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Soybean expansion in the Brazilian Amazon: direct and indirect impacts of the Soy Moratorium

Expansão da soja na Amazônia brasileira: impactos diretos e indiretos da Moratória da Soja

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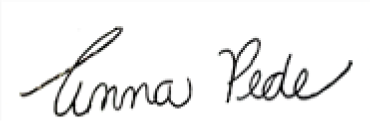

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"Terra, terra

Por mais distante

O errante navegante

Quem jamais te esqueceria?"

(Caetano Veloso)

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Abstract

In the 2000s, rising concern about the Amazon forest degradation shed light on the in-forest supply chains, especially cattle ranching and soy cultivation. This dissertation proposes an investigation of the impacts of the Amazon Soy Moratorium (ASM), a pioneer supply-chain commitment. ASM is an agreement by grain traders not to purchase soybeans cultivated in Amazon areas deforested after July 2006. Exploring Amazon's geographic frontier and satellite data, this dissertation investigates ASM impacts on soy expansion using a Regression Discontinuity Design. Results point that ASM had no statistically significant impact on soy-driven deforestation. However, results suggest a relative increment in the soy cover in the Amazon area, meaning that soy expansion continued but on land occupied by other activities. To complement these results, performing a Difference-in-Differences analysis, I found that in areas close to the biome border, ASM induced the displacement of soy cultivation to pasture areas.

Key-words: Brazilian Amazon, Deforestation, Land-use, Soy Moratorium.

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Resumo

Na década de 2000, a crescente preocupação com a degradação da floresta amazônica colocou em evidência as cadeias produtivas desenvolvidas na região, especialmente a pecuária e o cultivo da soja. Esta dissertação propõe uma investigação dos impactos da Moratória da Soja sobre a expansão da soja na Amazônia. A Moratória é um acordo entre os *traders* do grão de não comprar soja cultivada em áreas desmatadas na Amazônia após julho de 2006. Explorando a fronteira geográfica do bioma e dados de satélite, são investigados os impactos sobre a expansão da soja usando um *Regression Discontinuity Design*. Os resultados apontam que a Moratória não teve impacto estatisticamente significante no desmatamento direto causado pela soja. No entanto, os resultados sugerem um incremento relativo na cobertura da soja na região amazônica, indicando que a expansão da soja continuou a ocorrer, mas em áreas ocupadas por outras atividades. Para complementar esses resultados, com uma análise de Diferença em Diferenças, foi encontrado que em áreas próximas à fronteira do bioma, a Moratória induziu o deslocamento do cultivo de soja para áreas de pastagem.

Palavras-chave: Amazônia Brasileira, Desmatamento, Uso da terra, Moratória da soja.

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1 Introduction

Forests are essential carbon storages; however, permanence is vulnerable due to natural and human disturbances, making deforestation a relevant contributor to clime change (Fawzy et al., 2020). In 2010, emissions from deforestation and land use accounted for around one-quarter of total global greenhouse emissions, and tropical forest cleaning contributed to almost 20% of all anthropogenic emissions (Gibbs and Herold (2007), IPCC (2014)) . Since agriculture is a significant deforestation driver in tropical areas, reconciling the increasing global demand for food - and the pressure to expand the agricultural frontier - and environmental protection is one of the biggest challenges for climate change mitigation.

In Brazil, the agricultural frontier's expansion has been responsible for a large share of Amazon's deforestation in recent decades. Amazon's Arc of Deforestation[1] became the world's most active tropical frontier during the 2000-2005 period mainly due to the expansion of cattle ranching and soy cultivation over the forest(Morton et al., 2013).

In 2004, Amazon's deforestation reached a record of 27,800 square kilometers, inciting international attention over Brazil's conservation efforts and pressuring the retailers associated with Amazon-produced commodities. In this context, the Brazilian Soy industry most relevant agents signed the Amazon Soy Moratorium agreement (hereafter ASM). The Moratorium is committed not to purchase Soybeans planted in the Amazon Biome in areas deforested after July 2006.

Although Brazil made significant improvements in the environmental legislation after 2004, which were fundamental for the subsequent deforestation slowdown, the potential political cycle's impact on the legislation enforcement makes private supply-chain initiatives attractive complementary policies (Heilmayr et al., 2020). However, due to Amazon's complex land use dynamic, assessing how the Soy Moratorium effectively impacted Amazon's land use is challenging.

This dissertation proposes an investigating of two channels of ASM impacts. First, the direct impact on soy-driven deforestation. The hypothesis is that inside the Amazon biome ASM reduced forest areas' conversion into soybeans after 2006. Observing localities close to Mato Grosso's Amazon frontier, results point that the agreement did not impact soy-driven deforestation, reinforcing literature evidence that soy has been a minor direct

[1] Name attributed to the forest's southern border.

deforestation driver. The results considering overall soy expansion showed that soy crops continued to expand in the Amazon over non-forested areas, demonstrating that the agreement allows the existing soy expansion dynamic to continue.

