Agricultural Displacement and Deforestation Leakage in the Brazilian Legal Amazon

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Abstract: Does environmental policy aiming to reduce deforestation induce displacement of existing agricultural activities? To shed light on this question, we exploit a spatial discontinuity design, to examine whether or not the Soy Moratorium and the Zero Deforestation Cattle Agreements in the Brazilian Amazon have displaced production or deforestation 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, Amazon, soy, cattle, deforestation, leakage, spillovers.

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1 Introduction

Expansion of large-scale cattle and soy production in the Brazilian Amazon since the 1970s has led to high rates of deforestation. 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, relatively little attention has been paid to the neighboring less protected 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 two policies implemented in major Amazon commodity supply chains, the Soy Moratorium (SoyM) and the Zero-Deforestation Cattle Agreements (CA), have led to soy, cattle and deforestation spillovers from the Amazon ecosystem into the less regulated Cerrado ecosystem. Both the SoyM and the CA were initiated following international scandals that linked the production of soy and cattle with deforestation in the Amazon. The SoyM began in 2006 and prohibited producers from growing soy on land deforested after 2006. The CA began in 2009 and mandated that slaughterhouses refrain from buying cattle from properties with deforestation after 2009. Both of these supply chains policies are enforced only in the regulated Amazonian ecosystem, the Amazon biome.

We exploit the spatial discontinuity provided by the biome border to identify spillover effects. Our methodology uses the distance between the biome border and the units of analysis in the Cerrado as a proxy for treatment or expected intensity of leakage. The assumption underlying our econometric strategy is that if there are spillover effects, they should occur disproportionately more in the areas closest to the biome border than in those 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[1] observations, we estimate the effect of a discrete and of 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 to maximize profits. If a company operates in a region that suddenly becomes more

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

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 government regulations and international actors that can direct negative marketing campaigns against the sector, agricultural expansion may be preferable in the less regulated and less scrutinized region.[2] 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, all other factors being equal (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% (approximately 850,000 hectares) relative to the region farther from the Amazon during the period 2007-2013. We show that the CA resulted in an increase in the cattle herd of 24.6%, or approximately 410,000 head, in the proximate region relative to the more remote region over the time period 2010-2013. The spillovers from the CA resulted in the deforestation of 10,700 hectares in the biome adjacent to the Amazon, an increase of 12.7% compared to before the policies. In Cerrado, soy expanded mainly on pasture and on other areas that had already been deforested. This explains why the leakage in deforestation is less than the soy and cattle spillovers. Our results are robust to falsification tests, to the use of 10 km x 10 km instead of 5 km x 5 km grid cells and to different specifications of the distance treatment. Therefore, as policies become more stringent in the Amazon, policymakers should consider extending them in to the Cerrado.

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

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

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 also contributes to both the indirect land use change and the deforestation leakage literatures. We are the first to show how environmental policies caused displacements of agricultural activities into less environmentally constrained regions and how it led to leakage in deforestation and indirect land use changes.

Indirect land use change occurs when one land use displaces another, so that the second land use expands in another region, sometimes at the expense of forests (Andrade de Sá et al., 2013). In the Brazilian context, indirect land use change typically manifests in the following way: crops expand into pastures, pushing pasture into forest (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, are responsible for most of the indirect land use change that has been quantified in recent research. In the 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 hectare in sugarcane would require only 0.14 hectare of new land and 0.47 hectare converted land 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 of the Brazilian Amazon. Our empirical strategy differs from previous work by employing a source of variation, the spatial discontinuity, that has never been used to identify causal indirect land use changes.

One form of deforestation leakage is the shift of deforestation activities from inside protected regions to outside protected regions (Angelsen, 2010). Literature on deforestation leakage has generally focused on the effect that protecting forests has on the nearby regions (Alix-Garcia et al., 2012; Berck and Bentley, 1997; Delacote et al., 2016; Wear and Murray, 2004; Wu, 2000). While studies in the Brazilian Amazon have emphasized the role of population pressure, roads, agriculture and the cattle herd as drivers of deforestation (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), little is known about whether the anti-deforestation policies generated deforestation leakage. We are the first to study this leakage in the context of asymmetric environmental policies between two neighboring ecosystems.

