen the large cross-sectional variation in values of credit contracts generated by different municipality sizes, we use a normalized measure of rural credit. This normalization ensures that our analysis captures relative variations in credit lending within municipalities. The variable is constructed according to the following expression:

$$Credit_{it} = \frac{C_{it} - \overline{C}_{it}}{sd\left(C_{it}\right)} \qquad (10)$$

where $Credit_{it}$ is the normalized amount of rural credit loaned in municipality i and

[10] Only a fraction of the state of Maranhão is considered part of the Legal Amazon. Our sample only includes municipalities from this fraction.

month-year t; the term C_{it} is the amount of rural credit loaned in municipality i and month-year t in BRL; and the terms $\overline{C}_{it}$ and $sd\left(C_{it}\right)$ are, respectively, the mean and the standard deviation of the amount of rural credit loaned in municipality i over the 2002 through 2011 period. The variable C_{it} replaces $Credit_{it}$ in robustness checks.

The final data set containing information on rural credit, time, and geographic variables at the municipality-by-month level is used to evaluate the impact of Resolution 3,545 on rural credit loans. Our sample does not include municipalities crossed by the biome frontier, since only those farmers whose landholdings are entirely located within the biome in these municipalities are subject to the resolution's conditions. The full sample is composed by 713 Legal Amazon municipalities (458 inside and 255 outside the Amazon Biome). We use our constructed distance variable to create a restricted subsample that only includes municipalities located within 100 kilometers of the biome frontier. This subsample has 387 municipalities (132 inside and 255 outside the Amazon Biome). We construct a second restricted subsample composed of municipalities where the pre-2008 average value of annual credit loans for cattle ranching was higher than that for crop production. This "cattle-oriented" subsample contains 301 municipalities located inside the Amazon Biome and 154 outside it. Finally, we construct an analogous restricted subsample of municipalities where the pre-2008 average value of annual credit loans for crop production was higher than that for cattle ranching. This "crop-oriented" subsample contains 133 located inside the Amazon Biome and 101 outside it.

5.2. Data on Deforestation

The second panel of data relates rural credit loans to deforestation at the municipality level. 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 credit panel into a municipality-by-year credit 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.[11] We recode credit loans accordingly, summing up monthly data into an annual basis, where year t data sums information over the twelve months leading up to August of t.

For any given municipality, cloud cover 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 PRODES/INPE.

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

To smoothen the cross-sectional variation in deforestation that arises from municipality size heterogeneity, we use a normalized measure of the annual deforestation increment. The normalization ensures that our analysis considers relative variations in deforestation increments within municipalities. The variable is constructed according to the following expression:

$$Deforest_{it} = \frac{ADI_{it} - \overline{ADI}_{it}}{sd\,(ADI_{it})} \tag{11}$$

where $Deforest_{it}$ is the normalized annual deforestation increment for municipality i and year t; ADI_{it} is the annual deforestation increment measured in municipality i between the 1$^{\text{st}}$ of August of $t-1$ and the 31$^{\text{st}}$ of July of t; and $\overline{ADI}_{it}$ and $sd\,(ADI_{it})$ are, respectively, the mean and the standard deviation of the annual deforestation increment calculated for each i over the 2002 through 2011 period. The variable ADI_{it} replaces $Deforest_{it}$ in robustness checks. Our sample does not include municipalities that showed no variation in deforestation throughout the sample years, as this variation is needed to calculate the normalized variable.

The final data set containing information on deforestation, rural credit, time, and geographic variables at the municipality-by-year level is used to estimate the effects of the credit restriction on deforestation. Again, we do not include municipalities crossed by the biome frontier. The full sample comprises 575 Legal Amazon municipalities (439 inside and 136 outside the Amazon Biome). We also construct the three restricted subsamples introduced in Section 5.1. Their composition is as follows: 251 municipalities within 100 kilometers of the Amazon Biome frontier (115 inside and 136 outside the biome); 406 cattle-oriented municipalities (301 inside and 105 outside the biome); and 141 crop-oriented municipalities (110 inside and 31 outside the biome).

5.3. Agricultural Output Prices and the Demand for Credit

Agricultural prices are endogenous to local agricultural production. Thus, to control for fluctuations in the demand for rural credit 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. (2011), 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 2011 BRL and are expressed as an index with base year 2011.

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

$$PPA_{itc} = PP_{tc} * A_{ic,2000-2001} \tag{12}$$

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.[12] 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.

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.

5.4. Stylized Facts and Trends

This section presents stylized facts and trends for rural credit and deforestation over the past ten years. In this set of descriptive results, the evolution of aggregate credit

[12] 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).

is influenced by both economic conditions and changes in the regulatory and institutional landscape. Tables and figures shown were built from the contract-level credit loan microdata set and the deforestation data set.

Table 1 presents descriptive statistics for average annual amounts of rural credit and deforestation at the municipality level. Figures for Amazon Biome municipalities before and after the implementation of Resolution 3,545 are compared with those for Legal Amazon municipalities outside the biome. The statistics point towards more accentuated aggregate rural credit growth in the post-resolution period in Legal Amazon municipalities located outside the Amazon Biome, where borrowers were not subject to the resolution's restrictions. Average Pronaf loans inside the biome also seem to have grown more than non-Pronaf loans, as is to be expected in light of the exemptions introduced for small-scale producers operating in the Amazon Biome. Average deforestation, which is significantly higher in Amazon Biome municipalities, dropped sharply both inside and outside the biome.

Stylized facts also hint at potential effects of Resolution 3,545. In Figure 3, average rural credit loan trends for Amazon Biome municipalities do not seem to follow those for its unrestricted counterpart outside the biome in the post-2008 period. The difference in growth rates appears in both cattle and crop-oriented samples, suggesting that the resolution imposed a binding credit constraint for rural producers within the biome. As the pattern of credit loan trends differ for cattle and crop-oriented samples, our empirical analysis explores whether the resolution's impact depends on economic activity heterogeneity.

A closer look at the evolution of rural credit loans throughout 2008 reveals that the constraint seems to have been anticipated by credit takers. Figure 4 illustrates this phenomenon. While credit concession in 2006 and 2007 concentrated in the second half of each year, it followed a very different pattern in 2008, peaking in April and again in June. The total amount of credit negotiated in 2008, however, is similar to that of previous years. Considering that the adoption of the measures established in Resolution 3,545 was optional as of May 1st and compulsory as of July 1st, the unseasonable peaks in 2008 likely reflect borrowers' efforts to have early access to resources that would soon be restricted. Consequently, an accentuated decrease in the concession of credit was not observed in 2008 despite the restrictions imposed by Resolution 3,545. This behavior is more clearly seen in the trends for cattle-specific contracts than for crop-specific ones, perhaps due to the intrinsically seasonal component of crop production. Alternatively, this could be because crop farmers were less vulnerable to the reduction in subsidized rural credit. If able to access credit from other sources even after the resolution had been adopted, they would have had less need to anticipate credit prior to the policy.

In addition to assessing the resolution's impact on rural credit concession, we are interested in understanding how it affected deforestation. Figure 5 portrays the evolution of average municipality-level deforestation. Deforestation dropped significantly starting in the mid-2000s in Legal Amazon municipalities both inside and outside the Amazon Biome. In the post-2008 period, however, trends for biome municipalities appear to behave differently from those for non-biome municipalities - deforestation exhibits more accentuated drops inside the biome immediately after the adoption of Resolution 3,545 in both cattle and crop-oriented subsamples. Although not yet conclusive, this could be an indication that deforestation is a credit-dependent activity and that there are relevant credit constraints for forest clearing in the Amazon Biome.

The stylized facts discussed in this section provide a descriptive overview of how Resolution 3,545 might have affected the evolution of rural credit and deforestation in the Amazon Biome. However, these facts capture the effects of other influencing factors, particularly those of economic circumstances in the Amazon Biome during the period of interest. To evaluate the impact of Resolution 3,545, we must isolate the effect of the resolution from that of other determinants of rural credit.

6. Empirical Strategy

This section describes the empirical strategy used to identify the causal effect of rural credit on deforestation. Since only equilibrium prices and quantities are observed in the credit market, many of the identification concerns mentioned in the literature have been related to reverse causality and omitted variables. Reverse causality might take place if the expansion of agricultural activities beyond the farmer's landholding is done at the expense of public areas of forest. In this case, deforestation and appropriation of public land increase real estate and collateralized asset-based lending, thereby allowing the farmer to overcome borrowing constraints. Omitted variables that are simultaneously associated with credit and land use, such as regional growth and agricultural output prices, may also trivially jeopardize identification. In this paper we limit identification problems by exploring the different margins of a credit policy break that generated exogenous variations in credit supply, within and across Brazilian Amazon municipalities, in the late 2000s.

Our strategy follows a two-stage procedure. First, we evaluate Resolution 3,545's impact on rural credit market quantities. Then, we use different margins of this policy change to derive instrumental variables for rural credit, which help us identify a causal effect of rural credit on deforestation in a two-stage least squares (2SLS) estimation.

6.1. First Stage: Impact on Rural Credit

We explore different dimensions of Resolution 3,545 to provide a general characterization of its impacts on rural credit. First, the resolution specifically established that the conditions to credit concession applied to municipalities in the Amazon Biome only. This generates an explicit geographic cleavage between two groups of municipalities within the Legal Amazon. We refer to municipalities located entirely within the Amazon Biome as the intervention group. Legal Amazon municipalities located outside the biome form the control group. Although intervention and control groups may systematically differ in terms of long-persistent geographical characteristics, both have been exposed to similar economic fluctuations and political cycles. This is particularly consistent for municipalities near the biome frontier. This specific geographic break in Resolution 3,545, nested within our monthly data on municipalities, allows us to perform a difference-in-differences estimation defined by the following equation:

$$Credit_{it} = \alpha_i + \phi_t + \beta_1(Biome_i * Post2008_t) + \beta_2 Prices_{it} + \beta_3 Priority_{it} + \epsilon_{it} \qquad (13)$$

where $Credit_{it}$ is the normalized amount of rural credit loaned in municipality i and time t, which indexes a specific month throughout the period.

