Environmental Policies, Agricultural Displacement and Deforestation Leakage: A Causal Study in the Brazilian Legal Amazon

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Abstract: Does environmental policy aiming to reduce deforestation induce displacement of existing agricultural activities? We exploit a natural experiment in Brazil to shed light on this question. Using a spatial discontinuity design, we examine whether or not the Soy Moratorium and the Zero Deforestation Cattle Agreements in the Brazilian Amazon have displaced production into neighboring regions. Our results show evidence that the Soy Moratorium induced soy spillovers onto previously cleared land - mainly pasture - in the less regulated ecosystem. The Cattle Agreements, which were implemented three years after the Soy Moratorium, caused increased competition for land as they pushed cattle production into areas where soy had previously expanded and resulted in increased deforestation.

Keywords: Brazil, soy, cattle, deforestation, leakage, spillovers.

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1 Introduction

Beginning in the 1970s, cattle ranchers, then soy producers migrated to the Brazilian Amazon in search of cheaper agricultural land. With them they brought the deforestation frontier. This dynamic, together with decades of agricultural expansion, has led to high rates of deforestation that have attracted international attention. In response, the Brazilian government, international agencies and non-governmental organizations (NGOs) have implemented a significant number of policies in the Amazon to deter deforestation (Hargrave and Kis-Katos, 2013; Nepstad et al., 2014). While there has been a substantial decrease in the deforestation rate in the Amazon, little attention has been paid to the neighboring unprotected regions. Do anti-deforestation policies push agricultural activities into less protected regions? If there is leakage of these activities, is the end result intensification on existing agricultural land, or expansion into unprotected forests?

We analyze whether the Soy Moratorium (SoyM) and the Zero-Deforestation Cattle Agreements (CA) have led to a displacement in soy and cattle production, as well as to deforestation, away from the regulated Amazon Biome (or ecosystem) and into the unregulated Cerrado Biome in Brazil. The two supply-chain policies were initiated following international scandals that linked the production of soy and cattle with deforestation in the Amazon. The SoyM began in 2006 and imposed that producers grow soy only on land deforested before 2006. The CA began in 2009 and mandated that slaughterhouses refrain from buying cattle from properties with deforestation after 2009. Supply chains policies are enforced only in the Amazon Biome.

We exploit the spatial discontinuity provided by the ecosystem border as a quasi-experiment to identify spillover effects. Our methodology uses the distance between the unprotected and the protected Biome as a proxy for treatment, or expected intensity of leakage. The assumption underlying our econometric identification is that if there are spillover effects, they should occur disproportionately more in the areas closest to the Biome border than in the regions farther from the border. Since it is possible that leakage also occurs farther from the border, our strategy identifies a lower bound. Using grid cells and municipality observations, we identify the effect of a discrete and a continuous treatment variable based on distance within a difference-in-differences framework.

Our estimation strategy is consistent with microeconomic theory and empirical observations about the locations of agricultural companies in South America. Theory suggests that firms seek to minimize their transportation costs in order to maximize profits. If a company operates in a region that suddenly becomes more regulated, it may wish to expand its activities elsewhere, potentially into a less regulated region where it can minimize its transportation costs among existing properties and new ones. We can also imagine a multifarm company with properties in both ecosystems. Following a change in policy, they may need to decide in which ecosystem to invest. Under the scrutiny of international actors that can direct negative marketing campaigns against the sector, agricultural expansion may be preferable in the less regulated and scrutinized region.[1] Furthermore, if companies originally wanted to be in the regulated region because of inherent and market characteristics, then areas closest to this region are likely to have some of these characteristics as well. Consistent with this concept, le Polain de Waroux et al. (2016) find that agricultural actors within the Amazon are mobile and respond to opportunities and changes that involve legal aspects of land use. Drivers that attract companies are mainly proximity to current investments and weaker enforcement policies. Furthermore, cattle ranching companies are more often interested in buying forest land in places with lower environmental regulations (le Polain de Waroux et al., 2016).

We find evidence that the SoyM resulted in spillovers into the Cerrado Biome: within 100 km of the frontier with the Amazon, soy production increased by 31% relative to

[1] In a general equilibrium reality, all such decisions are also influenced by prices, land availability/quality and other factors such as labour and infrastructure.

the region farther from the Amazon: approximately 850,000 ha. We show that the CA resulted in an increase in the cattle herd of 24.6%, or approximately 410,000 head relative to the more remote region. The spillovers from the CA created leakage of 10,700 deforested hectares. Our findings show that soy expanded mainly on pasture and on areas already deforested. This explains why the leakage in deforestation is less than the soy and cattle spillovers. Our results are robust when related to different specifications and falsification tests. Therefore, the Cerrado reveals important lessons to bear in mind as environmental policies become more stringent.

Policymakers and researchers are increasingly concerned about the consequences of incomplete or differentiated environmental regulations that can restrict industrial activity (Greenstone, 2002), create pollution havens (Eskeland and Harrison, 2003; Hanna, 2010; Herath et al., 2005; Millimet and Roy, 2015; Mulatu and Wossink, 2014) or lead to leakage where regulation is weaker or does not apply (Alix-Garcia et al., 2012; Arriagada et al., 2012; Copeland and Taylor, 2004; Fowlie, 2009; Gibbs et al., 2015b; le Polain de Waroux et al., 2017). In contrast to this study, literature on the effect of asymmetric environmental regulation and comparative advantage among industries has heretofore concentrated on the analysis of leakage in air pollution or greenhouse gas emissions. Compared to the pollution haven literature, our research enjoys the advantage of not dealing with endogenous policies. Indeed, most countries or states that set higher air pollution standards already have comparative advantages or are self-selected. The Brazilian context is different: environmental policies have been pushed to protect forests by international organizations without consideration of comparative advantage.

This paper contributes to both the indirect land use change and the deforestation leakage literatures. In these studies, first, it is unclear whether environmental policies lead to displacements of agricultural activities into less environmentally constrained regions and next, if they do, there is no consensus about whether those displacements are likely to lead to leakage in deforestation.

Indirect land use change occurs when agricultural production moves from one region and drives expansion of the same land use to another region (Andrade de Sá et al., 2013). Many studies find that for the most part, crops are expanding into pastures but that pasture expansion into forest results in "indirect land use change" driven by changes in cropping choice (Andrade de Sá et al., 2013; Arima et al., 2011; Barona et al., 2010; Ferreira Filho and Horridge, 2014; Graesser et al., 2015; Lapola et al., 2010; Mendonça et al., 2012). In Brazil, two important crops, sugarcane and soy, have generated indirect land use change. In the Brazilian Amazon, Andrade de Sá et al. (2013) studied the indirect effects of sugarcane production in the state of São Paulo on forest conversion more than 1500 km away. Their results suggest that between 1970 and 2006, expansion of sugarcane in the south of Brazil has been positively correlated with deforestation in the Amazon. With a dynamic general equilibrium model and data from 2005 Ferreira Filho and Horridge (2014) found that each additional ha in sugarcane would require only 0.14 ha of new land and 0.47 ha converted from pasture. Regarding soy, results from Arima et al. (2011) suggest a 10% reduction of this crop in old pasture areas would have decreased deforestation by as much as 40% in the more forested municipalities[2] of the Brazilian Amazon. This well-developed research topic in land use science usually relies on econometric methods or general equilibrium models that are not conducive to causal interpretation. Our empirical strategy differs from this work by using exogenous factors (the policy change affecting specific agricultural commodities and the spatial discontinuity created by the biome frontier) to identify the indirect land use changes.

Deforestation leakage could be defined as deforestation activities that shift from inside protected regions to outside of them (Angelsen, 2010). Literature on deforestation leakage has generally focused on the effect that protecting forests for environmental services or protecting areas through payments has on the nearby regions (Alix-Garcia et al., 2012; Berck and Bentley, 1997; Delacote et al., 2016; Wear and Murray, 2004; Wu, 2000).

[2] A municipality is the equivalent of a county in the United States.

We are the first to study deforestation leakage in the context of asymmetric environmental policies between two neighbouring ecosystems.

Our study is similar to that of le Polain de Waroux et al. (2017) in the sense that we consider the same region and period, and we particularly focus on soy, beef and deforestation. In contrast, those authors sought to capture changes in imports and exports that are related to an increase in environmental enforcement, while we study the direct impact in terms of production in the less regulated biome that arises from the change in supply-chain policies specific to the soy and cattle sectors.

Our paper is organized as follows: Section 2 provides background on the context of the Brazilian Amazon and includes a brief discussion on related literature. Section 3 presents our data. In Section 4, we describe our empirical strategy. Section 5 presents our results and shows complementary results that illustrate the mechanism. Finally, Section 6 offers our conclusions.

2 Background

2.1 Deforestation and agricultural expansion in the Amazon

Brazil is home of about 60% of the Amazon rainforest, the equivalent of 4.2 million km^2 (Andrade de Sá et al., 2013). Over the last several decades, Brazilian governmental units, both local and national, as well as international agencies and environmental organizations, have implemented a significant number of policies to deter deforestation (Assunção et al., 2013; Assunção and Rocha, 2014; Hargrave and Kis-Katos, 2013; Nepstad et al., 2014). The combination of policies coupled with the international and national economic conditions decreased deforestation in the Brazilian Amazon: deforestation, which varied between 10,000 and 30,000 in the 1990s, was reduced to about 8,000 km^2 in 2016 (INPE, 2016). The Amazon's portion of Mato Grosso had very high deforestation rates with a peak in 2004 of almost 12,000 km^2. After 2004 there was a rapid decrease in deforestation rates, which stabilized in 2009 at about 1,000 km^2 per year (INPE, 2016). In contrast, the Cerrado's portion of Mato Grosso lost 3,000 km^2 to deforestation in 2003; this decreased to 500 km^2 in 2009 and rose to 1,272 km^2 in 2012 (Hansen et al., 2014). Even though deforestation decreased in the Amazon, anti-deforestation policies have not been sufficient to compete with market forces that favored the expansion of agricultural and livestock activities, and deforestation is rising again.