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

Until the 1970s, the Brazilian Amazon has generally been disconnected from national and global markets. Spurred by improved local credit, tax exemptions and infrastructure, new markets emerged encouraged by 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. Recent soy demand increases driven by Chinese imports intensified the Amazonian soy production.

Brazil is home to 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 government agencies, international agencies and environmental organizations have implemented several policies to deter deforestation (Assunção et al., 2013; Assunção and Rocha, 2014; Hargrave and Kis-Katos, 2013; Nepstad et al., 2014). These policies together with changing economic conditions, contributed to decrease deforestation in the Brazilian Amazon: it fell from between 10,000 and 30,000 km^2 in the 1990s, 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 (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 rates are no longer decreasing.

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. 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 often face challenges in managing environmental regulation. For example, regulations may be in place, but only superficially enforced. The Brazilian government and its anti-deforestation regulations are no exception, though enforcement has improved in recent years. In this low-enforcement context, it was not until international and national NGOs denounced the agricultural processes driving deforestation in the Brazilian Amazon that changes began to occur. To modify agricultural practices, they targeted soy and cattle sectors and created a negative publicity campaign. Because the soy and cattle markets are concentrated in the hands of relatively few actors in the region, environmental activists used the agribusinesses corporations' visibility as an asset to force change. The NGOs' campaigns and political pressure led to the signature of two anti-deforestation agreements in which the signatories 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 other private actors, like banks.

The first of these agreements to be implemented was the Soy Moratorium. In 2006, a Greenpeacesponsored 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 traders 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 (MODIS) detects the non-compliant producers and a list is created. The traders that signed the SoyM use the list to avoid purchases from the non-compliant producers. Simultaneously, soy traders are 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 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 of 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 a geospatial

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

firm to support their monitoring system. Comprised of the G4 and the TACs, the Zero-Deforestation Cattle Agreements (CA) is monitored only in the Amazon biome.[4] At this date, a small body of literature analyzed the impacts of this supply-chain policy. JBS, the biggest beef exporter of the world, has been shown to statistically alter its purchase behavior and boycott suppliers with deforestation following the CA in Pará (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 from these properties to those that were not yet registered.

The CAR is fundamental to current enforcement of the soy and beef supply-chain policies. In Brazil, the law required 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. Agricultural producers generally use the services of local technicians to create the CAR and for a reasonable amount, obtain the deforestation history of their parcel. Indeed, even if previous owners deforested after the threshold date, non-compliance would be attributed to the current owner. 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 have emphasized to protect the Amazon biome over other parts of Brazil because of its higher ecosystem value. Indeed, the National Institute for Space Research in Brazil (INPE) provides public official deforestation data for the Amazon (PRODES and DETER), but no official deforestation data for the Cerrado. Because of this, producers may be avoiding detection in the Amazon by different strategies, including preferring locations within the Cerrado biome (Richards et al., 2016).

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

[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.

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.

In the face of land use constraints, a producer has two choices: land intensification or extensification. Previous empirical work has showed that agricultural productivity increases led to both expansion and intensification where the net effect depend on the specific municipality characteristics prior to the increase in agricultural productivity (Assunção et al., 2017). 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 a greater investment per unit of land. The SoyM is an incentive toward intensification in the Amazon biome. Differently, extensification implies that the producer uses additional land to produce greater output, while maintaining a similar average production per hectare. The producer can extensify on previously cleared land or may clear forested land. In the Amazon biome, once environmental policies are more stringent, as under the Soy and Cattle moratoria, deforestation for extensification becomes a riskier activity. On the contrary, in the Cerrado biome, deforestation-related extensification is not as risky.