We estimate models for total municipality rural credit loans, as well as for cattle and crop-specific loans separately. Our variable of interest is the interaction of a dummy indicating whether the municipality is located within the Amazon Biome, $Biome_i$, with a variable that marks the period after the implementation of Resolution 3,545, $Post2008_t$, which includes all years from 2008 onwards. We consider all of 2008 as part of the post-resolution period to avoid finding a significant coefficient when, in fact, we are simply capturing the anticipation effect (recall that credit concession in the biome was relatively high in the first half of 2008 and relatively low in the second half).

The term α_i includes municipality fixed effects, which absorb initial conditions and persistent municipality characteristics, such as geography and transport infrastructure. The term ϕ_t includes month fixed effects, which also absorb year fixed effects by construction. These variables 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 $Priority_{it}$ indicates municipalities included in a priority list of top deforesters, which have recently been the focus of conservation policy efforts. The parameter of interest β_1 captures the causal effect of Resolution 3,545 on rural credit if the residuals contain no omitted variables driving the correlation between the policy and either the demand for and/or supply of credit loans.

We rely on another difference-in-differences strategy to explore a second dimension of Resolution 3,545's design. As explained in Section 3.2, Resolution 3,545 established exemptions regarding requirements for small producers. Considering that Pronaf beneficiaries are, by definition, small producers, and taking into account that the restrictive conditions were eased specifically for credit loans contracted via Pronaf credit lines, the comparison between Pronaf and non-Pronaf loans within municipalities, before and after the resolution, offers another source of exogenous variation in credit supply. The specificities of the policy design therefore enable us to construct intervention and control groups within municipalities located in the Amazon Biome. We take advantage of this by estimating a triple-differences model that compares rural credit loans before and after the implementation of Resolution 3,545, in municipalities located inside and outside the biome, and between Pronaf and non-Pronaf groups within municipalities. This strategy, based on an extension of model (13), is defined by the following equation:

$$
\begin{aligned}
Credit_{itk} = \alpha_i + \phi_t + \beta_1 Nonpronaf_{it} + \beta_2(Nonpronaf_{it} * Biome_i) + \\
+\beta_3(Nonpronaf_{it} * Post2008_t) + \beta_4(Biome_i * Post2008_t) + \\
+\beta_5(Nonpronaf_{it} * Biome_i * Post2008_t) + \beta_6 Prices_{it} + \beta_7 Priority_{it} + \epsilon_{itk}
\end{aligned}
\tag{14}
$$

where $Credit_{itk}$ is now the amount of rural credit loaned in municipality i, at time t, and of type $k \in \{\text{Pronaf}, \text{non-Pronaf}\}$. The term $Nonpronaf_{it}$ is a dummy assuming value 1 if ($k =$ non-Pronaf) and 0 otherwise, which we interact with the dummies $Post2008_t$ and $Biome_i$. The parameter of interest β_5 is expected to capture the marginal variation in non-Pronaf credit loans within the Amazon Biome after the implementation of Resolution 3,545.

We discuss some caveats associated with models (13) and (14) in robustness checks. In all specifications, standard errors are robust to arbitrary forms of heteroscedasticity and clustered at the municipality level to allow for correlation at a given time, as well as across time within municipalities.

6.2. Second Stage: Impact on Deforestation

Using the municipality-by-year panel detailed in Section 5.2, we can therefore use models (13) and (14) as first stage regressions in a 2SLS approach, which helps us identify a causal effect of rural credit on deforestation.

We begin by defining a second stage specification for which model (13) is the first stage:

$$
Deforest_{it} = \alpha_i + \phi_t + \delta_1 \widehat{Credit}_{it} + \delta_2 Prices_{it} + \delta_3 Priority_{it} + X_{it}\delta_4 + \epsilon_{it} \tag{15}
$$

where $Deforest_{it}$ is deforested area in municipality i and year t, and $\widehat{Credit}_{it}$ is the total value of rural credit loans in municipality i and year t, instrumented by the interaction variable $(Biome_i * Post2008_t)$. The terms α_i, ϕ_t, $Prices_{it}$, and $Priority_{it}$ are defined as in model (13), although the subscript t now indexes year. All regressions include the term X_{it}, which adds controls for the size of unobservable areas (or measurement error) during the period of remote sensing.

The second stage specification alternatively uses model (14) as first stage, and is defined analogously to model (15). In this case, however, the unit of observation is the cell indexed by itk, where $k \in \{\text{Pronaf}, \text{non-Pronaf}\}$. The dependent variable is now $Deforest_{it}$, invariant to k. The variable of interest is $\widehat{Credit}_{itk}$, the total value of rural credit loans in municipality i and year t, instrumented by the interaction variables $Biome_i * Post2008_t$, $Nonpronaf_{it} * Post2008_t$, and $Nonpronaf_{it} * Biome_i * Post2008_t$.

The identification hypothesis in both 2SLS specifications is that, conditioned upon the control variables, instrumented credit is orthogonal to any latent determinant of deforestation. Alternatively, the instrumental variables should be strongly correlated with rural credit loans, but orthogonal to the error term in the second stage regression. As argued above, this strategy is valid because Resolution 3,545 provides sources of plausibly exogenous variation in rural credit loans in the Legal Amazon.

Resolution 3,545 was formally designed to restrict the concession of credit in the Amazon Biome, with exceptions rendered to small producers. As argued in the previous section, these two dimensions of the resolution's design provide potential sources of exogenous variation in rural credit loans within the Legal Amazon.

A third dimension of its design strengthens the validity of using the resolution-induced change in rural credit as an exogenous source of variation. Resolution 3,545 conditions were such that borrowers who proved that they had the intention to comply with environmental regulation were allowed access to credit. This meant that producers who feared the resolution might affect their future access to credit could signal an intent to change their deforestation behavior in the future and be considered compliant with environmental regulation at the present. This could invalidate the exclusion restriction of our instrumental variable, should farmers who were not meeting environmental regulation at the present alter their deforestation behavior for reasons other than a concurrent reduction in credit caused by Resolution 3,545. The resolution's design, however, mitigates this issue. It introduces a bias that actually runs in the opposite direction of our expected positive coefficient, since these producers will suffer no credit effect (as their intention to comply makes them compliers), but still reduce deforestation, driving downwards the coefficient of interest. Yet, because in terms of meeting the resolution's requirements intention to comply was equivalent to compliance, there were no other channels linking Resolution 3,545 and deforestation during the period of interest. This eliminates a potential source of concern regarding the validity of using the policy change as an instrument for credit and enables us to empirically examine the relationship between credit and deforestation.

7. Policy Implementation and Effectiveness

This section evaluates the impacts of Resolution 3,545 on rural credit loans. We start by describing the main results obtained using the empirical strategies detailed in Section 6.1. We then explore heterogeneity and characterize the policy impact. Finally, we discuss caveats and present robustness checks.

7.1. Credit Constraint

Table 2 presents the results for regressions based on model (13) (Panel A) and model (14) (Panel B), using normalized rural credit at the municipality level as the dependent variable. Coefficients in Panel A show that, conditioned upon controls, Resolution 3,545 was associated with a reduction in rural credit concession in the Amazon Biome, as compared with the rest of the Legal Amazon. This effect is significant for total rural credit, as well as for cattle and crop-specific loans. The impact on cattle-specific loans is larger than that on crop-specific loans, and the difference between their respective coefficients is statistically significant. A plausible explanation for this difference is that cattle ranching is relatively more land-intensive than crop farming, and therefore less compliant with environmental regulation. In fact, previous studies have shown that three quarters of the land cleared in the Legal Amazon have been used for cattle ranching-related activities, although the relative participation of crop farming-related activities in cleared forest areas has recently increased (see Chomitz and Thomas (2003) and Morton et al. (2006)).

Panel B corroborates the findings of Panel A, reporting even larger impacts when considering the resolution's impact on different kinds of credit takers. For a given municipality in the Amazon Biome, credit for the non-Pronaf category decreased relatively more than for the Pronaf category. These results are to be expected, given that Resolution 3,545 and associated legislation exempted small-scale producers - particularly Pronaf beneficiaries - from the more restrictive conditions.

In Table 3, we present results from a counterfactual analysis to quantify the magnitude of the impact. Our estimates indicate that, in the absence of the policy, total rural credit and cattle-specific credit in the Amazon Biome would have been much greater than was actually observed from 2008 onwards. Based on coefficients from Panel A, in which the control group is composed of municipalities outside the Amazon Biome, we estimate that approximately BRL 2.9 billion (USD 1.4 billion) were not loaned in the 2008 through 2011 period due to restrictions imposed by Resolution 3,545. This is equivalent to about BRL 725 million (USD 350 million) less credit per year. The reduction in cattle-specific credit loans accounts for 90% of this difference. Estimates obtained from comparing the resolution's impact on Pronaf and non-Pronaf credit are very similar, although the relative role of cattle-specific loans is slightly smaller in this simulation.