Considering such dynamic, the second part of the research estimates ASM's indirect impact on soy expansion. Since the commitment only restricts cultivation on forest-occupied areas, it could induce soy expansion to previously deforested areas occupied by other activities, especially cattle ranching. Using a difference-in-differences estimate, I found that ASM increased the pastures' transition into soy in Amazon areas near the biome boundary.

This dissertation adds to the literature investigating ASM impacts on Amazon's deforestation (Gibbs et al. (2015), Peixoto (2017), Heilmayr et al. (2020), Svahn and Brunner (2018)) by precisely observing soy-driven deforestation rather than the overall deforestation impact. It also contributes to the literature on the commitment secondary impacts (Moffette and Gibbs (2018), Gollnow et al. (2018)) by investigating soy-expansion's behaviour over non-forested areas after 2006.

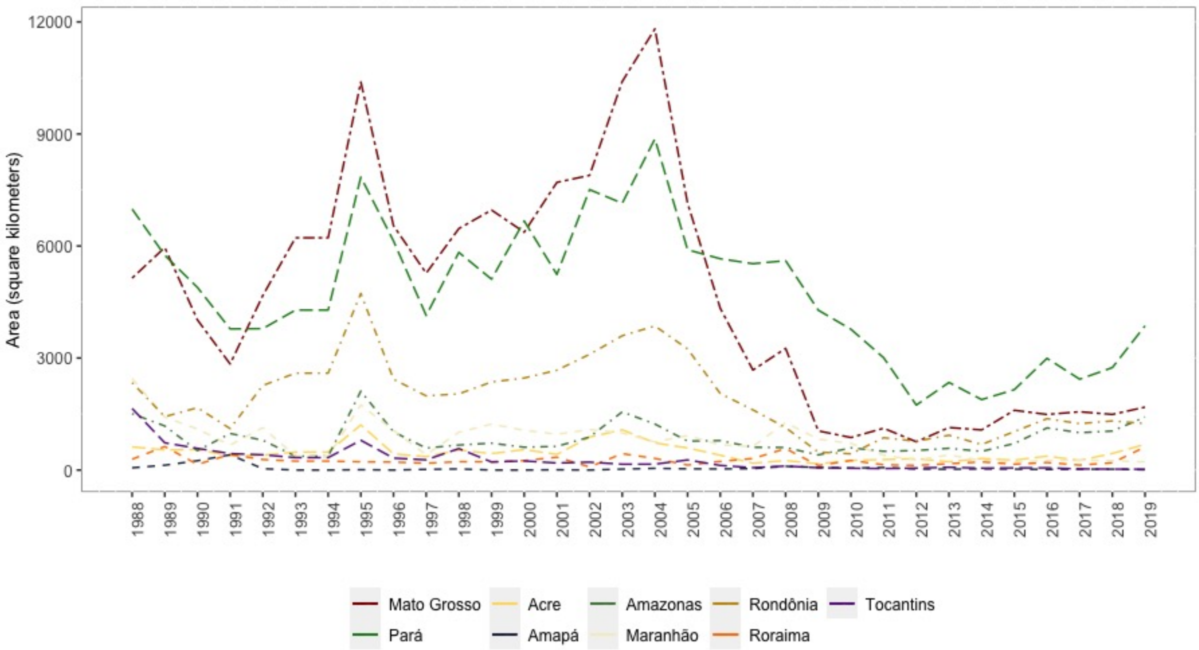
The remainder of the dissertation is structured as follows. Section 2 presents the background, discussing Amazon's deforestation drivers, the Soy Moratorium Agreement peculiarities, and literature evidence. Section 3 presents the empirical strategy and results of the investigation of ASM's direct deforestation impact. Section 4 discusses the secondary land-use impacts. Section 5 presents the final remarks and the dissertation contributions and limitations.

2 Background

Continuous population growth in the XXI century will call for an expansion in agricultural production to ensure food security (FAO, 2009). Since land available for agriculture is limited, this will require improvements in agriculture productivity and incentivize agricultural frontier's expansion in substitution to original forest cover. Concurrently, forests conservation is a fundamental pillar for climate change mitigation since forests are significant Carbon stocks and have essential environmental functions (Climate Policy Initiative, 2013).

From a global perspective, Brazil and the Amazon forest are at the center of this debate. Amazon is the world's largest tropical forest, with an original extension of 6.7 million square kilometers. Brazil holds the majority of the forest area, and between 1988 and 2019, it lost 450,000 square kilometers of forest cover (INPE, 2020). Figure 1 presents the evolution of the deforestation increment by state. Mato Grosso and Pará, states with a significant agricultural sector, exhibit the highest rates.

Figure 1 – Amazon deforestation increment by state: 1988-2019



Source: INPE.