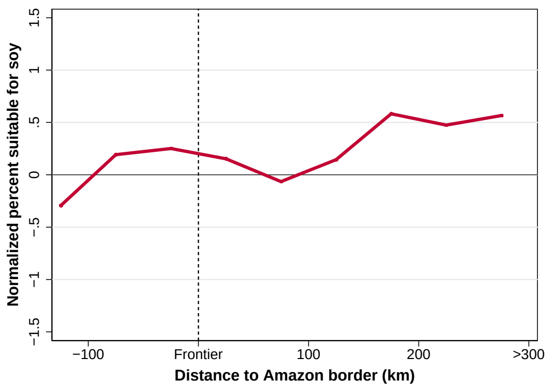
When there is a biome-specific environmental policy, two types of producers are affected: those who already own a farm in the Amazon biome, and newcomers that want to undertake activities there. In the face of stricter forest protection, Amazon biome agribusinesses that want to expand can choose to intensify, to buy a new property that respects environmental policies or to expand their activities in a less strict region. Whether they already own a property in the Cerrado or not, extensifying activities in this less constrained biome may be the profit-maximizing option for lands with similar prices. In addition, newcomers that would have otherwise invested in the Amazon biome are likely to be more easily 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 their Amazon's farm to be close to their Cerrado's farm, or they may wish to be near the Amazon because of market advantages and because it was their preferred site originally.

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. Often, cattle production involves two farms: one for breeding and another for fattening. It is advantageous for cattle ranchers to have geographically concentrated land to minimize transportation costs. Furthermore, cattle ranching activities require different sets of inputs and labor, so proximity to another farm can help to 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.

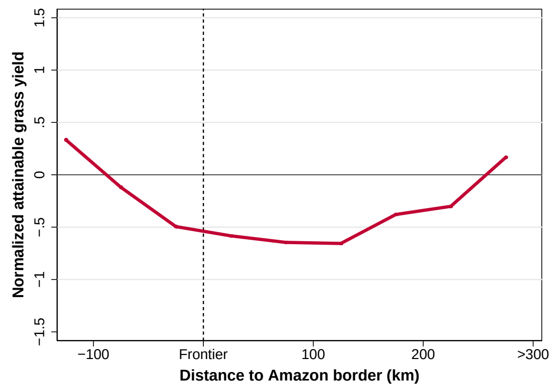
The data show that producers own multiple properties across biomes. There are 82,253 mapped properties in Mato Grosso (SICAR Brazil, 2015). Of all those properties, 19.6% have ownership that we can identify as possessing more than one property. For those 16,158 unique mapped properties, we find 6,498 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 hectares 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 regions farther from the Amazon. Figure 1 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.[5] In figures 1a and 1b, 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 1c 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. Furthermore, moderate slope does not constrain cattle production. Indeed, heads of cattle are significantly more numerous in the distant zone of Mato Grosso's Cerrado (section 4.2).

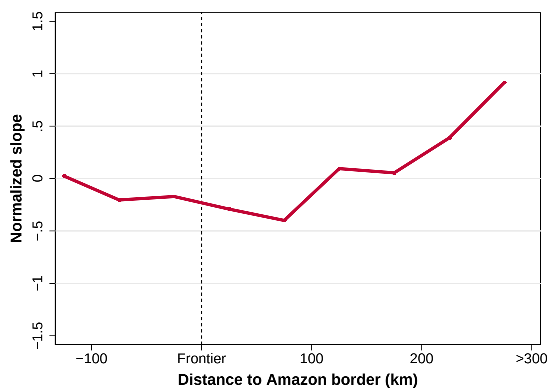
[5]We group together regions farther than 300 km since the regions between 300 and 500 km represent less than 10% of the sample size.



(a) Area suitable for soy



(b) Potential grass yield



(c) Slope

Figure 1: 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.

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 because spatially-explicit, multi-temporal data were not available. 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 2 shows the grid cells within the Cerrado biome region according to the distance to the Amazon biome frontier. Note that federal highways are relatively evenly distributed between the near and far regions.