7.2. Heterogeneity

Having estimated a significant impact of Resolution 3,545 on the concession of rural credit in the Amazon Biome, we are now interested in exploring potential heterogeneous effects arising from sectoral heterogeneity. Using the cattle-oriented and crop-oriented subsamples described in Section 5.1, we test whether the resolution's impact differed among municipalities with different leading economic activities. These restricted samples further allow us to test whether our estimated coefficients have been jeopardized by comparing municipalities that are not, in fact, economically comparable.

Table 4 presents results obtained by reproducing the specifications of Table 2 using the restricted cattle and crop-oriented subsamples. The significant negative coefficient estimated for our variable of interest in the cattle-oriented subsample confirms that Resolution 3,545 reduced cattle-specific loans inside the Amazon Biome, even when the comparison is made using only cattle-oriented municipalities both inside and outside the biome. This supports our main results, providing further evidence that the credit constraint was caused by the policy change. Results are similar for the crop-oriented subsample. In fact, restricting the sample to municipalities that are economically more alike has highlighted the policy impact, as estimated coefficients are even larger than in our original specifications.

We also consider the distribution of loan size to analyze the impact of heterogeneity along a different dimension. The dependent variable is now the number of credit contracts in each municipality categorized according to contract size. This exercise uses the specification that takes all municipalities in the Amazon Biome as the treatment group, and all Legal Amazon municipalities outside the biome as the control group. We start by dividing credit contracts into three categories based on their size: small (up to the median), medium (between the median and the 75^{th} percentile), and large (above the 75^{th} percentile). We then aggregate these contracts by municipality to use as dependent variable. Given that small producers benefitted from less stringent conditions for credit concession, while medium and large producers faced more restrictive conditions, we expect Resolution 3,545 to have a negative impact on the number of medium and large contracts, and a neutral impact on small contracts. In fact, a positive impact on small contracts could also be expected, should credit agents choose to reallocate resources away from the more restricted group of credit takers and towards small producers.

Table 5 indicates that Resolution 3,545 had a significant negative impact on the number of medium and large cattle-specific credit contracts. The effect on crop-specific contracts is marginally significant and negative for medium credit contracts. The absence of a significant negative impact on large producers suggests they could more easily meet the conditions required in Resolution 3,545, be it due to their better organizational capacity to follow through with the regularization procedure, or to their easier access to external funding. After all, in regions where crop production is predominant in the Amazon Biome, rural economic activities are mostly based on large-scale soybean farmers, who likely have other sources of credit financing. Table 5 shows, moreover, that the resolution had a significant positive effect on small cattle-specific credit contracts. This corroborates the hypothesis stating that Resolution 3,545 had a distributional effect, leading credit agents to change their allocation of resources, moving it away from the group of credit takers subject to the resolution's conditions and towards the group that received legal exemptions.

Overall, the results obtained so far show that Resolution 3,545 produced differentiated effects within the Amazon Biome. While the policy change led to a reduction in the number of medium and large cattle-specific contracts and in the number of medium crop-specific contracts, it had no impact on both large and small crop-specific loans, and a positive impact on small cattle-specific loans. The resolution also appears to have led to greater credit reduction in municipalities where cattle ranching is the main economic activity, though the impact on rural credit in municipalities where crop production is the main economic activity is not negligible.

7.3. Caveats and Robustness Checks for Credit Results

Although our results are generally consistent with Resolution 3,545's institutional context, we run a series of tests to check their robustness. We focus on three sources of potential concern. First, it could be that our regressions capture a spurious effect due to the definition of the intervention and comparison groups that we erroneously attribute to the policy change. Second, our identification strategy relies on the hypothesis that, after controlling for observable characteristics and municipality and time fixed effects, both intervention and control groups are comparable. Yet, municipalities in different regions could differ in terms of regional economic dynamics or non-observable regional characteristics. In this sense, comparing municipalities that are near the Amazon Biome frontier with those that are far from it could jeopardize our results. Third, the use of a normalized dependent variable could be driving our results.

We tackle these issues in three sets of robustness checks. First, we explore the resolution's conditions - namely, its restriction to the Amazon Biome and the exemptions created for small producers - to perform falsification tests. We start by considering the specifications presented in Table 2, Panel A, in which municipalities inside the Amazon Biome are taken as the treatment group and compared to Legal Amazon municipalities outside the biome. In the first falsification test, we repeat the exercise using the amount of credit loaned strictly to Pronaf beneficiaries as the dependent variable. As this group of borrowers benefitted from the aforementioned institutional exemptions, we expect this falsification test to capture no significant impact of Resolution 3,545 on Pronaf credit inside the biome. If anything, the test could return a positive significant impact of the resolution on Pronaf credit, should its distributional impact actually have caused a shift of credit towards unrestricted small producers inside the biome, as discussed in Section 7.2. We then move on to the specifications presented in Table 2, Panel B, in which we compare Pronaf and non-Pronaf credit inside and outside the Amazon Biome. In the second falsification test, we again repeat the specifications, but restrict our sample to Legal Amazon municipalities located outside the biome. As Resolution 3,545 conditions did not apply to the Legal Amazon as a whole, we expect this falsification test to capture no significant negative impact of the resolution on Pronaf and non-Pronaf credit outside the biome.

Panels A.1 and B.1 of Table 6 present the results for the two falsification tests. In Panel A.1, we note that the coefficient for the $Biome * Post2008$ variable is now insignificant, as expected. When using crop-specific contracts, the coefficient is positive, although relatively small, indicating that a small shift in allocation of financing resources towards Pronaf beneficiaries did occur for crop-specific loans. In Panel B.1, the coefficient of interest becomes non-negative, as expected. When focusing on cattle-specific contracts, results indicate that non-Pronaf credit was increasing more than Pronaf credit. Interestingly, should this pattern also apply to non-Pronaf credit inside the Amazon Biome, the real impact of Resolution 3,545 could be even higher than we have estimated.

Our second set of robustness checks tests if results have been driven by regional or economic differences between municipalities. To do this, we create a subsample restricted to municipalities that are within 100 kilometers of the Amazon Biome border. Treatment and control groups still refer to Legal Amazon municipalities inside and outside the biome, respectively, but now both treatment and control municipalities must meet the maximum distance to biome border criteria. This subsample contains municipalities that are geographically closer to one another, and are thus thought to be more alike across both observable and non-observable fixed characteristics and trends.

Panel A.2 and B.2 in Table 6 show the results for this second robustness check. Specifications are analogous to those of Table 2. Robustness results shown in Panel A.2 are consistent with those of our main specifications and estimated coefficients are, in fact, higher. This suggests that municipalities closest to the biome frontier, which are probably in a more economically dynamic region, are more heavily dependent on credit and were thus more affected by the conditions established in Resolution 3,545. Moreover, it seems plausible that, in a region with more dynamic agricultural production, producers are less compliant with environmental regulations. Estimated coefficients of interest remain negative and significant in Panel B.2, except in the specification for crop-specific loans, which is now less significant, although of magnitude similar to that of Table 2.

The third and final robustness check consists of replacing the normalized credit variable with an absolute measure of total rural credit to test if our results have been driven by inaccuracies introduced via the normalization of the dependent variable. Results are presented in Panels A.3 and B.3 of Table 6, again using the specifications of Table 2. Estimated coefficients are essentially the same as those obtained in our main regressions.

Overall, the robustness of our results support the specifications chosen for our main regressions, as well as the interpretation of our results.

8. Credit Constraint and Deforestation

This section presents the results of the second stage of our 2SLS strategy, that is, the impact of the credit constraint on deforestation in the Amazon Biome. As mentioned in Section 1, the direction of the effect of a reduction in credit on deforestation depends on how rural credit is used. If used to improve production techniques and intensify productivity per unit of land used for agricultural production, a credit restriction could limit productivity gains and thereby generate an incentive for producers seeking to expand their production to move into new areas. If, however, credit is used to expand production at the extensive margin - to clear forest areas and accommodate a growing herd, for example - the expected result of a reduction in credit should be a decrease in deforestation. Which of these mechanisms prevails in the Amazon Biome is an empirical question.

We can also think about our regressions as an econometric test about the existence of binding credit constraint in activities related to deforestation. The usual way to assess if a firm is credit constrained in terms of investment, for instance, is to measure if the firm increases its amount of investment following a policy change that facilitates its access to credit (Banerjee and Duflo (2012)). Should the firm do so, it had not yet reached its optimal amount of investment before the policy - the firm faced credit constraints. The argument we make here is analogous to that of the credit constrained firm, but runs in the opposite direction. If a deforester decreases the amount of forest cleared due to a restriction in subsidized credit - meaning he would increase deforestation if he had more subsidized credit - then the deforester is credit constrained. In other words, the deforester requires access to credit to implement his activities, be it the actual clearing of forest or activities practiced after the forest area has been converted. If he is changing his investment (deforestation) behavior as a response to a reduction in the availability of subsidized credit, then he is not substituting the lost subsidized credit for market credit, which serves as evidence that he is credit constrained.

At the same time, if farmers are decreasing the amount of deforestation in response to a reduction in subsidized credit availability, it means that, within the theoretical framework discussed in Section 4, they are not switching from the modern to the traditional technology. Rather, they are adjusting their optimal farmland decision within regions of fixed technology. Should they be changing between technologies, we would observe an increase in deforestation as a response to a reduction in availability of subsidized credit.