Historically, new markets, improved access to local credit, and government incentives such as tax exemptions, funding of agricultural research, and improved marketing channels and infrastructure, all encouraged the rapid expansion of agricultural exports (Barbier, 2004; Barona et al., 2010). Driven by these incentives, the Brazilian Amazon became highly agricultural, a source of significant production of soy and cattle. Indeed, growing demand from new markets for soy, mainly for export to China, has led to rising production, which makes this crop the most important in terms of harvested area since the 1990s. In 1990, approximately 200,000 km^2 of soy were planted in Brazil, of which 1.4% were grown in the Amazon Biome. Twenty-five years later, 12.8% of the 322,000 km^2 was planted in the Amazon Biome (IBGE, 2017). In addition, the cattle population in the Amazon has grown from 15 million in 1990 to more than 60 million in 2015 (IBGE, 2017), which corresponds to an increase from 10.1% to 28.4% of the total cattle herd in Brazil.

The decision to clear land depends on the profits expected of doing so (Pfaff, 1999). It is optimal for landowners to clear land when agriculture produces higher profits than other uses would. Studies about deforestation in the Brazilian Amazon have emphasized the role of population pressure, roads, agriculture and the cattle herd (Arima et al. 2007, Anderson 1996, Anderson et al. 2002, Barreto et al. 2008, Bowman, 2016, Eweres et al. 2008, Hargrave et al. 2013, Pfaff 1999). Other factors beyond inputs and production outputs influence profits. Among others, environmental policies and the reduction of exports or lower prices caused by negative publicity in European and North American markets affects profits.

Mato Grosso covers approximately 904,000 km^2. The state is divided among the Amazon Biome (54%), the Cerrado Biome (40%) and the Pantanal Biome (6%). Typically, the Amazon Biome is composed of humid tropical rainforests, the Cerrado is a tropical savanna and the Pantanal is covered by wetlands. Mato Grosso has a hot, semi-humid to humid climate (Foppen Aw). This state is responsible for approximately 85% of the Brazilian Amazon soy production (Kastens et al., 2017), and 9% of the global supply (IDH, Sustainable Trade Initiative, 2017), with a total production of about 55 million tons harvested in 2014 (Mato Grosso Brazil COP21, 2015). It is the top producer of beef and supplies both domestic and international markets (IDH, 2017). Since Brazil is the biggest producer and exporter of beef (FAS/UDSA, 2017) and exporter of soy (Observatory of Economic Complexity, 2015), the state of Mato Grosso is a predominant actor in the country.

2.2 Soy Moratorium and Zero-Deforestation Cattle Agreements

In developing countries, states face especially important challenges in managing environmental regulation. Often, regulations are in place but only superficially enforced. Though enforcement has increased in recent years, the case of the Brazilian government and anti-deforestation regulation is no exception. In this low-enforcement context, international and national NGOs denounced the agricultural processes that accentuate deforestation in the Brazilian Amazon. To modify agricultural practices, they targeted soy and cattle sectors and created negative publicity campaign for foreign markets. Because the soy and cattle markets are concentrated in the hands of relatively few actors in the region, the environmental activists used the agribusinesses corporations' visibility as an asset to force change (le Polain de Waroux et al., 2016). The NGOs' campaigns and political pressure led to the signature of two anti-deforestation agreements in which the exporters are charged with excluding properties with recent deforestation (Gibbs et al., 2015a,b; Lambin et al., 2017). These agreements have also been supported in various ways by the Brazilian government and private actors like banks.

In 2006, a Greenpeace-sponsored campaign against deforestation linked to the Brazilian soy industry led to the Soy Moratorium (SoyM) in the Amazon Biome. Starting on July 26 of that year, the Brazilian Association of Vegetable Oil Industries (ABIOVE), the National Grain Exporters Association (ANEC) and commodity that purchase around 90% of the soy produced in the Brazilian Amazon (ADM, Bunge, Cargill, and others) agreed to boycott farmers who grew soy on land cleared after 2006 (Rausch and Gibbs, 2016). Moreover, the Banco do Brasil (a major Brazilian bank) further incentivized this agreement by restricting credit to farmers who deforested after the same date (ABIOVE, 2010). The Soy Moratorium Working Group, composed of traders, NGOs and government agencies, manages the satellite monitoring system of the supply-chain policy (GTS, 2014). The overlay of yearly deforestation imagery from the Brazilian Space Agency (PRODES) and crop production after 2006 from MODIS satellite allows to detect potential non-compliant producers. Areas of potential non-compliance are manually interpreted using Landsat images and individual visits confirm the identity of non-compliant producers and farms. The traders that signed the SoyM are given a list which they use to purchase from properties in compliance. Simultaneously, soy traders are also encouraged to boycott production on embargoed areas.[3] Previous research suggests that the soy supply-chain policy has been effective, since only a small area of soy expansion has occurred on land deforested after 2006 (Gibbs et al., 2015b; Rudorff et al., 2011). However, the SoyM may indirectly cause deforestation by displacing pasture through restrictions on expansion into recently deforested areas. And while the portion of soy expansion on

[3]Embargo is a tool managed by the Brazilian Environmental Agency (IBAMA) to apply the Brazilian Forest Code and fine illegal deforestation.

recently cleared area decreased drastically in the Amazon Biome, it has remained stable in the Cerrado Biome (Gibbs et al., 2015b).

Inspired by the signature of the SoyM, Greenpeace led a new campaign; this time linking the Amazonian cattle sector to deforestation. In 2009, major meatpackers (JBS, Marfrig, Berlin, later incorporated by JBS, and Minerva) signed the "G4" agreement (Greenpeace, 2009) in which they agreed to buy from direct suppliers that were registered, mapped, not in protected or indigenous areas, and free embargoes or deforestation post-2009 (Gibbs et al., 2015a). Simultaneously, legal suits and other actions from Federal prosecutors in Brazil sustained the implementation of the policy. In the state of Pará, the Prosecutor filed a billion-dollar lawsuit against the cattle industry that spans ranchers, retailers and slaughterhouses (Gibbs et al., 2017). In 2009, 21 lawsuits led to the signing of 140 legally binding "Terms of Adjustment of Conduct" (TACs) — the federal counterpart of the G4 agreement. Between 2009 and 2013, an additional 24 lawsuits stimulated the signing of 42 TACs by other slaughterhouses in the Brazilian Amazon. To determine deforestation on their suppliers ranches, major meatpackers often rely on services from geospatial firm to support their monitoring system. The Zero-Deforestation Cattle Agreements (CA) which comprises the G4 and the TACs, are monitored only in the Amazon Biome.[4] At this date, a small body of literature analyzed the impacts of this supply-chain policy. In the state of Pará, the biggest beef exporter of the world, JBS, has been showed to statistically alter its purchase behavior and boycott suppliers with deforestation following the CA (Gibbs et al., 2015b). Gibbs et al. (2017) demonstrated how the company increased purchases from properties with deforestation in Mato Grosso's Cerrado Biome, while purchases were reduced in the Amazon Biome. On the properties that were registered in a Rural Environmental Registry (Portuguese acronym CAR), Alix-Garcia and Gibbs (2017) showed avoided deforestation due to the CA and leakage

[4]While the TACs should also cover the Cerrado Biome within the Legal Amazon, this is not implemented because there is no governmental deforestation data for this region.

from these properties to those that were not yet registered.

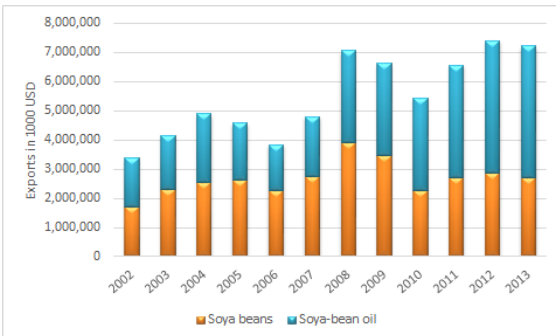
The CAR is fundamental to the way the soy and beef supply-chain policies are enforced. In Brazil, the law obligated landowners to map their rural properties. Boundaries have been made public and facilitated detecting deforestation within suppliers for the agribusinesses and exporting meatpackers. From the producers' perspective, enrollment in CAR reveals their deforestation behavior to their buyers, the government and researchers. Furthermore, even if previous owners deforested after the threshold date, current owner results in a non-compliance situation. Therefore, agricultural producers generally use the services of technicians to create the CAR and for a reasonable amount, obtain the deforestation history of their parcel. Therefore, the supply-chain policies enhanced by the CAR create a credible threat for the producers and play a role in their deforestation behavior.

Brazilian laws and supply-chain policies are emphasized in the Amazon Biome because of its higher ecosystem value. The National Institute for Space Research in Brazil (INPE) provides public official deforestation data (PRODES and DETER), while there are no official deforestation data for the Cerrado Biome. A study by Richards et al. (2016) suggests that producers may be avoiding detection by different strategies, including, among others, preferring locations within the Cerrado Biome.

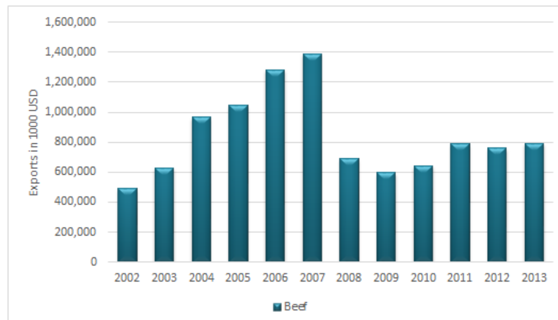
Figure 1 depicts changes in international exports from Brazil during the period before and after the two specific supply-chain policies. We show the exports for both soy and cattle, and differentiate them between the Europe 25 group and China, because it is possible that the former group would be more environmentally sensitive to marketing campaigns from NGOs. Two years before the SoyM, in 2004, Greenpeace began to denounce soy linked to deforestation Greenpeace (2010). One year before the CA, in 2008, the first reports linking deforestation to cattle ranching in the Amazon were released (Roberto Smeraldi, head of Friends of the Earth Brazil, 2008; The Independent, 2008). Those events are likely to have affected exports prior to the dates of the signature of the supply-chain policies. As reference dates, we use 2004 and 2007 to express percentage change in exports following those campaigns. Figure 1a shows a decrease of 21.6% in soy exports to the 25 richest countries in Europe in 2006 compared to 2004. Years 2005 and 2007 are also relatively low in exports of soy. Years 2005 and 2007 are also relatively low in exports of soy. Figure 1b presents a decrease of 57% in 2009 relative to 2007 in beef exports from Brazil to Europe.[5] Exports of soy show an increase two years after the SoyM, which is not the case for the CA. This may be due to the Mad Cow report that surfaced in 2012 for Brazil. In comparison, we show generally constant increases in China over the same period both in the soy market (Figure 1c) and in the beef market (Figure 1d).