Our main dependent variables are soy area (ha), head of cattle, and deforestation (ha). Data cover the 2001-2013 period. Soy area 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 define a "soy from pasture" layer based on soy areas planted on areas defined as pasture the year before. This criteria reduces the number of observations by one year and corresponds to the 2002-2013 period.

Head of cattle are municipality level data and come from the Brazilian Institute of Geography and Statistics (IBGE). These data are based on a mandatory animal health registry that compiles all cattle transactions in Brazil, which provides high quality aggregate of cattle heads at the municipal level. 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 from Hansen et al. (2014). Spatial resolution is of one arc-second per pixel which corresponds to approximately .076 hectare in our study region. We choose a canopy cover of 30% for the pixel to be considered as forested[6]. 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 reduces the influence of extreme observations.

Control variables come from several sources. The soil suitability data come from two sources. Soy soil

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

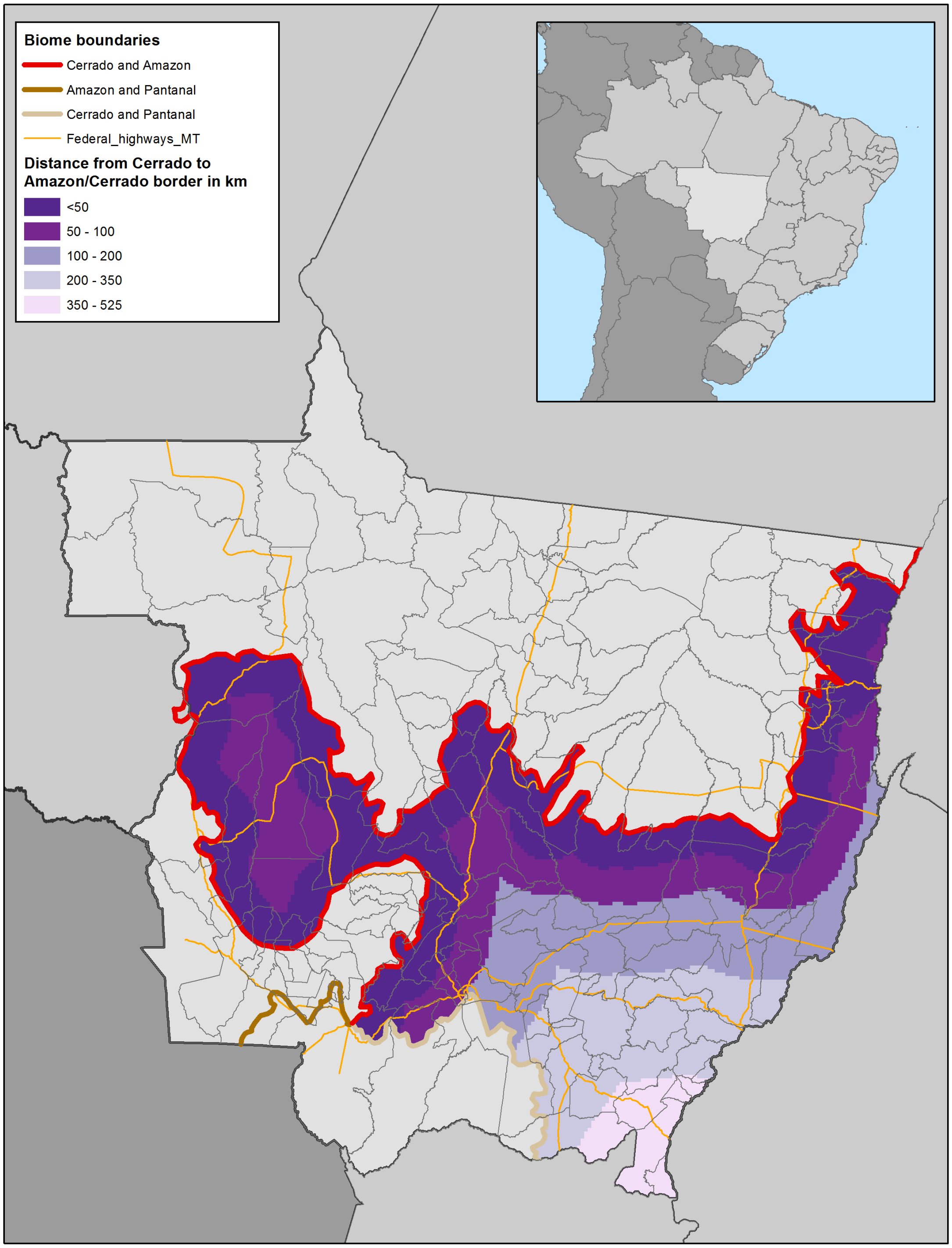


Figure 2: Study region according to distance to the Amazon biome

suitability is based on Soares-Filho et al. (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 2003-2013. 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

If there are spillovers, areas closer to the border should see a higher increase in agricultural production and possibly deforestation as well, if agriculture increases in an extensive rather than an intensive way.[7] We analyze the influence of the policies and the distance on the dependent variable using all grid cells (for soy and deforestation) and all municipalities (for cattle). Specifically, we estimate:

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

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, and 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 equals 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:

[7]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.

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

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 the time dummies (T_t). These interactions allow to estimate the flexible time trends ϕ_{xt} between the different level of soil suitability and deforestation risk. Specifically, in the regression on soy, I control soy suitability, in the regression on cattle, I control for pasture suitability and in the regression on deforestation, I control for all soil suitability covariates (slope, soy and pasture suitability). Regressions on soy and deforestation include grid cell fixed effects and the regression on cattle heads uses municipality fixed effects (δ_i), which control 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 the entire 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.[8]

Regressions based on municipality are weighted by 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.

We include in the deforestation specification both the post-SoyM and post-CA interactions with the treatment variable. The objective is to identify first if there is leakage in deforestation and second, if there is leakage, whether it came from the SoyM or the CA.

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.

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

4.2 Descriptive statistics

Table 1 presents outcomes and covariates means, standard deviations and normalized differences. We divide the sample between *Close* and *Far*, using the 100 km threshold.

For soy, we observe significantly less area suitable 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 more productive and supports 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. 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. In terms of minimum distance to nearest federal highway and distance to nearest silo pre-SoyM (2005), it is on average higher in the *Close* region. The distance to the nearest slaughterhouse pre-CA (2008), the road density and the federal highway density are similar between the groups.

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, standard deviations and normalized differences)