8.1. *Main Results*

Table 7 presents results for the evaluation of how Resolution 3,545 affected deforestation in the Amazon Biome. Column 1 displays coefficients estimated in a fixed effects specification without the use of instrumental variables (IV). The coefficient capturing the impact of rural credit on deforestation is positive, but very small. As discussed in Section 6, however, these specifications suffer from an endogeneity problem, due both to omitted variables and simultaneity. The IV approach is used to tackle this problem. In column 2, we present coefficients estimated in IV regressions that instrument rural credit by the policy variable $Biome * Post2009$. Results suggest that credit has a positive and strongly significant relationship with deforestation, and that the reduction in the concession of rural credit in the Amazon Biome caused by Resolution 3,545 contributed to the curbing of deforestation in the biome. In particular, municipalities that were most affected by the resolution-induced credit reduction were also the ones that presented the sharper drops in deforestation. Similar results, shown in column 3, are obtained when using the triple interaction term $Nonpronaf * Biome * Post2009$ as an instrumental variable, in addition to the variables $Biome * Post2009$ and $Nonpronaf * Post2009$.

To better grasp the economic significance of our results, we conduct counterfactual simulations analogous to those presented in Section 7.1, but now using the specification of Table 7, column 2. Results shown in Table 8 indicate that, in the absence of Resolution 3,545, deforestation in the Amazon Biome would have been 2,783 square kilometers greater than was actually observed in the 2009 through 2011 period. This is equivalent to an increase of about 18% over observed deforestation. In 2010, for example, deforestation would have totaled 7,398 square kilometers had the resolution not been introduced, compared to the 5,657 square kilometers that were actually observed. This result is particularly impressive if we take into consideration the comparatively low deforestation rates recorded during this period.

Our results serve as evidence of the existence of binding credit constraints in the Amazon Biome. Farmers appear to have responded to a reduction in the availability of subsidized credit by changing their optimal allocation of resources and thereby reducing deforestation. Were there no binding credit constraints, farmers' actions would not have resulted in a change in deforestation in the post-policy period. Moreover, our results suggest that the prevailing mechanism relating rural credit and forest clearings in the Amazon Biome is that in which credit is used to expand production by operating in the extensive margin of land use, and not by increasing productivity. The predominance of cattle ranching in the region and the correlation between this activity and extensive land use in the Amazon could explain these results. Intensification of land use for crop farming in Brazil is also much more developed than for cattle ranching.

8.2. Heterogeneity

To test whether the relationship between credit and deforestation depends on regional heterogeneity, particularly that of leading economic activity, we repeat the empirical exercise of Section 8.1 using cattle and crop-oriented municipalities. This allows us to investigate if different types of economic activity use credit differently, increasing production either at the extensive or intensive margin.

Table 9 presents heterogeneity results. Coefficients estimated for cattle-oriented municipalities, shown in Panels A.1 and B.1, are very similar to those of Table 7, confirming the positive relationship between credit and deforestation. The reduction in credit concession caused by Resolution 3,545 therefore implied a reduction in deforestation in municipalities where cattle ranching predominates. Yet, coefficients estimated for crop-oriented municipalities, shown in Panels A.2 and B.2, indicate that rural credit has no impact on deforestation. As has been documented before (FAO (2007)), crop production in Brazil underwent several technological improvements, allowing production to increase in the intensive margin. If farmers are able to increase production via intensification, they will not use credit to clear new land for production. In this case, changes in rural credit do not affect deforestation.

The results can also be regarded as evidence that crop farmers are not credit constrained. They may have compensated the reduction in subsidized rural credit with an increase in other sources of financing (market credit), thereby maintaining their pre-resolution levels of investment, farmland, and deforestation. Cattle ranchers, on the other hand, seem to be credit constrained (or at least became constrained after the policy change), since they reduce the amount of deforestation in response to the reduction in the availability of credit.

8.3. Robustness Checks

The concerns mentioned in Section 7.3 also apply to our second-stage regressions. As the Amazon is an extremely large area, municipalities in the treatment groups systematically differ from those in the control groups. To tackle this issue, we run robustness checks using the subsample of municipalities within 100 kilometers of the biome border. Results for this test, shown in Panels A.1 and B.1 of Table 10, indicate that not only are estimated coefficients significant, but also greater in magnitude. As the frontier covers an area with very high deforestation rates - it contains a large fraction of the so-called "Arc of Deforestation," deforestation hotspots in the Brazilian Amazon - this result is to be expected. As argued in Section 7.3, the economic dynamics of this region likely makes this area more dependent on rural credit. An exogenous reduction in rural credit would therefore have a higher impact on agricultural activities in the region, and thereby more strongly affect deforestation.

To test whether our results are driven by the use of the normalized variables, we also repeat 2SLS estimations using absolute values for the deforestation and rural credit variables. Results presented in Panels A.2 and B.2 of Table 10 show that coefficients estimated using IV regressions remain positive and significant, although their magnitude varies according to the specification.

Finally, to test whether our results are driven by a natural convergence of high to low deforestation rates, we control for an interaction between a non-linear trend and the 2002 deforestation rates in each municipality. If the results are driven only by the convergence process, our main coefficient should become zero. Results presented in Panels A.3 and B.3 of Table 10 show that coefficients remain positive and significant even when we control for these trends. First stage results are also significant when controlling for these trends, indicating that our instruments are not weak. These estimates corroborate the idea that our results are not driven by a natural process of convergence.

The robustness tests conducted support our main specifications and interpretation of results. The significant reduction in rural credit concession caused by Resolution 3,545 seems to have played an important role in curbing forest clearings in the Amazon Biome in the late 2000s and early 2010s.

9. Final Comments

In this work, we investigate the reduction in the availability of credit implied by Resolution 3,545. We focus on key aspects of the implementation and consequences of this novel credit policy, exploring the associated exogenous variation in rural credit concessions to empirically evaluate the resolution's impact on both rural loans and forest clearings.

We document that credit takers anticipated the credit constraint imposed by Resolution 3,545, but that the policy change did, in fact, lead to a reduction in the concession of rural credit in the Amazon Biome. Counterfactual simulations suggest that, in the 2008 through 2011 period, approximately BRL 2.9 billion (USD 1.4 billion) were not loaned due to restrictions imposed by the resolution. This result was largely driven by a reduction in cattle-specific loans. Resolution 3,545 also caused a decrease in total amount of non-Pronaf credit, as compared to Pronaf credit, within the biome. This is to be expected in light of the legal exemptions that were introduced for small-scale producers regarding legal requirements to access rural credit.

Estimations from instrumental variable regressions further show that the resolution-induced restriction in credit helped contain deforestation in the Amazon Biome. This result suggests that the expansion of agriculture at the extensive margin in the biome is financially constrained. Counterfactual simulations indicate that over 2,700 square kilometers of forest would have been cleared from 2009 through 2011, had Resolution

3,545 not been implemented. Considering that deforestation rates in the late 2000s and early 2010s were around 7,000 square kilometers per year, the effect attributed to the resolution is quite substantial.

The results yield two key policy implications. First, the evidence shows that conditional rural credit can be an effective policy instrument to combat deforestation. Yet, the differential effects across sectors and regions suggest that it should complement, rather than substitute, other conservation efforts. Our findings - namely that the credit reduction came mostly from the reduction of cattle loans rather than crop loans - also indicate that pre-existent socioeconomic circumstances matter for policy impact. Implementation details also matter. The lag between the announcement and enforcement of the resolution induced farmers to anticipate credit in 2008, mitigating part of the effect. Also, less stringent requirements and exemptions determined that large producers were more affected than small ones.

Second, our analysis suggests that the financial environment in the Amazon is characterized by significant credit constraints. Specially in municipalities where cattle ranching is the predominant economic activity, fewer resources correspond to less deforestation. This is a key finding with implications for policy design. In particular, policies that increase the availability of financial resources (for example, payments for environmental services) could lead to higher deforestation rates, depending on the economic environment and existing resources in the area. Our results do not suggest that these policies will necessarily increase deforestation, but that policy design should take into account the nature of financial constraints prevailing in the Amazon to avoid potentially adverse rebound effects.

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Figure 1: The Brazilian Amazon Biome and Legal Amazon

Figure 2: Theoretical Model - Optimal Farmland Size ($M_0 < \overline{M} < \overline{\overline{M}}$)