Considering the predominance of the state of Mato Grosso in the production of soy and cattle within the country, and also in international markets, SoyM and CA are likely to have affected the decision-making process of producers.

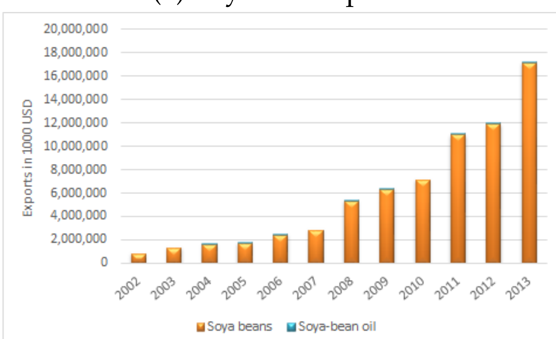
[5] Even though Brazilian exports are only partially coming from the Amazon and Amazon's soy and beef production are partly destined to the Europe 25 countries, main soy and beef production is coming from the Amazon and the NGO-led campaign had their most sensitive public within the Europe 25 countries.



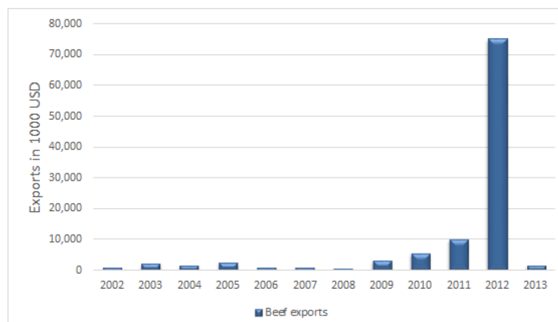
(a) Soy to Europe 25



(b) Beef to Europe 25



(c) Soy to China



(d) Beef to China

Source: World Integrated Trade Solution

Figure 1: Graphs (a) and (b): exports from Brazil to Europe 25 (Austria, Belgium, Belgium-Luxembourg, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, United Kingdom). Graphs (c) and (d): exports from Brazil to China.

2.3 Why proximity to the Amazon matters

The identification strategy of this paper relies on the assumption that leakage should be greater near the border of the Amazon Biome and less in areas more remote from the border. This section will explain why proximity to the Amazon is important.

To produce more efficiently, an agribusiness or afarmer has two choices: land intensification or extensification. On one hand, intensification corresponds to an increased yield per unit of land. Producers can choose among various options, principally by increasing inputs or incorporating more productive technologies. Intensification does not require more land but generally results in agreater investment per unit of land. The SoyM is an incentive toward intensification in the Amazon Biome. On the other hand, extensification implies that the producer uses additional land to produce greater output, while maintaining a similar average production per hectare. In that case, extensification can use previously cleared land or may clear forested land in order to expand. In the Amazon Biome, extensification of cattle or soy can still occur, but it becomes more costly if it involves deforestation. Indeed, once environmental policies are more stringent, deforestation becomes a riskier activity. On the contrary, however, in the Cerrado Biome, extensification is not risky.

Even though extensification bears little risk for the agribusinesses or ranchers, it may generate deforestation. Deforestation can follow direct or indirect land use change. Indirect land use change could occur if soy agribusinesses in the Cerrado expand onto pasture land. If agribusinesses do this, it could create regional tensions regarding land use. Since soy production is a more lucrative activity than ranching, soy growers can purchase pastures, which forces ranchers to search for cheaper land in the Cerrado, and such land usually corresponds to forested or natural vegetation areas.

When there is an environmental policy, two types of producers are affected: those who already own a farm in the Amazon Biome, and newcomers that want to undertake activities there. In the face of stricter forest protection, Amazon Biome agribusinesses that want to expand can choose first, to intensify, or alternatively, to buy new property that respects environmental policies, or finally, to expand their activities in a less strict region. Whether they own property in the Cerrado or not, extensifying activities in this less constrained Biome can be the profit-maximizing option. In addition, newcomers that were going to the Amazon Biome can be influenced by changes in environmental policy. They may still prefer to go to this region or they may modify their decision and buy land in a nearby less regulated region. In summary, agribusinesses may either prefer that their Amazon farm be close to their Cerrado farm, or they may wish to be near the Amazon because of market advantages and because it was their preferred site originally.

In order to understand how distance might matter, it is first important to examine production processes for both cattle and soy and why owners have more than one property. Cattle production typically involves two farms: one for breeding and another for fattening. It is advantageous for cattle ranchers to to have geographically concentrated land in order to minimize transportation costs. Furthermore, cattle ranching activities require different sets of inputs and labor, so proximity to another farm can help lower costs. Soy production requires a high level of investment, machinery and capital. Sharing trucks and machinery is optimal. Therefore, if the ownership of an Amazon property decides to expand activities at a new property, a choice in the nearer Cerrado area may minimize their costs.

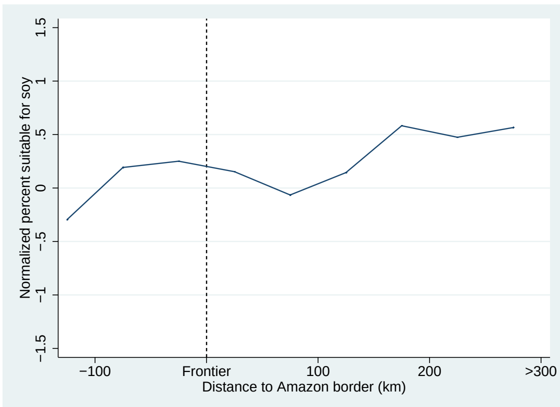
The data show that producers own multiple properties across Biomes. There are 82,253 mapped properties in Mato Grosso (SICAR Brazil, 2015). Of all those properties, 19.6% have ownership that we can identify as possessing more than one property. For those 16,158 unique mapped properties, we find 6,498 owners that have more than one property. For these owners, the average is approximately four properties each. Among all owners with multiple properties, 11% own properties across Biomes. This corresponds to 2,240 properties in the Cerrado that cover 5,269,546 ha and 2,229 in the Amazon with 7,451,469 ha.

In Mato Grosso, areas suitable for soy and potential grass yield are relatively more favorable in the more remote regions. Figure 2 shows normalized measures of suitability relative to distance to the Amazon Biome. We plotted the distances from 125 km within the Amazon Biome to 300 or more km within the Cerrado.[6] In figures 2a and 2b, we observe that areas suitable for soy and attainable grass yield are similar for the near Amazon and the full Cerrado; both remain between $\pm.5$ of the mean of the standardized variable. Figure 2c depicts how the slope average increases over distance and remains relatively high after 225 km. While slope can be a constraint for agricultural purposes, in certain cases it can be useful. Indeed, soy production can benefit from plains with higher elevation because nights are cooler and this preserves soil humidity better. Since suitable areas for soy are chosen based on slope, climate and soil, we support this affirmation. Furthermore, moderate slope does not constrain cattle production. This is supported by our summary statistics presented in section 4.2 that show more cattle production in the more distant zone of Mato Grosso's Cerrado.

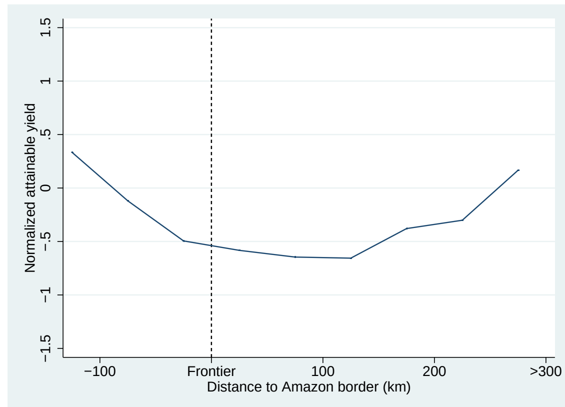
3 Data sources and transformations

The unit of analysis for soy production and deforestation is a 5 km x 5 km grid (and as a robustness check, a 10 km x 10 km grid), while for cattle production it is the municipality. For each unit of analysis, we define the distance to the Amazon-Cerrado border as the shortest distance between the spatial unit and the closest point of the border. We analyze the entire Cerrado Biome in Mato Grosso. For each unit of analysis to be considered as within the Cerrado Biome, we require that 95% of its area be in this Biome. Figure 3 shows the gridcells within the Cerrado Biome region according to the distance to the

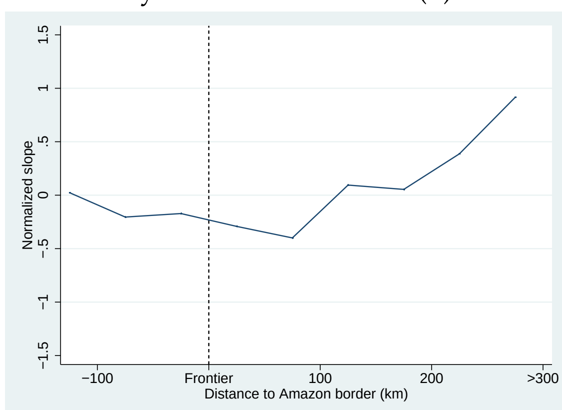
[6] We group together regions farther than 300 km since the regions between 300 and 500 km represent less than 10% of the sample size.



(a) Area suitable for soy



(b) Potential grass yield



(c) Slope

Figure 2: Normalized variables for area suitable for soy, potential grass yield and average slope. Calculated per intervals of 50 km and plotting at the mid-distance. Negative distance corresponds to regions in the Amazon and positive distance to regions in the Cerrado.

Amazon Biome frontier. Note that federal highways are relatively evenly distributed between the near and far regions.