	Close		Far		Norm. diff.
Outcomes					
Soy/1000 ha (2005)	125.35	(259.25)	109.85	(220.93)	0.05
Soy single cropping/1000 ha (2005)	86.99	(186.65)	91.73	(190.92)	-0.02
Soy double cropping/1000 ha (2005)	36.72	(124.80)	15.44	(61.89)	0.15
Pasture to soy/1000 ha (2005)	26.59	(70.02)	23.63	(57.58)	0.03
Soy/1000 ha (2013)	146.44	(276.32)	123.23	(244.89)	0.06
Soy single cropping/1000 ha (2013)	50.06	(115.83)	43.79	(110.67)	0.04
Soy double cropping/1000 ha (2013)	87.75	(208.79)	69.80	(174.00)	0.07
Pasture to soy/1000 ha (2013)	13.64	(35.64)	11.22	(32.13)	0.05
Cattle head/1000 ha (2008)	221.43	(169.65)	397.65	(229.29)	-0.62
Cattle head/1000 ha (2013)	243.40	(173.98)	435.21	(291.33)	-0.57
Defor/1000 ha forest cover (2005)	7.43	(30.11)	6.75	(25.53)	0.02
Defor/1000 ha forest cover (2013)	3.80	(19.85)	2.75	(10.32)	0.05
Covariates					
Area suitable for soy (ha)	1275.53	(1079.21)	1646.49	(855.51)	-0.27
Av. rain soy season (Sept-Dec) (1998-2009)	719.63	(189.22)	723.20	(198.32)	-0.01
Av. rain non-soy season (Jan-July) (1998-2009)	883.97	(228.33)	922.56	(219.98)	-0.12
Attainable grass yield (t/ha)	1.06	(0.08)	1.17	(0.07)	-1.11
Slope	6.14	(4.64)	10.32	(6.97)	-0.50
Percent forest cover (2000)	51.94	(34.02)	34.16	(21.77)	0.44
Indigenous protected area/1000 ha	476.37	(947.53)	121.20	(505.40)	0.33
Protected area/1000 ha	58.99	(357.83)	10.83	(139.67)	0.13
Sustainable area/1000 ha	48.09	(326.62)	136.96	(554.18)	-0.14
Urban area/1000 ha (2005)	1.31	(24.11)	1.88	(27.61)	-0.02
Water area/1000 ha (2005)	1.17	(11.02)	2.58	(29.50)	-0.04
Change in embargoes/1000 ha (2013-2005)	0.05	(0.34)	0.05	(0.30)	0.01
Dist. to fed. highway (km)	46.64	(40.23)	38.58	(28.25)	0.16
Dist. to nearest silo in 2005 (km)	30.79	(26.24)	23.39	(22.59)	0.21
Dist. to nearest slaughterhouse in 2008 (km)	74.26	(39.51)	73.05	(37.13)	0.02
Road density (m/ha)	2.43	(2.05)	2.39	(1.65)	0.01
Fed. highway density (m/ha)	0.07	(0.37)	0.09	(0.42)	-0.03
Obs. grid cells	8741		5250		13991
Obs. municipios	16		32		48

Note: This table presents means, standard deviations and normalized differences at the municipality level, for cattle head and attainable grass yield, and at the grid cell level for all other variables. *Close* represents the units of analysis within a distance of 100 km from the Amazon frontier and *Far* includes those farther from 100 km. Normalized differences are a scale-free measure of the difference in distributions between samples (Imbens and Wooldridge, 2009).

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[9], 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 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). Column (5) shows that the region within 100 km of the biome frontier experienced an increase of 12.7% in deforestation because of the CA. The impact calculated on the continuous proximity variable is positive and statistically significant at the 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 regressions for the 10 km x 10 km grid cells sample. The results

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

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.

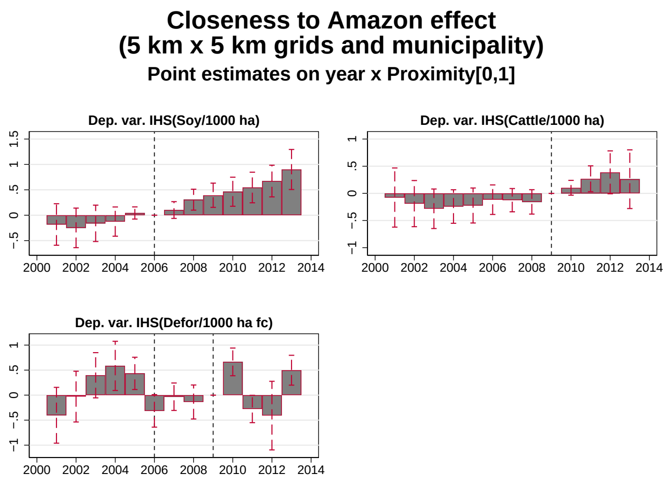
Table 3: Impact of the supply-chain policies on areas close to the Amazon frontier (10 km x 10 km grids)