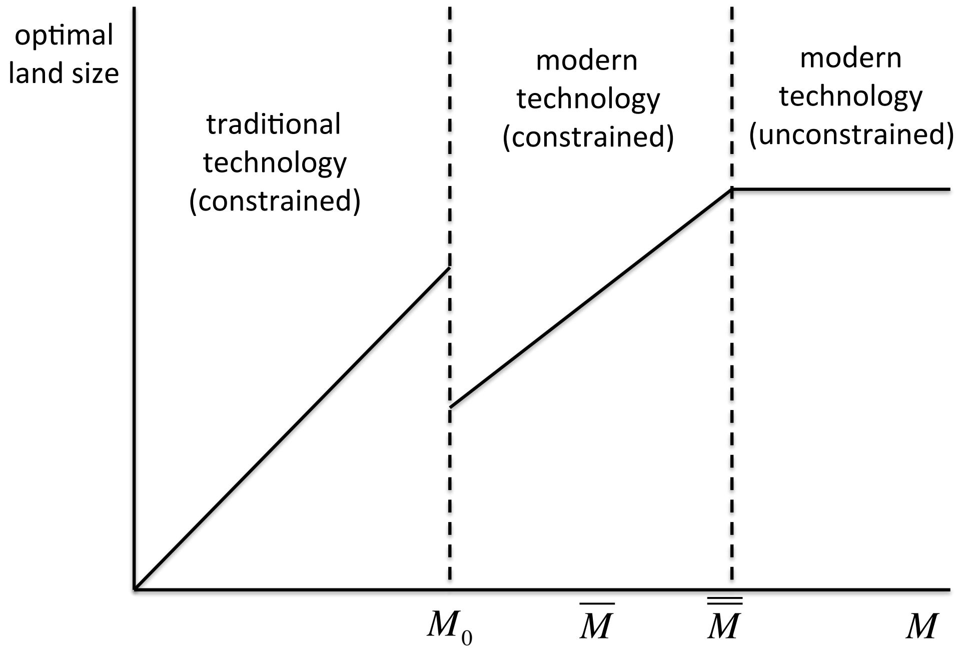
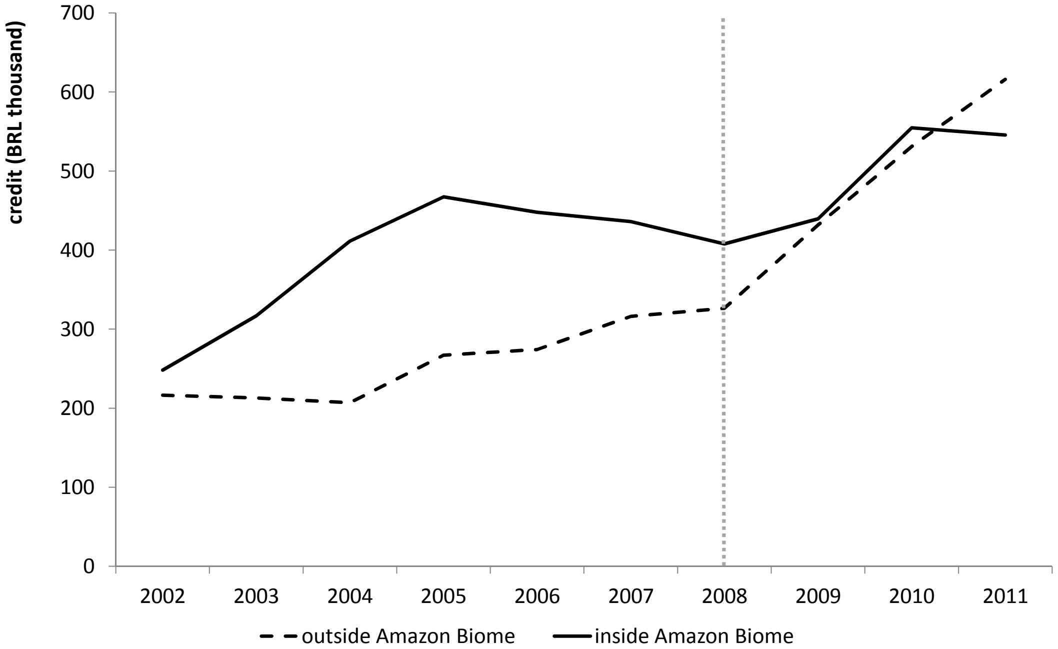
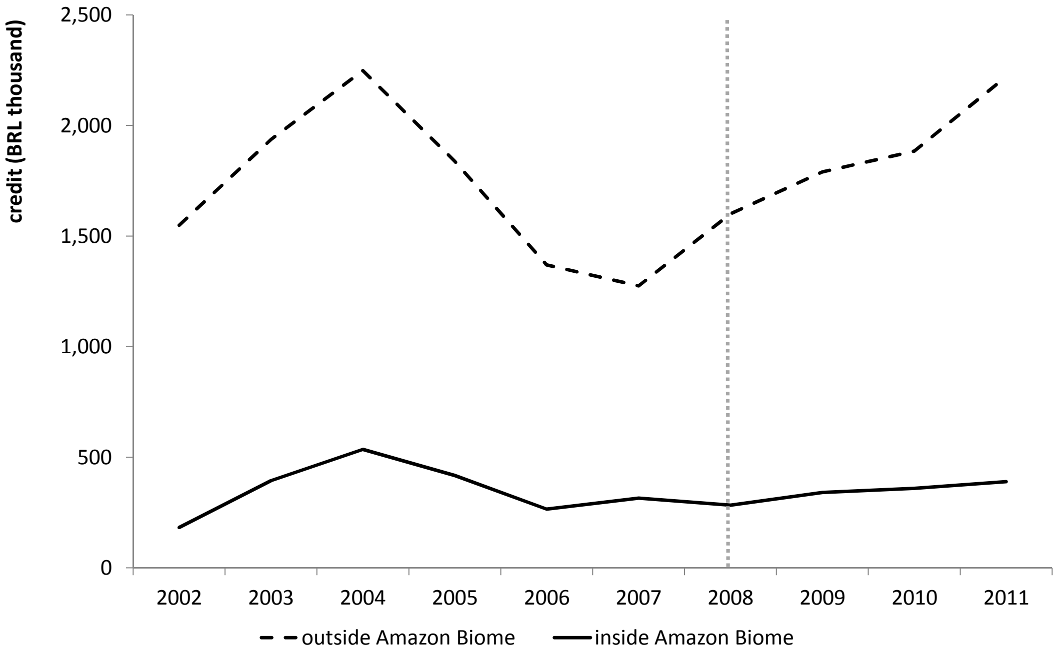


Figure 3: Annual Concession of Rural Credit in the Legal Amazon (municipality-level average value of rural credit loans, 2002-2011)

(a) Cattle-oriented sample



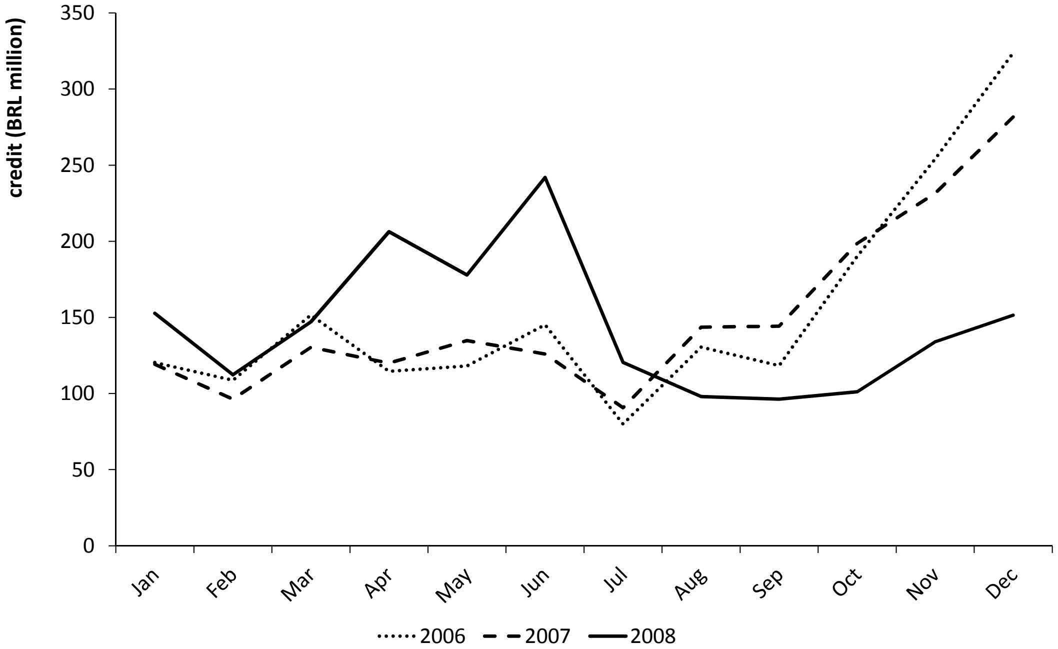
(b) Crop-oriented sample



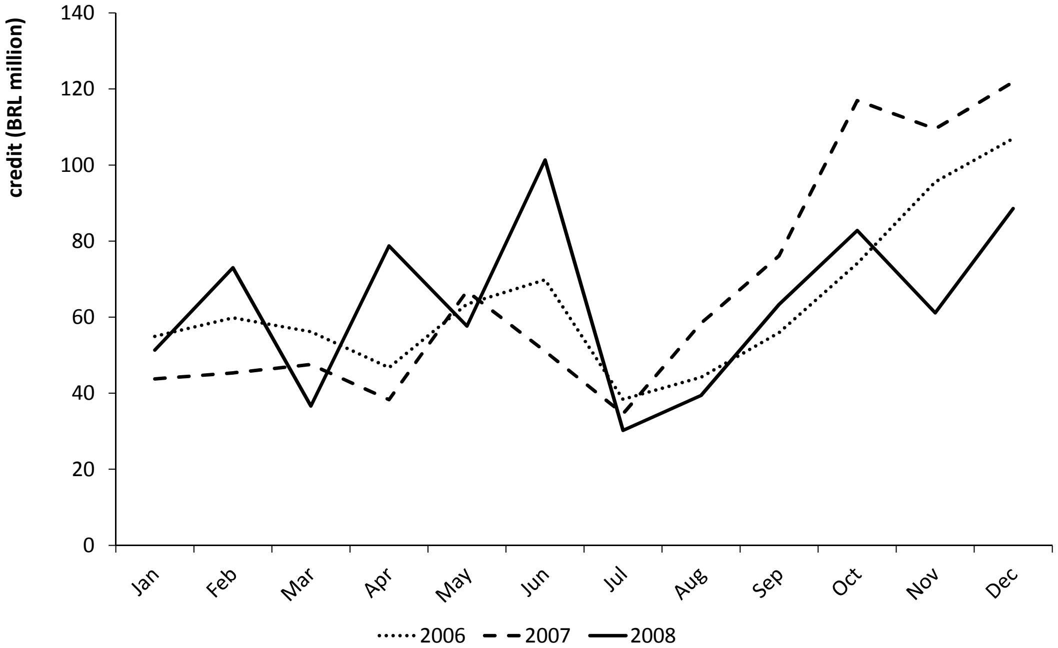
Notes: Authors' elaboration based on data from Recor/Central Bank.