Our main dependent variables are soy production (ha), head of cattle, and deforestation (ha). Data cover the 2001-13 period. Soy production is provided by Kastens et al. (2017), a unique dataset created for the state of Mato Grosso. To characterize the spatial dynamics of agricultural production, the authors use a vegetation index (VI) defined by remote-sensing experts using the Moderate Resolution Imaging Spectroradiometer (MODIS). We also have measures of single and double soy cropping, sugarcane (for falsification test), and pasture area as well (Kastens et al., 2017). We transform the original pasture/cerrado data in such a way that we keep only pixels previously assigned according to our definitions of forest and deforestation presented below. This rigorous exclusion ensures that forest is excluded from the "soy from pasture" layer we create. Specifically, to count an area as soy from pasture, we require that the previous year be identified as pasture, which reduces the total number of observation by one year. Head of cattle are municipality level data and come from the Brazilian Institute of Geography and Statistics (IBGE). In addition, the IBGE provides data on chicken production that are used to create a falsification test. To consider the indirect effect on deforestation, we use forest cover and deforestation data fromHansen et al. (2014). Spatial resolution is of one arc-second per pixel which corresponds to approximately .076 ha in our study region. We choose a canopy cover of 30% for the pixel to be considered as forested[7]. Only pixels considered to be forested in 2000 can be deforested in subsequent years. Reforestation is excluded from the analysis. We transform our dependent variable with the inverse hyperbolic sine (IHS) (Burbidge et al., 1988), which is identified at zero and reduce the influence of extreme observations.

Control variables for Brazilian municipalities come from several sources. The soil suitability data come from two sources. Soy soil suitability is based on Soares-Filho et al.

[7]Results are robust to the use of a canopy cover of 50% (available from authors).

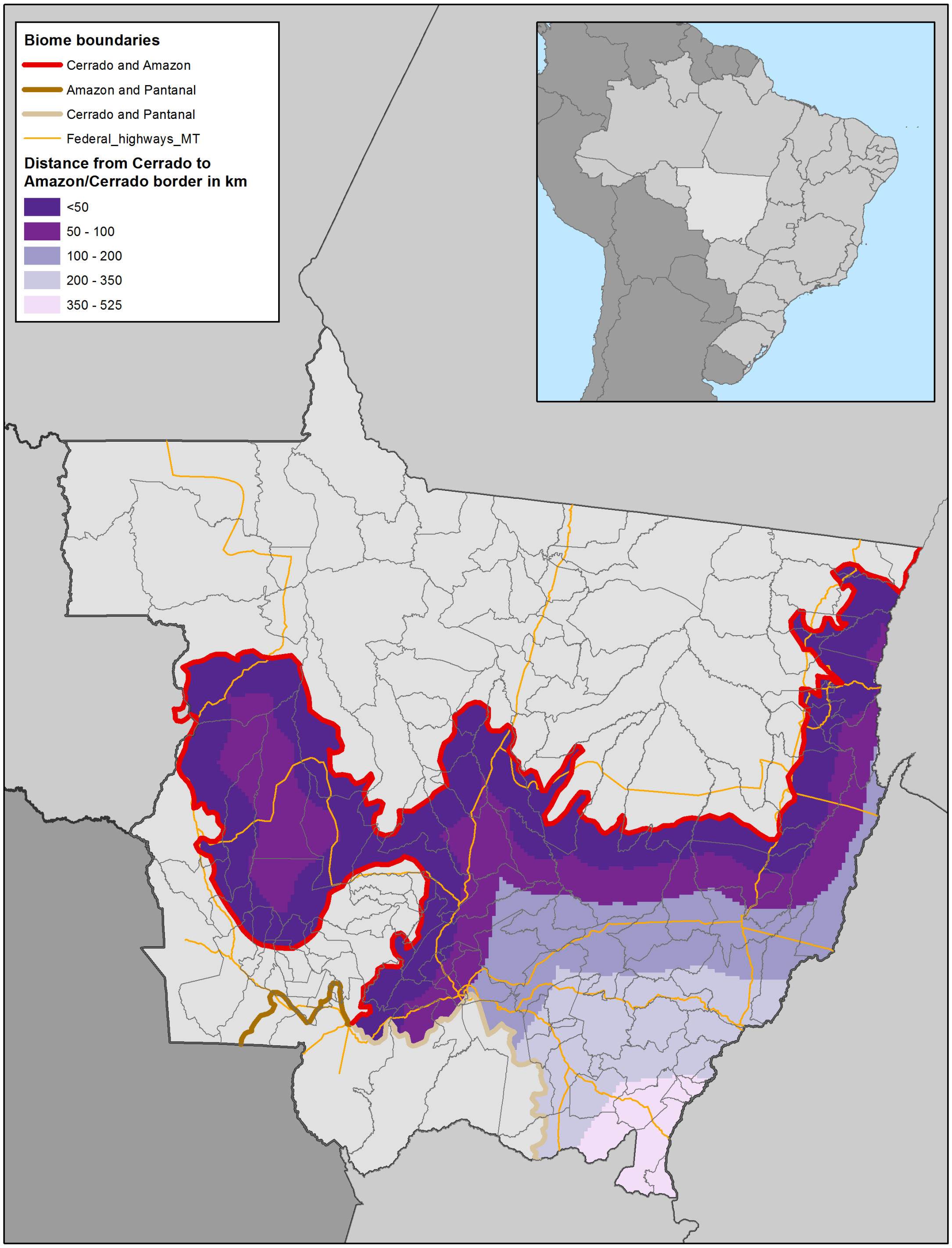


Figure 3: Study region according to distance to the Amazon Biome

(2014). The authors identify areas suitable for soy based on slope, soils and climate; protected and indigenous areas are excluded from the map. As a control, we use the percentage of the grid cell that is suitable for soy. The attainable grass yield (t/ha) with intermediate inputs and rainfed water come from the Food and Agriculture Organization (FAO)'s Global Agro-Ecological Zones (GAEZ) 2002 database. GAEZ data are also used in Nunn and Qian (2011). To compare rainfalls, we use data from the Tropical Rainfall Measuring Mission, a joint work between NASA and the Japan Aerospace Exploration. Finally, the Brazilian Ministry of the Environment (MMA) provides borders of the protected areas for the years 2003-13. Protected areas are divided into two categories: strict protection and sustainable use. The National Indian Foundation (FUNAI) provides borders of Indigenous territory.

4 Empirical strategy

4.1 Spillovers

We estimate the reduced form effects induced in the Cerrado Biome, first by the Soy Moratorium on soy production, and next, by the Cattle Agreements on the cattle herd, two supply-chain policies that function in the Amazon Biome. These two estimations enable us to define whether or not there could be spillovers induced by an increase in agricultural production. Then, we measure the effect of these two policies on deforestation.

If there are spillovers, areas closer to the border should see a higher increase in agricultural production and possibly deforestation as well, if in fact agriculture increases in an extensive rather than an intensive way.[8] We analyze the influence of the policies and the distance on the dependent variable using all grid cells (for soy and deforestation)

[8] Our methodology is inspired by the work of Dube et al. (2013) who analyze the cross-border spillover effects of the U.S. Gun Laws in violent events in Mexico.

and all municipalities (for cattle). Specifically, we estimate:

$$Y_{it} = \alpha + (Post\_policy_t * Proximity_i)\beta + (X_i * \gamma_t)\phi + \delta_i + \gamma_t + \epsilon_{it}, \quad (1)$$

The dependent variables are i) the soy ha (IHS) per 1000 ha, ii) the heads of cattle per 1000 ha and iii) ha deforested (IHS) per 1000 ha of forest cover of 2000. In the soy and deforestation regression, the dummy $Post\_policy_t$ is equal to 1 after 2006, 0 otherwise. For the cattle heads regression, the post-CA period is equal to 1 after 2009, and 0 otherwise. The variable identifying the treatment effect is $Post\_policy_t * Proximity_i$. The variable $Proximity_i$ is a continuous treatment that equal 1 when the unit of observation is closest to the Biome border and 0 when the observation is farther away. The transformation is as follows:

$$Proximity_i = \left| \frac{Dist_i}{MaxDist} - 1 \right|, \quad (2)$$

where $Dist_i$ is the distance to the Amazon frontier of the unit of analysis i and $MaxDist$ is the farthest distance from the Amazon frontier in the Cerrado Biome of all units of analysis. This transformation presents a mirror on the interval [0,1] of the distance variable. We include robustness checks with other distance specifications in Appendix A.

Controls X_i include different soil suitability variables (soy suitability, pasture suitability, average slope) interacted with year fixed effects (γ_t). These interactions allow for flexible trends between the different level of soil suitability and deforestation risk. Specifically, the regression on soy controls for the time trend in terms of soy suitability, the regression on cattle controls for different time trends in terms of pasture suitability and the regression on deforestation controls for all soil suitability. Regressions on soy and deforestation include grid cell fixed effects and regression on cattle heads uses municipalities fixed effects (δ_i), which controls for time invariant characteristics that could correlate with outcomes and proximity to the Amazon. We also include time fixed effects (γ_t) to sweep out shocks to agricultural and deforestation practices that would affect all the Cerrado in a similar way. Residuals (ϵ_{it}) are clustered at the municipality level, allowing for arbitrary serial and spatial correlation of shocks within municipalities.[9]

Regressions based on municipality are weighted with their areas since they vary significantly. This is not necessary for the grid cells since 99% of our sample is composed of grid cells of 2500 ha.

To allow for flexibility in identifying first, if there is leakage in deforestation, and then, if there is leakage, whether it came from the SoyM or the CA, we include in the deforestation specification both the post-SoyM and post-CA interactions with the treatment variable.

Moreover, we also estimate models where we discretize distance in a binary variable where *Close* is equal to one and *Far* to zero. We use an arbitrary distance of 100 km and conduct sensitivity analysis with different thresholds.

The identification of our main results relies on the common trend assumption between the closest region and the farthest region. This may not be the case if areas far away are growing faster in terms of agricultural expansion. We test for those common trends and present the results in Section 5.1.

4.2 Descriptive statistics

Table 1 presents outcomes and covariates means and standard deviations. We divide the sample between *Close* and *Far*, using two different thresholds, 100 km and 150 km.