	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

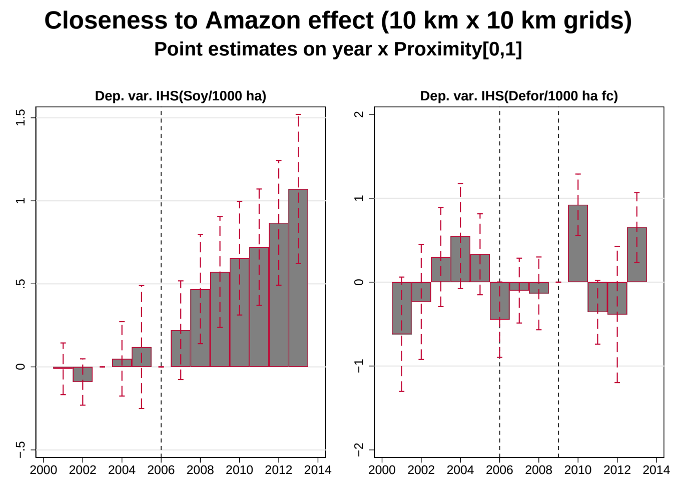
Note: Robust standard errors are in parentheses and are clustered at the municipal level. Regressions includes unit of analysis fixed effect, time fixed effects and soil quality time trend. Pre-period means corresponds to soy per 1000 ha in 2005 for the first two columns, to the cattle herd per 1000 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 3a, 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 estimator and other control variables are the same as presented in Equation 1.

In Figure 3a, soy pre-trends for 2001-2005 are not significantly different from zero, which confirms the robustness of the results presented in Table 2. The gradually increasing 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 3a. Results are robust to the 10 km x 10 km grid cells (Figure 3b). The yearly effects of proximity to the Amazon on deforestation present no statistical differences, except for the 2004 and 2005 years. However, the statistically non-significant differences in pre-trends for the deforestation data in the 10 km x 10 km provides substantial confidence that it is likely that if there would not have been the policies of the SoyM and the CA, both the near and the far Cerrado would have follow similar trends in terms of deforestation. 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.



(a) 5 km x 5 km



(b) 10 km x 10 km

Figure 3: 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 the flexible time trends presented in section 4. 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 results suggest the leakage is due to the 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 market 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.[10] To better understand the dynamics, we test how intensification versus extensification of production changed in the Cerrado because of the policies.

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

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 different *Close* thresholds defined as within 100 km of the frontier (columns (1), (4) and (7)) and within 150 km (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 the 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.[11]

[11] 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)	(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	0.19**	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.

It appears that expansion of soy in pasture lands has created land market adjustment between soy agribusinesses and ranchers, where the latest group had to search for cheaper land after soy agribusinesses increased its purchase of land in pasture. Scarcity of land that has already been deforested may have pushed agricultural actors to increase deforestation.

5.3 Falsification tests

In order to show that the results are not driven by agricultural infrastructure and political priorities, we use Equation 1 with two other outcomes that should not be affected by the SoyM and the CA. Estimations are performed with five specifications of the *Close* indicators and with the *Proximity* treatment. If confounding factors such as agricultural dynamism in the near Amazon occur after the policies, then our estimates could be false positives. For this purpose, we use the chicken population and the sugarcane production. Results shown in Table 6 present all statistically insignificant coefficients and support the specific impacts of the 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 31% of soy (848,622 hectares) [12] and the CA, an additional 24.6% of cattle (410,301 head of cattle) in the near Cerrado.[13] The estimated impact of the CA on leakage in deforestation is approximately 12.7% (10,707 ha).[14] We show this result emerges from land market adjustment where the increased use of pasture to grow soy led to competition between soy producers and cattle ranchers. The hypothesized price increase in pasture would have led ranchers to search for cheaper land.

The intensification in cattle production can be another mechanism that explains the difference between the relatively small amount of deforestation compared to the increase in cattle production. Intensification could have reduced the total amount of deforestation both relative to the increase in production and consistent with land price increase generated by the agricultural displacements. This is subject to further study.

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. Similarly, we cannot identify degradation, meaning that the forest biomass would have declined following perturbation of the ecosystem.