Figure 4: Monthly Concession of Rural Credit in the Amazon Biome (total value of rural credit loans, 2006-2008)

(a) Cattle-specific contracts



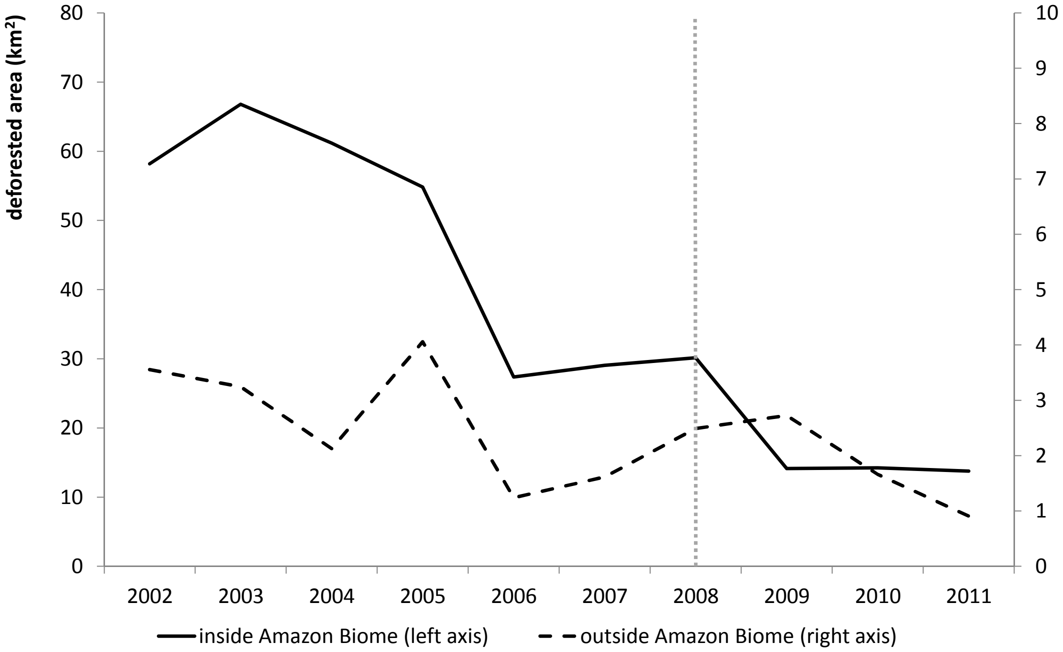
(b) Crop-specific contracts



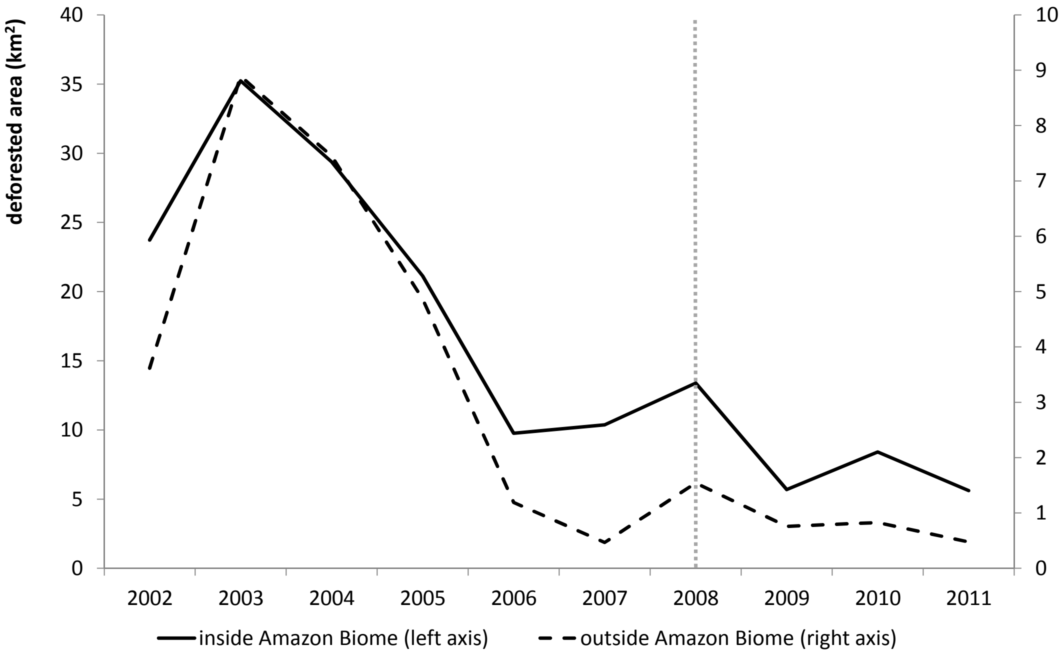
Notes: Authors' elaboration based on data from Recor/Central Bank.

Figure 5: Deforestation in the Legal Amazon (municipality-level average deforestation, 2002-2011)

(a) Cattle-oriented sample



(b) Crop-oriented sample



Notes: Authors' elaboration based on data from PRODES/INPE.

Table 1: Municipality-Level Average Annual Rural Credit and Deforestation Before and After Resolution 3,545 (credit in BRL thousand by type of contract; deforestation in km^2)

		Aggregate Credit			Pronaf Credit			Non-Pronaf Credit			Deforestation
		Total	Cattle	Crop	Total	Cattle	Crop	Total	Cattle	Crop	
Panel A: All municipalities											
Inside biome	Pre-resolution	5,509	3,531	1,978	1,254	841	413	4,255	2,690	1,565	40.36
	Post-resolution	6,360	4,429	1,930	1,976	1,458	518	4,383	2,971	1,413	14.90
Outside biome	Pre-resolution	12,092	2,865	9,227	784	475	309	11,308	2,390	8,918	3.03
	Post-resolution	15,594	5,371	10,223	1,110	776	334	14,484	4,595	9,889	1.72
Panel B: Cattle-oriented municipalities											
Inside biome	Pre-resolution	5,799	4,655	1,144	1,581	1,152	430	4,218	3,504	714	49.57
	Post-resolution	6,954	5,843	1,110	2,396	1,941	455	4,558	3,902	656	18.07
Outside biome	Pre-resolution	4,865	2,987	1,878	757	490	267	4,108	2,497	1,611	2.64
	Post-resolution	7,894	5,715	2,180	1,024	774	250	6,870	4,940	1,930	1.95
Panel C: Crop-oriented municipalities											
Inside biome	Pre-resolution	5,841	1,620	4,221	738	289	449	5,103	1,331	3,772	21.60
	Post-resolution	6,127	2,010	4,118	1,352	613	739	4,775	1,397	3,379	8.27
Outside biome	Pre-resolution	23,112	2,679	20,433	826	453	373	22,286	2,226	20,060	4.41
	Post-resolution	27,334	4,848	22,486	1,242	780	462	26,093	4,068	22,025	0.90

Notes: Descriptive statistics for average values of annual rural credit are calculated using municipality-level data constructed from the Recor/Central Bank contract-level microdata set. Statistics are shown for aggregate rural credit, and for Pronaf and Non-Pronaf credit separately. Descriptive statistics for deforestation are calculated using municipality-level satellite-based deforestation data from PRODES/INPE. Figures in Panel A are for the full, unrestricted sample; in Panel B for the cattle-oriented subsample; and in Panel C for the crop-oriented subsample.

Table 2: The Effect of Resolution 3,545 on Rural Credit in the Amazon Biome

Panel A: Biome as treatment group			
	Total	Cattle	Crop
Biome * Post2008	**-0.216**	**-0.289**	**-0.078**
	(0.029)* **	**(0.033)*** **	**(0.024)*** **
Observations	85,440	85,440	85,440
Number of Municipalities	712	712	712
Year and Municipality FE	Yes	Yes	Yes
Sample	Legal Amazon	Legal Amazon	Legal Amazon

Panel B: Biome and non-Pronaf as treatment groups			
	Total	Cattle	Crop
Biome * Non-Pronaf * Post2008	**-0.369**	**-0.407**	**-0.189**
	(0.039)* **	**(0.041)*** **	**(0.033)*** **
Non-Pronaf * Post2008	0.064	0.116	-0.005
	(0.030)**	(0.031)***	(0.025)
Biome * Non-Pronaf	0.148	0.163	0.076
	(0.016)***	(0.016)***	(0.013)***
Biome * Post2008	0.026	0.007	0.064
	(0.030)	(0.033)	(0.025)***
Non-Pronaf	-0.025	-0.046	0.002
	(0.012)**	(0.012)***	(0.010)
Observations	170,880	170,880	170,880
Number of Municipalities	712	712	712
Year and Municipality FE	Yes	Yes	Yes
Sample	Legal Amazon	Legal Amazon	Legal Amazon

Notes: Coefficients shown are estimated using fixed effects specifications in a municipality-by-month panel data set covering the 2002 through 2011 period. The sample includes all Legal Amazon municipalities that are not crossed by the Amazon Biome frontier. The dependent variable is normalized rural credit at the municipality level calculated using all contracts (column 1), cattle-specific contracts only (column 2), and crop-specific contracts only (column 3). All regressions include controls for municipality fixed effects, month-year fixed effects, cattle prices (current and lagged), crop prices (current and lagged), and priority municipality status. Robust standard errors are clustered at the municipality level. Significance: *** p<0.01, ** p<0.05, * p<0.10.