For soy, we observe significantly less area suitable for soy in the near region, while the average rain during the soy season is very similar and relatively similar for the rest of the year. In terms of attainable grass yield, the far Cerrado is substantially more productive

[9]Note: when a grid cell falls within more than one municipality, it is attached to the municipality where its greatest area falls.

and this is also supported by much larger cattle herds in this part of the Biome. Slope is on average higher in the far region. Indigenous, protected and sustainable areas are different and this justifies a robustness test integrating them as controls in our regressions. We note much more forest cover in 2000 in the close region. This justifies our choice to normalize the deforestation variable by the forest cover. Water surfaces and urban areas are comparable. Finally, we show the average number of environmental embargoes, a policy from the Brazilian government to control deforestation, and remark that for both pre- and post-policy there are no significant differences. Therefore, embargoes should not be a driver of land-use changes within the Cerrado.

We acknowledge that other policies occurring in the Amazon may have affected the increase in soy and cattle production, such as the embargoes and blacklisted municipalities. However, none of these other policies are specific to the soy or cattle sector, as are the SoyM and the CA. Furthermore, those policies have been more constant over time, while the SoyM and the CA occurred respectively in 2006 and 2009.

Table 1: Summary statistics (means and standard deviations)

	100 km				150 km			
	Close (1)		Far (2)		Close (3)		Far (4)	
Outcomes								
Soy/1000 ha (2005)	125.35	(259.25)	109.85	(220.93)	112.09	(246.94)	139.23	(241.23)
Soy/1000 ha (2013)	146.44	(276.32)	123.23	(244.89)	131.36	(263.92)	154.56	(267.82)
Soy single cropping/1000 ha (2005)	86.99	(186.65)	91.73	(190.92)	78.70	(179.17)	115.40	(208.15)
Soy single cropping/1000 ha (2013)	50.06	(115.83)	43.79	(110.67)	45.97	(111.72)	52.32	(119.59)
Soy double cropping/1000 ha (2005)	36.72	(124.80)	15.44	(61.89)	31.93	(116.68)	20.29	(70.59)
Soy double cropping/1000 ha (2013)	87.75	(208.79)	69.80	(174.00)	77.82	(197.91)	89.46	(193.03)
Pasture to soy/1000 ha (2005)	26.59	(70.02)	23.63	(57.58)	24.15	(66.84)	28.99	(62.25)
Pasture to soy/1000 ha (2013)	13.64	(35.64)	11.22	(32.13)	12.69	(35.22)	12.86	(32.08)
Cattle head/1000 ha (2008)	221.43	(169.65)	397.65	(229.29)	251.94	(160.63)	418.93	(249.25)
Cattle head/1000 ha (2013)	243.40	(173.98)	435.21	(291.33)	276.14	(169.24)	458.80	(319.36)
Defor/1000 ha forest cover (2005)	7.43	(30.11)	6.75	(25.53)	7.30	(29.71)	6.85	(24.94)
Defor/1000 ha forest cover (2013)	3.80	(19.85)	2.75	(10.32)	3.64	(18.78)	2.77	(10.45)
Covariates								
Area suitable for soy (ha)	1275.53	(1079.21)	1646.49	(855.51)	1286.03	(1066.52)	1755.20	(776.22)
Av. rain soy season (Sept-Dec) (1998-2009)	719.63	(189.22)	723.20	(198.32)	713.05	(189.50)	741.92	(199.38)
Av. rain non-soy season (Jan-July) (1998-2009)	883.97	(228.33)	922.56	(219.98)	878.55	(228.20)	951.09	(211.23)
Attainable grass yield (t/ha)	1.06	(0.08)	1.17	(0.07)	1.08	(0.08)	1.19	(0.07)
Slope	6.14	(4.64)	10.32	(6.97)	6.47	(4.94)	11.00	(7.13)
Percent forest cover (2000)	51.94	(34.02)	34.16	(21.77)	50.13	(33.03)	32.40	(20.97)
Indigenous protected area/1000 ha	476.37	(947.53)	121.20	(505.40)	435.60	(914.62)	98.39	(454.39)
Protected area/1000 ha	58.99	(357.83)	10.83	(139.67)	54.52	(343.10)	4.96	(84.15)
Sustainable area/1000 ha	48.09	(326.62)	136.96	(554.18)	109.86	(495.24)	6.25	(114.76)
Urban area/1000 ha (2005)	1.31	(24.11)	1.88	(27.61)	1.51	(26.45)	1.57	(22.72)
Water area/1000 ha (2005)	1.17	(11.02)	2.58	(29.50)	2.10	(23.33)	0.62	(5.23)
Change in embargoes/1000 ha (2013-2005)	0.05	(0.34)	0.05	(0.30)	0.05	(0.32)	0.06	(0.34)
Observations								
Grid cells	8741		5250		10153		3838	
Municipios	16		32		23		25	

Note: This table provides means and standard deviations for outcomes and covariates at the municipality level (cattle head and attainable grass yield (t/ha)) and at the grid cell level (all others). *Close* represents the unit of analysis within a distance of 100 km (or 150 km) from the Amazon frontier and *Far* includes the farther from 100 km (or 150 km). Standard deviations are in parentheses.

5 Results

5.1 Effects of the supply-chain policies on soy, cattle and deforestation

This section presents the results of the analysis of spillovers in soy production, cattle production and deforestation within the Cerrado Biome in Mato Grosso.

Results of Equation 1 are presented in Table 2. In columns (1), (3) and (5) we show the results of the interaction of the *PostPolicy* indicator variables with the indicator of closeness, defined as less than 100 km from the Amazon border. Columns (2), (4) and (6) show the results from the interaction of *PostPolicy* with the *Proximity* continuous treatment. In the seventh row, we provide the untransformed pre-period mean of the units of analysis within 100 km of the frontier, for soy/1000 ha, cattle/1000 ha and deforestation/1000 ha of forest cover to facilitate reference. The number of observations is lower for the regressions on deforestation since 142 grid cells do not have forest cover and would not provide variation to the analysis. All specifications are estimated by Ordinary Least Squares, with standard errors clustered by municipality.

The SoyM generated substantial spillovers into the Cerrado Biome. As shown in column (1), grid cells within 100 km of the Amazon border experienced an increase of 31% in soy per ha[10], compared to the grid cells beyond 100 km. Similarly, we find that the CA significantly increased the cattle herd near the Amazon Biome. In column (3), the coefficient of interest for the cattle equation is .22 (24.6%). Columns (2) and (4) present how the spillover effects decrease as the unit of analysis becomes farther from the Amazon Biome.

In columns (5) and (6), we examine whether the spillovers in soy and cattle production have induced leakage in deforestation. The coefficient on *Post2006 x Close* is negative and not statistically significant (-0.04, se 0.07). This suggests that spillovers

[10] To obtain the specific impact in terms of percentage, we calculate the marginal effects for the untransformed variables as: $exp(\beta) - 1$.

from the SoyM did not increase deforestation near the Biome border, compared to areas farther from the border. Consistent results for *Post2006 x Proximity[0,1]* are shown in column (6) with an estimated effect of -0.18 (se 0.17). Given this result, we now focus on the effect on deforestation of the CA. As shown in column (5), we find that the region within 100 km of the Biome frontier experienced an increase of 12.7% in deforestation. The impact calculated on the continuous proximity variable is positive and statistically significant at 10% level (0.19, se 0.11). Results are robust to the use of two specifications of distance (Appendix A).

Table 3 shows the soy and deforestation set of regressions for the 10 km x 10 km grid cells sample. The results are similar for soy, while slightly larger in magnitude for both column (1) with a point estimate of .31 (se 0.07) and column (2) with a point estimate of .64 (se 0.14). For the effect of the SoyM on deforestation, point estimates are smaller and remain statistically non-significant. The effect of the CA on deforestation shows a larger point estimate .16 (se 0.04) in column (3) and larger estimate of .28 (se 0.14) in column (4), which is also more statistically significant. Results are robust to the use of two specifications of distance also for the 10 km x 10 km grid cells (Appendix D.3).

Table 2: Impact of the supply-chain policies on areas close to the Amazon frontier (5 km x 5 km grids)

	IHS(Soy/1000 ha)		*IHS(Cattle/1000 ha)*		*IHS(Defor/1000 ha of fc)*	
	(1)	(2)	(3)	(4)	(5)	(6)
Post2006 x Close	0.27***				-0.04	
	(0.05)				(0.07)	
Post2006 x Proximity[0,1]		0.60***				-0.18
		(0.12)				(0.17)
Post2009 x Close			0.22***		0.12***	
			(0.07)		(0.03)	
Post2009 x Proximity[0,1]				0.41**		0.19*
				(0.20)		(0.11)
R-squared	0.07	0.07	0.44	0.42	0.06	0.05
N	181,883	181,883	624	624	180,167	180,167
Untransformed pre-period mean	125.3	125.3	181.0	181.0	7.4	7.4
Time x Soil aptitude	X	X	X	X	X	X
Cell fixed effect	X	X			X	X
Municipality fixed effect			X	X		

Note: Unit of observation is the grid cell for columns (1-2) and (5-6) and the municipality for columns (3-4). Robust standard errors are in parentheses and are clustered by municipality level for regressions at the grid cell level. Pre-period means corresponds to soy per 1000 ha in 2005 for the first two columns, to the cattle herd per 1000 ha in 2008 for columns (3) and (4) and to the deforestation per 1000 ha of forest cover in 2005 for columns (5) and (6). Pre-period means are calculated for the *Close* group. * $p< 0.10$, ** $p<0.05$, *** $p<0.01$.