The increase in the soy and cattle agricultural production in the Cerrado has also affected biodiversity. Indeed, the combination of both deforestation and clearance of natural vegetation implies a reduction in

[12]Pre-mean is equal to 125.3 hectares of soy/1000 ha * 21,850 thousand hectares in the near Cerrado * 31% = 848,622 ha.
[13]Pre-mean is equal to 181 head of cattle/1000 ha * 9,212 thousand hectares in municipalities of the near Cerrado * 24.6% = 410,301.
[14]The pre-mean is equal to 7.4 deforestation/1000 ha of forest cover * 11,348 thousand hectares of forest cover * 12.7% = 10,707 ha.

terms of ecological habitat that affects biodiversity. Quantifying this loss is not the goal of this paper but still should be considered as a side-effect, together with water contamination and emissions from land-use change as negative externalities of the spillovers effects from the Amazon to the Cerrado.

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

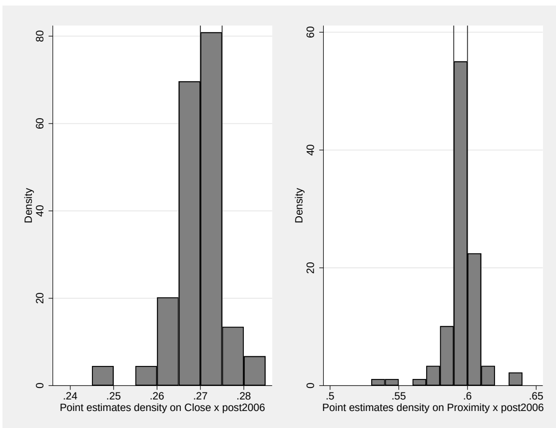
B Estimating the impact post-SoyM on Cattle spillovers

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

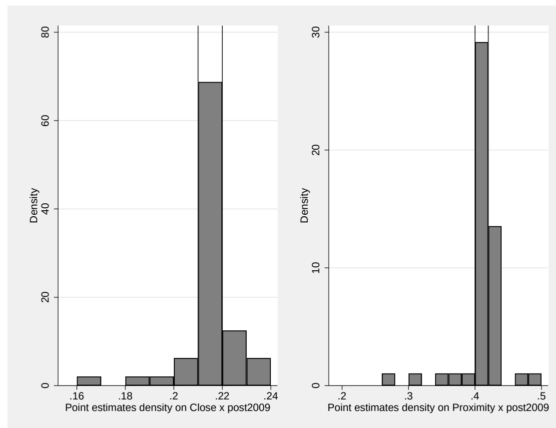
	(1)	(2)	(3)	(4)
Post2006 x Close	0.0808**			
	(0.0400)			
Post2009 x Close	0.1616**			
	(0.0638)			
Post2006 x Proximity[0,1]		0.0945		
		(0.1097)		
Post2009 x Proximity[0,1]		0.3490*		
		(0.1744)		
Post2006 x Distance			-0.0002	
			(0.0002)	
Post2009 x Distance			-0.0007*	
			(0.0004)	
Post2006 x Inverse 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.

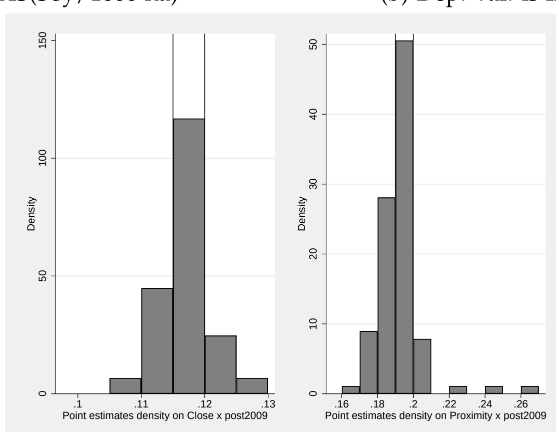
C Sensitivity to municipality outliers (5 km x 5 km)



(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 4: Histograms of estimated coefficients when dropping one municipality at a time. Regressions includes unit of analysis fixed effects, time fixed effects and the flexible time trends presented in section 4. 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.