Table 3: Counterfactual Simulations - The Effect of Resolution 3,545 on Rural Credit in the Amazon Biome (credit in BRL million)

Panel A: Biome as treatment group

Year	Total			Cattle			Crop		
	Observed	Estimated	Difference	Observed	Estimated	Difference	Observed	Estimated	Difference
2002	1,595			1,092			503		
2003	2,306			1,312			994		
2004	3,002			1,679			1,324		
2005	2,982			1,945			1,037		
2006	2,623			1,856			767		
2007	2,630			1,818			812		
2008	2,506	3,174	668	1,740	2,253	512	765	944	179
2009	2,772	3,594	821	1,845	2,564	719	927	1,079	152
2010	3,203	3,852	649	2,271	2,873	601	932	1,008	76
2011	3,170	3,928	758	2,258	3,037	779	912	945	33
2008-2011 Total	**11,651**	**14,547**	**2,896**	**8,114**	**10,727**	**2,611**	**3,536**	**3,976**	**440**

Panel B: Biome and non-Pronaf as treatment groups

Year	Total			Cattle			Crop		
	Observed	Estimated	Difference	Observed	Estimated	Difference	Observed	Estimated	Difference
2002	1,595			1,092			503		
2003	2,306			1,312			994		
2004	3,002			1,679			1,324		
2005	2,982			1,945			1,037		
2006	2,623			1,856			767		
2007	2,630			1,818			812		
2008	2,506	3,036	530	1,740	2,052	312	765	943	178
2009	2,772	3,607	835	1,845	2,449	604	927	1,085	158
2010	3,203	3,795	592	2,271	2,694	423	932	1,002	70
2011	3,170	3,905	736	2,258	2,886	628	912	933	21
2008-2011 Total	**11,651**	**14,342**	**2,693**	**8,114**	**10,081**	**1,967**	**3,536**	**3,963**	**427**

Notes: Counterfactual simulations are conducted using the sample, specifications, and estimated coefficients from Table 2. Results shown are for total rural credit (columns 1-3), cattle-specific contracts (columns 4-6), and crop-specific contracts (columns 7-9). Observed rural credit is obtained from Recor/Central Bank and estimated rural credit is calculated by replacing the coefficient of the policy variable by zero.

Table 4: Sectoral Heterogeneity - Cattle-Oriented and Crop-Oriented Subsamples

Panel A: Biome as treatment group		
	Cattle-oriented	Crop-oriented
Biome * Post2008	**-0.300**	**-0.128**
	(0.042)* **	**(0.040)*** **
Observations	54,600	27,960
Number of Municipalities	455	233
Year and Municipality FE	Yes	Yes
Sample	Legal Amazon	Legal Amazon

Panel B: Biome and non-Pronaf as treatment groups		
	Cattle-oriented	Crop-oriented
Biome * Non-Pronaf * Post2008	**-0.490**	**-0.246**
	(0.053)* **	**(0.060)*** **
Non-Pronaf * Post2008	0.193	-0.030
	(0.040)***	(0.041)
Biome * Non-Pronaf	0.196	0.098
	(0.021)***	(0.024)***
Biome * Post2008	0.069	0.048
	(0.041)*	(0.042)
Non-Pronaf	-0.077	0.012
	(0.016)***	(0.016)
Observations	109,200	55,920
Number of Municipalities	455	233
Year and Municipality FE	Yes	Yes
Sample	Legal Amazon	Legal Amazon

Notes: Coefficients shown are estimated using fixed effects specifications in a municipality-by-month panel data set covering the 2002 through 2011 period. The cattle-oriented subsample includes Legal Amazon municipalities that are not crossed by the Amazon Biome frontier where the pre-2008 average value of annual credit loans for cattle ranching was higher than that for crop production; the crop-oriented subsample is defined analogously. The dependent variable is normalized rural credit at the municipality level calculated using cattle-specific contracts only (column 1), and crop-specific contracts only (column 2). All regressions include controls for municipality fixed effects, month-year fixed effects, cattle prices (current and lagged), crop prices (current and lagged), and priority municipality status. Robust standard errors are clustered at the municipality level. Significance: *** p<0.01, ** p<0.05, * p<0.10.

Table 5: The Effect of Resolution 3,545 on the Distribution of Rural Credit Contracts by Contract Size

	Number of cattle-specific contracts, by contract size			Number of crop-specific contracts, by contract size		
	Small	Medium	Large	Small	Medium	Large
Biome * Post2008	**3.405**	**-0.798**	**-1.345**	**1.642**	**-0.486**	**0.107**
	(1.508)**	**(0.421)***	**(0.331)*****	**(1.757)**	**(0.263)***	**(0.234)**
Crops price index	2.486	-0.300	0.428	-0.872	0.641	-0.215
	(3.938)	(0.705)	(2.458)	(3.708)	(0.529)	(0.696)
Crops price index (lagged)	16.342	-1.823	0.951	1.294	0.232	3.368
	(4.220)***	(0.805)**	(0.735)	(3.626)	(0.760)	(1.599)**
Cattle price index (1^{st} sem)	0.286	-0.053	-0.344	0.342	-0.114	12.650
	(0.148)*	(0.055)	(0.658)	(0.173)**	(0.041)***	(2.959)***
Cattle price index (lagged)	0.295	0.064	-0.034	0.242	0.159	-0.029
	(0.125)**	(0.058)	(0.059)	(0.170)	(0.035)***	(0.022)
Priority municipalities	1.190	-4.267	0.073	-1.142	-1.292	0.032
	(4.305)	(2.045)**	(0.062)	(6.908)	(0.790)	(0.030)
Observations	93,720	93,720	93,720	93,720	93,720	93,720
Number of Municipalities	781	781	781	781	781	781
Year and Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Coefficients shown are estimated using fixed effects specifications in a municipality-by-month panel data set covering the 2002 through 2011 period. The sample includes all Legal Amazon municipalities that are not crossed by the Amazon Biome frontier. The dependent variable is the number of small, medium, and large cattle-specific contracts only (columns 1-3) and the number of small, medium, and large crop-specific contracts only (columns 4-6). All regressions include controls for municipality fixed effects, month-year fixed effects, cattle prices (current and lagged), crop prices (current and lagged), and priority municipality status. Robust standard errors are clustered at the municipality level. Significance: *** p<0.01, ** p<0.05, * p<0.10.

Table 6: Robustness Checks - Falsification Tests, Alternative Sample and Alternative Dependent Variable

	Panel A.1: Falsification test - Pronaf credit as dependent variable			Panel A.2: Alternative sample - municipalities within 100km of biome frontier			Panel A.3: Alternative dependent variable - absolute values of rural credit		
	Total	Cattle	Crop	Total	Cattle	Crop	Total	Cattle	Crop
Biome * Post2008	**0.036**	**0.014**	**0.064**	**-0.159**	**-0.199**	**-0.106**	**-277.415**	**-144.285**	**-133.130**
	(0.030)	**(0.032)**	**(0.025)****	**(0.041)*****	**(0.046)*****	**(0.034)*****	**(57.051)*****	**(27.769)*****	**(49.758)*****
Observations	85,440	85,440	85,440	46,320	46,320	46,320	85,440	85,440	85,440
Number of Municipalities	712	712	712	386	386	386	712	712	712
Year and Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sample	Legal Amazon	Legal Amazon	Legal Amazon	<100km	<100km	<100km	Legal Amazon	Legal Amazon	Legal Amazon

	Panel B.1: Falsification test - subsample of Legal Amazon municipalities outside biome			Panel B.2: Alternative sample - municipalities within 100km of biome frontier			Panel B.3: Alternative dependent variable - absolute values of rural credit		
	Total	Cattle	Crop	Total	Cattle	Crop	Total	Cattle	Crop
Biome * Non-Pronaf * Post2008				**-0.096**	**-0.156**	**-0.047**	**-287.182**	**-186.752**	**-100.430**
				(0.057)*	**(0.060)*****	**(0.045)**	**(57.198)*****	**(26.928)*****	**(50.230)****
Non-Pronaf * Post2008	**0.064**	**0.116**	**-0.005**	0.064	0.116	-0.005	237.473	158.671	78.801
	(0.030)**	**(0.031)*****	**(0.025)**	(0.030)**	(0.031)***	(0.025)	(53.112)***	(21.711)***	(48.697)
Biome * Non-Pronaf				0.038	0.062	0.019	-626.448	-5.130	-621.319
				(0.023)*	(0.024)***	(0.018)	(157.541)***	(26.126)	(147.809)***
Biome * Post2008				-0.060	-0.057	-0.021	4.883	21.233	-16.350
				(0.043)	(0.046)	(0.034)	(12.823)	(9.166)**	(8.443)*
Non-Pronaf	-0.025	-0.046	0.002	-0.025	-0.046	0.002	876.975	159.534	717.441
	(0.012)**	(0.012)***	(0.010)	(0.012)**	(0.012)***	(0.010)	(154.199)***	(20.239)***	(145.679)***
Observations	61,200	61,200	61,200	92,640	92,640	92,640	170,880	170,880	170,880
Number of Municipalities	712	712	712	386	386	386	712	712	712
Year and Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sample	Outside Biome	Outside Biome	Outside Biome	<100km	<100km	<100km	Legal Amazon	Legal Amazon	Legal Amazon

Notes: Coefficients shown are estimated using fixed effects specifications in a municipality-by-month panel data set covering the 2002 through 2011 period. The sample includes all Legal Amazon municipalities that are not crossed by the Amazon Biome frontier, unless otherwise stated. Falsification tests are performed using normalized Pronaf rural credit as the dependent variable (Panel A.1) and a subsample of Legal Amazon municipalities located outside the Amazon Biome (Panel B.1). Alternative specifications tested include using a restricted sample of municipalities within 100 km of biome frontier (Panels A.2 and B.2) and absolute value of rural credit as the dependent variables (Panels A.3 and B.3). The dependent variables are calculated using all contracts (columns 1, 4 and 7), cattle-specific contracts only (columns 2, 5, and 8), and crop-specific contracts only (columns 3, 6, and 9). All regressions include controls for municipality fixed effects, month-year fixed effects, cattle prices (current and lagged), crop prices (current and lagged), and priority municipality status. Robust standard errors are clustered at the municipality level. Significance: *** p<0.01, ** p<0.05, * p<0.10.