Table 3: Impact of the supply-chain policies on areas close to the Amazon frontier (10 km x 10 km grids)

	IHS(Soy/1000 ha)		*IHS(Defor/1000 ha of fc)*	
	(1)	(2)	(3)	(4)
Post2006 x Close	0.31***		0.00	
	(0.07)		(0.10)	
Post2006 x Proximity[0,1]		0.64***		-0.04
		(0.14)		(0.23)
Post2009 x Close			0.16***	
			(0.04)	
Post2009 x Proximity[0,1]				0.28**
				(0.14)
R-squared	0.10	0.09	0.11	0.11
N	41,700	41,700	45,162	45,162
Untransformed pre-period mean	126.2	126.2	6.7	6.7
Time x Soil aptitude	X	X	X	X
Cell fixed effect	X	X	X	X

Note: Robust standard errors are in parentheses and are clustered at the municipal level. Regressions includes unit of analysis fixed effect, time fixed effects and soil quality time trend. Pre-period means corresponds to soy per 1000 ha in 2005 for the first two columns, to the cattle herd per 1000 ha in 2008 for columns (3) and (4) and to the deforestation per 1000 ha of forest cover in 2005 for columns (5) and (6). Pre-period means are calculated for the *Close* group. * p< 0.10, ** p<0.05, *** p<0.01.

We generate alternative specifications that have the advantage of testing for parallel pre-trends between the near Amazon region and the counterfactual. In addition, these specifications show the gradual effect of the supply-chain policies on soy, cattle and deforestation. Specifically, in Figure 4, we graph the point estimates and the 95% confidence intervals from the estimation of the interactions of year indicators (instead of *PostPolicy*) and the *Proximity*. The remaining specifications are the same as presented in Equation 1.

In Figure 4, soy pre-trends for 2001-2005 are not significantly different from zero, which confirms the robustness of the results presented in Table 2. The gradual yearly effect of the SoyM on intensification of agribusinesses is not surprising; companies react but since investments in land and equipment are required, changes do not occur quickly. For the cattle spillovers estimation, there is no difference in pre-trends for 2001-2008 in Figure 4. Finally, the yearly effects of proximity to the Amazon on deforestation present some differences. This could be explained by the 2003 and 2004 pick in deforestation in Mato Grosso's Amazon. For the years 2010 and 2013, there is evidence of higher deforestation following the CA. All our results are robust to the inclusion of protected areas as a control.

As a robustness check, Figure 5 present the results from the alternative specifications on the 10 km x 10 km grid cells for soy and deforestation. This time, there is no statistical difference in the pre-trends for both the 2001-2005 period for the soy production and for the 2001-2008 period in the deforestation regression.

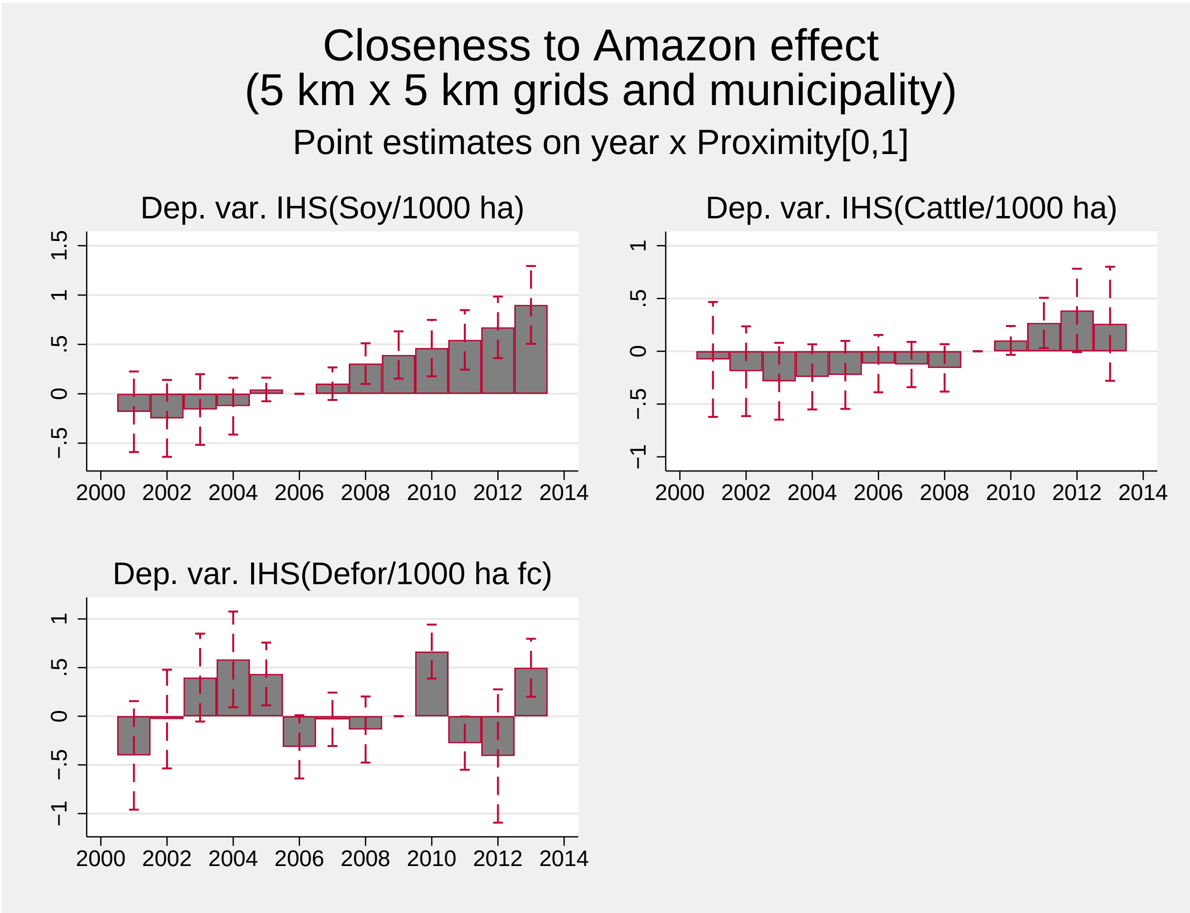


Figure 4: The change in soy, cattle and deforestation by year, considering a continuous treatment variable that varies between 0 and 1, where 1 is the group closest to the Amazon frontier and 0 the group that is farthest away. The year 2006 is omitted for soy, and 2009 for both cattle and deforestation. Regressions includes unit of analysis fixed effects, time fixed effects and flexible time trends presented in Section 4.1. Robust standard errors are clustered at the municipality level for the soy and deforestation regressions.

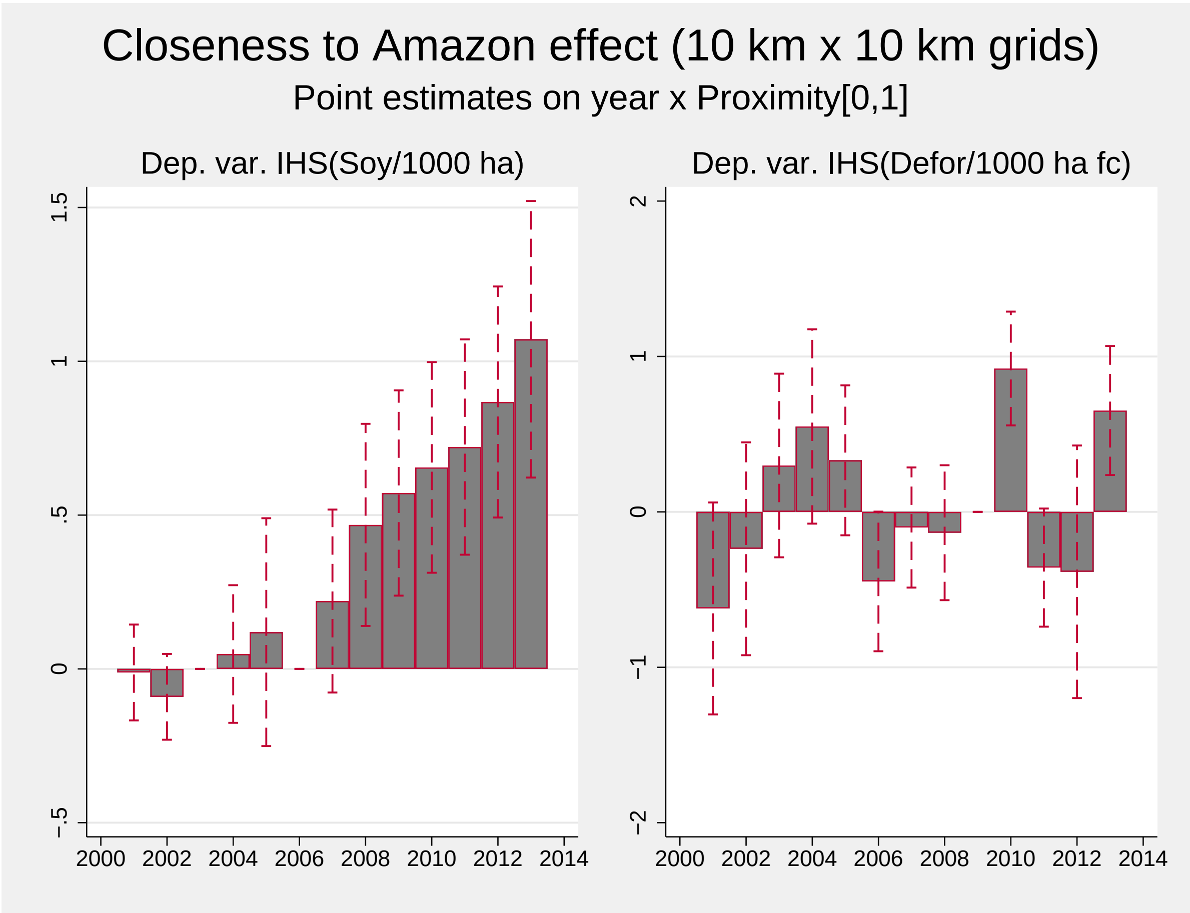


Figure 5: The change in soy, cattle and deforestation by year, considering a continuous treatment variable that varies between 0 and 1, where 1 is the group closest to the Amazon frontier and 0 the group that is farthest away. The year 2006 is omitted for soy, and 2009 for both cattle and deforestation. Regressions includes unit of analysis fixed effects, time fixed effects and flexible time trends presented in Section 4.1. Robust standard errors are clustered at the municipality level for the soy and deforestation regressions.

In Appendix B, we present results from the impact of both the SoyM and the CA on cattle production. Column (1) presents results using the *Close* indicator, column (2) the *Proximity* variable, column (3) the estimation on *Distance* and column (4) the estimation using the *Inverse distance*. In all estimations, point estimates from the CA are significantly bigger and statistically more significant than point estimates from the SoyM.

Finally, in Appendix C, we check whether a municipality could be driving our results. We present histograms of our coefficients of interest where each of the coefficients is obtained by dropping one municipality at a time. We show relatively symmetric distributions of our coefficients which is consistent with the finding that no outlier is driving our results.

5.2 Sensitivity analysis: geographical impact of spillovers and induced leakage

The result suggests that there is leakage due to CA. We test sensitivity to the cutoff for *Close*. The results are shown in Table 4 and are divided into three panels (cattle, soy and deforestation). Varying the Close indicator in the regression on cattle provides a constant decreasing point estimate. The region composed of the municipalities within 50 km of the Amazon Biome frontier has the highest point estimate (0.23, se 0.18). The estimate is not statistically significant, which is explained by a lack of power due to the lower number of observations in the 50 km distance to the Amazon Biome. The dynamics in soy spillover presents a different pattern where instead the highest point estimate is for all the grid cells within 100 km of the Biome frontier (0.27, se 0.05), with a lower point estimate within 50 km of the Biome frontier (0.15, se 0.06). Furthermore, the increase in soy production takes place over a longer distance.

The panel on deforestation suggests that the policies have created land competition between cattle and soy. Indeed, there is generally less deforestation between 2007 and 2009 near the Amazon Biome region compared to the control group, which shows that the increase in soy production did not cause leakage by itself. The increase in deforestation within 200 km of the Amazon border, with significant increase within 150 km after the CA, suggests that cattle ranchers caused the leakage.[11] To better understand

[11] These results are robust with the sample of the 10 km x 10 km grid cells (Appendix D.1).

the dynamics, we test how intensification versus extensification of production changed in the Cerrado as a result of the policies.

Table 4: Varying the Close Indicator

Panel: Cattle	(1)	(2)	(3)	(4)	(5)
	50 km	100 km	150 km	200 km	250 km
Post2009 x Close	0.23	0.22***	0.15**	0.11	0.03
	(0.18)	(0.07)	(0.07)	(0.07)	(0.08)
Obs.	624	624	624	624	624
Obs. Close	65	208	299	351	429
Panel: Soy					
Post2006 x Close	0.15**	0.27***	0.27***	0.26***	0.25***
	(0.06)	(0.05)	(0.06)	(0.05)	(0.06)
Obs.	181,883	181,883	181,883	181,883	181,883
Obs. Close	72,267	113,633	131,989	145,704	156,741
Panel: Deforestation					
Post2006 x Close	-0.18***	-0.04	-0.04	0.00	0.04
	(0.05)	(0.07)	(0.08)	(0.08)	(0.09)
Post2009 x Close	0.11***	0.12***	0.11***	0.09*	0.02
	(0.03)	(0.03)	(0.04)	(0.05)	(0.06)
Obs.	180,167	180,167	180,167	180,167	180,167
Obs. Close	72,267	113,633	131,989	145,704	156,741

Note: Robust standard errors are in parentheses and are clustered at the municipal level for soy and deforestation regressions. Regressions includes unit of analysis fixed effect, time fixed effects and soil quality flexible time trends. * p< 0.10, ** p<0.05, *** p<0.01.

Using the same empirical strategy presented in Equation 2, we examine three outcomes: soy in single cropping, soy in double cropping and pasture to soy.

Table 5 presents results on soy production (single and double cropping practices) and soy from pasture. We look at two *Close* threshold. More specifically we define *Close* as being within 100 km of the frontier, in columns (1), (4) and (7), and 150 km in columns

(2), (5) and (8). We also use the proximity variable as continuous treatment (columns (3), (6) and (9)).

We analyze two panels. The first panel looks only at *Post2006* interactions with the different specifications of the distance variable. The second panel estimates both the effect *Post2006* and *Post2009*. Our goal is to understand whether a shortage of available land for cattle would have led to land use competition and generated an increase in deforestation in the post-CA period.

Columns (1), (2) and (3) of Table 5 show that the increase in single soy cropping (in contrast to double cropping) occurred from 2006 and continued after 2009 at an increased rate. In terms of double cropping, estimated coefficients on the post-SoyM and distance treatment show statistically insignificant point estimates at 10% level (columns (4), (5) and (6)). Results in columns (7), (8) and (9) present how soy expanded more on pasture land relative to our counterfactual. This phenomenon occurred from 2007 and increased mainly after 2009.[12]

Results suggest that expansion of soy in pasture lands has created tensions between ranchers and agribusinesses over the need for land. Scarcity of land that has already been deforested may have pushed agricultural actors to increase deforestation.

[12]These results are robust and statistically more significant with the sample of the 10 km x 10 km grid cells (Appendix D.2).

Table 5: Soy intensification results within Cerrado Biome

	IHS(soy single/1000 ha)			*IHS(soy double/1000 ha)*			*IHS(soy from pasture/1000 ha)*		
	(1) 100 km	(2) 150 km	(3) Prox	(4) 100 km	(5) 150 km	(6) Prox	(7) 100 km	(8) 150 km	(9) Prox
Close x Post2006	0.19**	0.27***		0.15	0.00		0.06	0.11*	
	(0.09)	(0.10)		(0.11)	(0.12)		(0.05)	(0.06)	
Post2006 x Proximity[0,1]			0.46**			0.27			0.17
			(0.19)			(0.24)			(0.11)
Close x Post2006	0.12*	0.15**		0.16*	0.04		-0.00	0.04	
	(0.06)	(0.07)		(0.09)	(0.11)		(0.04)	(0.05)	
Close x Post2009	0.14*	0.21**		-0.01	-0.07		0.11***	0.11***	
	(0.08)	(0.09)		(0.04)	(0.05)		(0.04)	(0.04)	
Post2006 x Proximity[0,1]			0.25**			0.33*			0.03
			(0.12)			(0.20)			(0.09)
Post2009 x Proximity[0,1]			0.36**			-0.12			0.24**
			(0.17)			(0.10)			(0.10)
Observations	181883	181883	181883	181883	181883	181883	167892	167892	167892
Time x Soil aptitude	X	X	X	X	X	X	X	X	X
Cell fixed effect	X	X	X	X	X	X	X	X	X

Note: The change in single annual soy cropping, double soy cropping and soy planted on pasture by distance to the Amazon frontier in the Cerrado. Note: Unit of observation is the grid cell. Robust standard errors are in parentheses and are clustered at the municipal level. * p< 0.10, ** p<0.05, *** p<0.01.

5.3 Falsification tests

In order to show that the results are not driven by agricultural infrastructure and political priorities, we use the model presented in Equation 1 to estimate two other outcomes that should not be affected by the SoyM and the CA. Estimates are performed with five specifications of the *Close* indicators and with the *Proximity* treatment. To simulate a falsification test for the cattle herd, we use the chicken population. Indeed, both types of production require slaughterhouses. Such infrastructure could be leading the results of our analysis if there would have been a change in slaughterhouses after 2009 for the municipalities close to the Amazon, but not related to the CA. To simulate a falsification test for soy, we use sugarcane production, which should not be correlated with distance in the Cerrado. Generally, confounding factors that would make the near Amazon a more interesting agricultural region after the policies could lead to false positives in our estimates. Results shown in Table 6 present all non-significant coefficients and support specific impact of SoyM and CA on their respective agricultural production.

Table 6: Varying the Close Indicator

Panel: IHS(Sugarcane/1000 ha)	(1)	(2)	(3)	(4)	(5)	(6)
Post2006 x Close	-0.00	-0.03	-0.06	-0.09	-0.10	
	(0.03)	(0.04)	(0.05)	(0.07)	(0.09)	
Post2006 x Proximity[0,1]						-0.22
						(0.18)
Obs.	181,883	181,883	181,883	181,883	181,883	181,883
Obs. Close	72,267	113,633	131,989	145,704	156,741	.
Panel: IHS(Chicken/1000 ha)	50 km	100 km	150 km	200 km	250 km	Proximity
Post2009 x Close	-0.16	-0.19	-0.22	0.52	0.26	
	(0.14)	(0.22)	(0.29)	(0.48)	(0.62)	
Post2009 x Proximity[0,1]						0.59
						(0.76)
Obs.	623	623	623	623	623	623
Obs. Close	65	208	299	351	429	.

Note: Robust standard errors are in parentheses and are clustered at the municipal level. Regressions includes unit of analysis fixed effect, time fixed effects and soil quality flexible time trends. * $p< 0.10$, ** $p<0.05$, *** $p<0.01$.

6 Conclusion

The world's growing population demands a steady increase of meat and agricultural products. This exerts considerable pressures on land and forests. In the context of climate change, carbon dense ecoregions shift toward stricter environmental policy. Our study suggests that supply-oriented environmental policies in the Brazilian Amazon have had consequences beyond its borders. In the state of Mato Grosso, we show that environmental policy led to displacement of soy and cattle activities followed by an increase in deforestation in the neighboring Cerrado ecosystem.

This study focuses on the spillover effect and leakage in deforestation generated by two supply-chain policies in the Amazon. Several significant results emerge from our empirical analysis. We estimate that the SoyM led to an additional 848,622 ha of soy[13] and the CA, an additional 410,301 head of cattle in the near Cerrado.[14] The estimated impact of the CA on leakage in deforestation is approximately 10,707 ha.[15] We show this result emerges from tensions over land where the use of pasture to grow soy led to increased competition between soy producers and cattle ranchers.

A limitation of this study is that forest data can exclude part of the variation coming from sparse and dry vegetation found in the Cerrado Biome. Indeed, both dry and sparse vegetation are less detectable by satellite imagery. In that sense, we are identifying the lower bound in natural vegetation leakage, that is, we identify leakage in deforestation but disregard land use change that occurs in shrub or natural grasslands.

In order to effectively protect forests and incentivize intensification, soy and cattle suppliers should be monitored not exclusively in the Amazon but in the Cerrado as

[13]Pre-mean is equal to 125.3 ha of soy/1000 ha * 21,850 thousand ha in the near Cerrado * 31% = 848,622 ha.

[14]Pre-mean is equal to 181 head of cattle/1000 ha * 9,212 thousand ha in municipalities of the near Cerrado * 24.6% = 410,301.