Table 7: The Effect of Resolution 3,545 on Deforestation in the Amazon Biome (fixed effects and 2SLS regressions)

Panel A: Fixed effects and IV second stage			
	Fixed effects	IV: Biome * Post	IV: triple interaction
Total rural credit	**0.026**	**0.700**	**0.148**
	(0.013)**	**(0.238)*****	**(0.036)*****
Observations	5,750	5,750	10,571
Number of Municipalities	575	575	575
Year and Municipality FE	Yes	Yes	Yes
Sample	Legal Amazon	Legal Amazon	Legal Amazon

Panel B: IV first stage			
		IV: Biome * Post	IV: triple interaction
Biome * Post2009		**-0.385**	**0.126**
		(0.059)***	**(0.061)****
Non-Pronaf * Post2009			**0.196**
			(0.074)***
Biome * Post2009 * Non-Pronaf			**-0.949**
			(0.085)***
Observations		5,750	10,571
Number of Municipalities	575	575	575
Year and Municipality FE		Yes	Yes
Sample		Legal Amazon	Legal Amazon

Notes: Coefficients shown are estimated using fixed effects specifications in a municipality-by-year panel data set covering the 2002 through 2011 period. The sample includes all Legal Amazon municipalities that are not crossed by the Amazon Biome frontier and that showed variation in forest cover during the period. Fixed effects OLS and second-stage 2SLS estimations are shown in Panel A, and first-stage 2SLS estimations are shown in Panel B. IV models instrument rural credit by the policy variable from model 13 (column 2) or model 14 (column 3). All regressions include controls for municipality fixed effects, year fixed effects, cattle prices (current and lagged), crop prices (current and lagged), priority municipality status, clouds, and non-observable areas during period of remote sensing. Robust standard errors are clustered at the municipality level. Significance: *** p<0.01, ** p<0.05, * p<0.10.

Table 8: Counterfactual Simulations - The Effect of Resolution 3,545 on Deforestation in the Amazon Biome (Deforestation in km^2)

Year	IV: Biome * Post			IV: triple interaction		
	Observed	Estimated	Difference	Observed	Estimated	Difference
2002	21,549			21,549	18,810	
2003	25,686			25,686	22,844	
2004	23,087			23,087	19,176	
2005	20,087			20,087	19,847	
2006	9,946			9,946	10,717	
2007	10,565			10,565	10,825	
2008	11,295			11,295	12,252	
2009	5,220	5,688	468	5,220	6,446	1,226
2010	5,657	7,398	1,741	5,657	7,390	1734
2011	5,119	5,693	574	5,119	5,219	101
2009-2011 Total	**15,995**	**18,778**	**2,783**	**15,995**	**19,056**	**3,061**

Notes: Counterfactual simulations are conducted using the sample, specifications, and estimated coefficients from Table 7. Instruments used are Biome * Post (columns 1-3) and Biome * Post, Non-Pronaf * Post, and Non-Pronaf * Biome * Post (columns 4-6). Observed deforestation is obtained from PRODES/INPE and estimated deforestation is calculated by replacing the coefficient of the policy variable by zero.

Table 9: The Effect of Resolution 3,545 on Deforestation in the Amazon Biome Using Cattle and Crop-Oriented Subsamples (fixed effects and 2SLS regressions)

Panel A: Fixed effects and IV second stage						
	Panel A.1: Cattle-oriented municipalities			Panel A.2: Crop-oriented municipalities		
	Fixed effects	IV: Biome*Post	IV: triple interaction	Fixed effects	IV: Biome*Post	IV: triple interaction
Total rural credit	**0.023**	**1.033**	**0.225**	**0.040**	**-0.212**	**-0.027**
	(0.015)	**(0.334)*** **	**(0.051)*** **	**(0.026)**	**(0.308)**	**(0.034)**
Observations	4,120	4,120	7,904	1,410	1,410	2,593
Number of Municipalities	412	412	412	141	141	141
Year and Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes
Sample	Legal Amazon	Legal Amazon	Legal Amazon	Legal Amazon	Legal Amazon	Legal Amazon

Panel B: IV first stage						
	Panel B.1: Cattle-oriented municipalities			Panel B.2: Crop-oriented municipalities		
		IV: Biome*Post	IV: triple interaction		IV: Biome*Post	IV: triple interaction
Biome * Post2009		**-0.389**	**0.161**		**-0.353**	**0.041**
		(0.067)* **	**(0.069)** **		**(0.129)*** **	**(0.130)**
Non-Pronaf * Post2009			**0.279**			**-0.084**
			(0.083)* **			**(0.159)**
Biome * Post2009 * Non-Pronaf			**-0.954**			**-0.894**
			(0.096)* **			**(0.180)*** **
Observations		4,120	7,904		1,410	2,593
Number of Municipalities		412	412		141	141
Year and Municipality FE		Yes	Yes		Yes	Yes
Sample		Legal Amazon	Legal Amazon		Legal Amazon	Legal Amazon

Notes: Coefficients shown are estimated using fixed effects specifications in a municipality-by-year panel data set covering the 2002 through 2011 period. The sample includes all Legal Amazon municipalities that are not crossed by the Amazon Biome frontier and that showed variation in forest cover during the period. Samples are restricted to cattle (Panels A.1 and B.1) and crop-oriented (Panels A.2 and B.2) municipalities. Fixed effects OLS and second-stage 2SLS estimations are shown in Panel A, and first-stage 2SLS estimations are shown in Panel B. IV models instrument rural credit by the policy variable from model 13 (columns 2 and 5) or model 14 (columns 3 and 6). All regressions include controls for municipality fixed effects, year fixed effects, cattle prices (current and lagged), crop prices (current and lagged), priority municipality status, clouds, and non-observable areas during period of remote sensing. Robust standard errors are clustered at the municipality level. Significance: *** p<0.01, ** p<0.05, * p<0.10.

Table 10: Robustness Checks - IV Regressions with Alternative Sample, Alternative Dependent Variable and Controlling for the Interaction Between a Non-Linear Trend and Initial Deforestation

	Panel A - IV Second Stage					
	Panel A.1: Alternative sample - municipalities within 100 km of biome frontier		Panel A.2: Alternative variables - absolute values of total rural credit and deforestation		Panel A.3: Controlling for the interaction between a non-linear trend and initial deforestation	
	IV-Biome*Post	IV- Triple interaction	IV-Biome*Post	IV- Triple interaction	IV-Biome*Post	IV- Triple interaction
Total Rural Credit	**1.514**	**1.242**	**3.621**	**0.131**	**0.619**	**0.127**
	(0.602)**	**(0.413)*****	**(1.300)*****	**(0.039)*****	**(0.224)*****	**(0.034)*****
Observations	2,510	4,868	5,750	10,610	5,750	10,571
Number of Municipalities	251	251	575	575	575	575
Year and Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes
Sample	<100km	<100km	Legal Amazon	Legal Amazon	Legal Amazon	Legal Amazon
	Panel B - IV First Stage					
	Panel B.1: Alternative sample - municipalities within 100 km of biome frontier		Panel B.2: Alternative variables - absolute values of total rural credit and deforestation		Panel B.3: Controlling for the interaction between a non-linear trend and initial deforestation	
	IV- Biome*Post	IV- Triple interaction	IV- Biome*Post	IV- Triple interaction	IV- Biome*Post	IV- Triple interaction
Biome * Post2009	**-0.29**	**-0.081**	**-3.667**	**0.015**	**-0.376**	**0.131**
	(0.072)***	**(0.076)**	**(0.638)*****	**(0.833)**	**(0.081)*****	**(0.085)**
Non-Pronaf * Post 2009		**0.196**		**2.594**		**0.196**
		(0.071)***		**(1.014)****		**(0.092)****
Biome * Post2009 * Non-Pronaf		**-0.283**		**-3.615**		**-0.949**
		(0.105)***		**(1.169)*****		**(0.111)*****
Observations	2,510	4,868	5,750	10,610	5,750	10,571
Number of Municipalities	251	251	575	575	575	575
Year and Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes
Sample	<100km	<100km	Legal Amazon	Legal Amazon	Legal Amazon	Legal Amazon

Notes: Coefficients shown are estimated using fixed effects specifications in a municipality-by-month panel data set covering the 2002 through 2011 period. Second-stage 2SLS estimations are shown in Panel A, and first-stage 2SLS estimations are shown in Panel B. IV models instrument rural credit by the policy variable from model 13 (columns 1, 3 and 5) or model 14 (columns 2, 4 and 6). Alternative specifications tested include using a restricted sample of municipalities within 100 km of biome frontier (Panels A.1 and B.1); absolute value (instead of normalized value) of rural credit and deforestation variables (Panels A.2 and B.2); and controlling for the interaction between deforestation initial values and a non-linear trend (Panels A.3 and B.3). All regressions include controls for municipality fixed effects, year fixed effects, cattle prices (current and lagged), crop prices (current and lagged), priority municipality status, clouds and non-observable areas during period of remote sensing. Robust standard errors are clustered at the municipality level. Significance: *** p<0.01, ** p<0.05, * p<0.10.