[15]The pre-mean is equal to 7.4 deforestation/1000 ha of forest cover * 11,348 thousand ha of forest cover * 12.7% = 10,707 ha.

well. More broadly, our study suggests that policy makers should be concerned about the impact on forests in less protected regions when they design environmental policies.

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A Robustness checks on distance specifications

Table 7: Different specifications with distance variable (5 km x 5 km)

	IHS(Soy/1000 ha)		*IHS(Cattle/1000 ha)*		*IHS(Defor/1000 ha of fc)*	
	(1)	(2)	(3)	(4)	(5)	(6)
Post2006 x Distance	-0.00156**				0.00189***	
	(0.00077)				(0.00069)	
Post2006 x Dist. sq.	0.00000				-0.00000**	
	(0.00000)				(0.00000)	
Post2006 x Inverse Dist.		0.60730***				-0.53158***
		(0.19000)				(0.10954)
Post2009 x Distance			-0.00280**		-0.00201***	
			(0.00115)		(0.00047)	
Post2009 x Dist. sq.			0.00000*		0.00000***	
			(0.00000)		(0.00000)	
Post2009 x Inverse Dist.				15.56301***		0.16907*
				(4.54005)		(0.10147)
R-squared	0.07	0.06	0.44	0.46	0.06	0.06
N	181,883	181,883	624	624	180,167	180,167
Untransformed pre-period mean	125.348	125.348	180.966	180.966	7.430	7.430
Time x Soil aptitude	X	X	X	X	X	X
Cell fixed effect	X	X			X	X
Municipality fixed effect			X	X		

Note: Robust standard errors are in parentheses and are clustered at the municipal level for soy and deforestation regressions. Regressions includes unit of analysis fixed effect, time fixed effects and soil quality time trend. * p< 0.10, ** p<0.05, *** p<0.01.

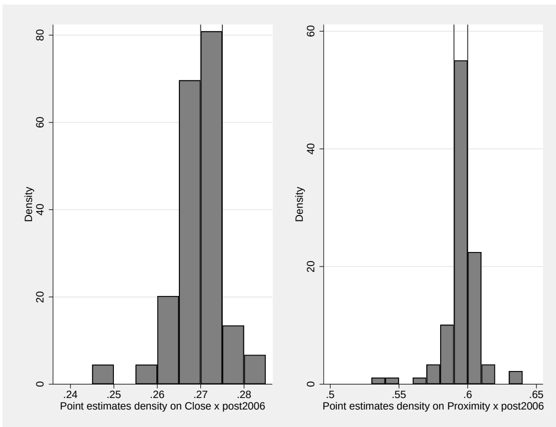
B Estimating the impact post-SoyM on Cattle spillovers

Table 8: Dependent variable is IHS(Cattle/1000 ha)

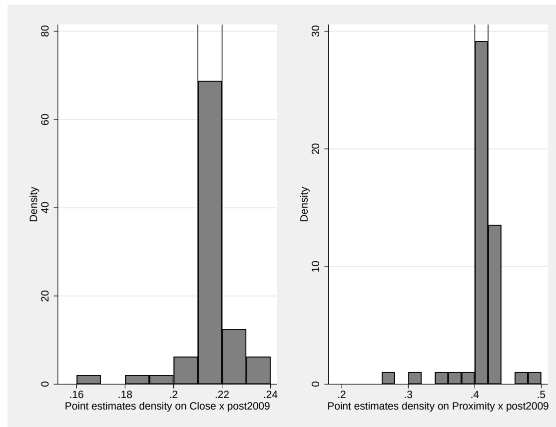
	(1)	(2)	(3)	(4)
Post2006 x Close	0.0808**			
	(0.0400)			
Post2009 x Close	0.1616**			
	(0.0638)			
Post2006 x Proximity[0,1]		0.0945		
		(0.1097)		
Post2009 x Proximity[0,1]		0.3490*		
		(0.1744)		
Post2006 x Distance			-0.0002	
			(0.0002)	
Post2009 x Distance			-0.0007*	
			(0.0004)	
Post2006 x Inverse Dist.				6.0790*
				(3.2301)
Post2009 x Inverse Dist.				11.5104***
				(4.1670)
R-squared	0.44	0.42	0.42	0.47
N	624	624	624	624
Time x Soil aptitude	X	X	X	X
Municipality fixed effect	X	X	X	X

* p< 0.10, ** p<0.05, *** p<0.01.

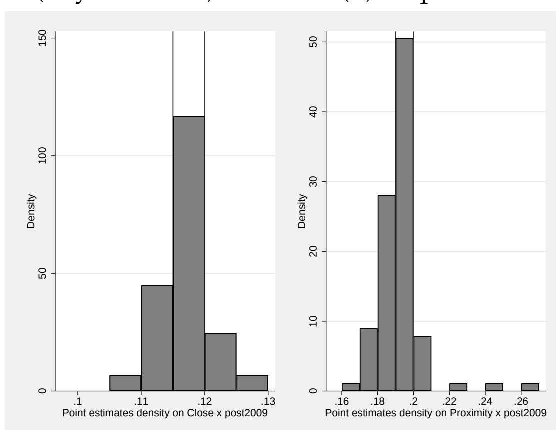
C Sensitivity to municipality outliers (5 km x 5 km)



(a) Dep. var. is IHS(Soy/1000 ha)



(b) Dep. var. is IHS(Cattle/1000 ha)



(c) Dep. var. is IHS(Defor/1000 ha of fc)

Figure 6: Histograms of estimated coefficients when dropping one municipality at a time. Regressions includes unit of analysis fixed effects, time fixed effects and flexible time trends presented in Section 4.1. Robust standard errors are clustered at the municipality level for the soy and deforestation regressions. Left-hand side graphs present the interaction between *Close* and *post-policy*, while the right-hand side graphs present the interactions between *Proximity* and *post-policy*. Each graphs present the estimated coefficients as a white bar with grey sides.

D Robustness on 10 km x 10 km grids

D.1 Sensitivity analysis

Table 9: Varying the Close Indicator (10 km x 10 km)

Panel: Soy	(1)	(2)	(3)	(4)	(5)
	50 km	100 km	150 km	200 km	250 km
Post2006 x Close	0.15*	0.31***	0.32***	0.28***	0.25***
	(0.08)	(0.07)	(0.08)	(0.07)	(0.08)
Obs.	41,700	41,700	41,700	41,700	41,700
Obs. Close	16,302	27,209	32,045	35,646	38,467
Panel: Deforestation					
Post2006 x Close	-0.16**	0.00	0.02	0.06	0.11
	(0.07)	(0.10)	(0.11)	(0.10)	(0.10)
Post2009 x Close	0.15***	0.16***	0.17***	0.14**	0.04
	(0.04)	(0.04)	(0.05)	(0.06)	(0.07)
Obs.	45,162	45,162	45,162	45,162	45,162
Obs. Close	16,302	27,209	32,045	35,646	38,467

Note: Robust standard errors are in parentheses and are clustered at the municipal level for soy and deforestation regressions. Regressions includes unit of analysis fixed effect, time fixed effects and soil quality flexible time trends. * p< 0.10, ** p<0.05, *** p<0.01.

D.2 Robustness checks on the mechanism

Table 10: Soy intensification results within Cerrado Biome (10 km x 10 km grid)

	IHS(soy single/1000 ha)			*IHS(soy double/1000 ha)*			*IHS(soy from pasture/1000 ha)*		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	100 km	150 km	Prox	100 km	150 km	Prox	100 km	150 km	Prox
Close x Post2006	0.24**	0.34***		0.17	0.01		0.07	0.14*	
	(0.09)	(0.10)		(0.10)	(0.12)		(0.06)	(0.07)	
Post2006 x Proximity[0,1]			0.60***			0.21			0.24*
			(0.19)			(0.24)			(0.13)
Close x Post2006	0.15**	0.19***		0.18*	0.05		-0.00	0.05	
	(0.06)	(0.07)		(0.10)	(0.11)		(0.05)	(0.06)	
Close x Post2009	0.17**	0.26***		-0.01	-0.06		0.13**	0.16***	
	(0.07)	(0.08)		(0.04)	(0.05)		(0.05)	(0.05)	
Post2006 x Proximity[0,1]			0.32**			0.30			0.06
			(0.13)			(0.22)			(0.11)
Post2009 x Proximity[0,1]			0.50***			-0.17			0.31***
			(0.14)			(0.11)			(0.10)
Observations	45175	45175	45175	41700	41700	41700	41700	41700	41700
Time x Soil aptitude	X	X	X	X	X	X	X	X	X
Cell fixed effect	X	X	X	X	X	X	X	X	X

Note: The change in single annual soy cropping, double soy cropping and soy planted on pasture by distance to the Amazon frontier in the Cerrado. Note: Unit of observation is the grid cell. Robust standard errors are in parentheses and are clustered at the municipal level. * p< 0.10, ** p<0.05, *** p<0.01.

D.3 Robustness checks on distance specifications

Table 11: Different specifications with distance variable (10 km x 10 km)

	IHS(Soy/1000 ha)		*IHS(Defor/1000 ha of fc)*	
	(1)	(2)	(3)	(4)
Post2006 x Distance	-0.001933*		0.001607*	
	(0.000989)		(0.000944)	
Post2006 x Dist. sq.	0.000002		-0.000004*	
	(0.000002)		(0.000002)	
Post2006 x Inverse Dist.		2.938735***		-2.596033***
		(1.034557)		(0.817853)
Post2009 x Distance			-0.002820***	
			(0.000582)	
Post2009 x Dist. sq.			0.000006***	
			(0.000002)	
Post2009 x Inverse Dist.				1.657845**
				(0.790060)
R-squared	0.09	0.09	0.11	0.11
N	41,700	41,700	45,162	45,162
Untransformed pre-period mean	126.2	126.2	6.7	6.7
Time x Soil aptitude	X	X	X	X
Cell fixed effect	X	X	X	X

Note: Robust standard errors are in parentheses and are clustered at the municipal level for soy and deforestation regressions. Regressions includes unit of analysis fixed effect, time fixed effects and soil quality time trend. * p< 0.10, ** p<0.05, *** p<0.01.