Broadly, Brazil is striving to meet economic growth goals with environmental conservation simultaneously. Although Amazon's sharp degradation in the last three decades has been mainly driven by agriculture (Richards et al., 2014); in the 2000s, the country implemented policies that sharply reduced deforestation while strengthening its global position as a leading agricultural producer. The successful experience in detaining deforestation comes from a broad set of government actions and private sector initiatives. The initiatives were taken after 2004, when, following several years of rising rates, deforestation reached 27,800 square kilometers.

Literature has evidenced the effectiveness of the environmental legislation adopted by the Brazilian government in the 2000s. The Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm), which combined a set of technological changes and legal actions, and the municipalities' "Blacklist" were crucial for the deforestation decrease (Assunção et al. (2017), Assunção and Rocha (2014)). Additionally, changes in the agricultural sector also impacted the deforestation pattern following 2004. A shift in market conditions, with a decline in prices, contributed to inhibiting forest clearing for the expansion of farmland (Assunção et al. (2012), Hargrave and Kis-Katos (2013)). Appendix A1 presents a timeline of the most relevant Amazon conservation initiatives since 2000 and other relevant aspects impacting Amazon's agricultural sector.

Soy cultivation and cattle grazing were the two main Amazon deforestation drivers in the 2000s (Diniz and Neto, 2009). Between 1990 and 2007, the Brazilian cattle herd grew from 147 million to 200 million, with 83% of this occurring in Amazon forest areas. It is estimated that in Mato Grosso and Pará, 80% of deforestation occurred due to pasture expansion (Alix-garcia and Gibbs, 2017).

Since 2001, Mato Grosso is Brazil's leading soy producer. The astonishing expansion of soybean crops in the Legal Amazon region [1] took place mostly on degraded pastures and replacing other cultures (Richards et al., 2014). Between 2001 and 2005, the soy area went from 3 million hectares to 6 million, and production increased by 85%. In this increment, the Amazon biome area accounted for 1 million hectares and 3 million tons of the production increase (Macedo et al., 2012).

In the Amazon region, the soy industry's favorable market conditions at the beginning of the 2000s led to the replacement of pasture areas, relatively less productive, by crops (Cohn et al., 2016). This substitution pushed cattle grazing, relatively less productive but less capital-intensive, to the bordering forest areas, causing deforestation. With this process, it is estimated that since 2002 the soybean sector has indirectly contributed

[1] Mato Grosso is entirely within the Legal Amazon but only partially covered by the Amazon Biome. The Legal Amazon is a political division while the biome reflects an ecological characterization.

to almost thirty-two percent of Amazon's forest loss (Richards et al., 2014). Further, although most of the soy expansion in the Amazon occurred in previously deforested areas, between 2001 and 2005, 12% of the deforestation of large areas (greater than 25 hectares) in Mato Grosso state took place for soy cultivation (Macedo et al., 2012).

After 2005, the soy industry encountered a different scenario due to a sharp reduction in prices (Assunção et al., 2012). The soy area in Mato Grosso was reduced by 1 million hectares and did not recover by 2010 [2]. Consequentially, the agricultural sector's indirect pressure on Amazon's deforestation declined after 2006 (Richards et al., 2014). Still, towards the end of the 2010s, Mato Grosso's cultivated soy area considerably expanded. At the same time, concern about Amazon's deforestation and Brazil's environmental law enforcement capacity reappeared.

Overall, agricultural expansion has been a critical direct and indirect contributor to Amazon's degradation in the last two decades. Due to an increasing concern about environmental protection, consumers and civil society organizations have become highly aware of the link between agricultural commodities production and deforestation worldwide. In response, major corporations have established robust supply chain governance, including zero-deforestation agreements and certifications schemes, to incorporate environmental responsibility in their production chains. Starting in 2006, interventions on the cattle and soy supply chains in Brazil became leading cases, followed by major agreements on Palm Oil production in Indonesia in 2017 (Gibbs et al. (2015), Alix-garcia and Gibbs (2017), Carlson et al. (2018)). The following section comments on Amazon's supply chain governance and provides details about the Soy Moratorium agreement.

2.1 Amazon Soy Moratorium

Amazon's record deforestation in 2004 made international organizations and civil society pay closer attention to Brazil's environmental protection efforts. Even with stronger conservation laws and enforcement, in a context of unsettled law enforcement capacity and uncertainties due to the political cycle fluctuations, public opinion also demands corporations tightly connected with deforestation to take direct action.

[2] Figure A2 displays the evolution of the cultivated soy area and production in Mato Grosso, comparing it to Brazi's leading producing states

A series of Greenpeace's campaigns targeting international buyers of commodities produced in the Amazon region shed light on the in-forest supply chains and the corporate responsibilities for its degradation (Greenpeace (2006) and Greenpeace (2009)). The soy and meat industries suffered the menace of international sanctions and commercial backlash in the North American and European markets.

In this context, in 2006, the national soy industry most relevant agents, the Brazilian Association of Vegetable Oil Industries (ABIOVE) and the National Grain Exporters Association (ANEC), signed the Soy Moratorium agreement. At first, the agreement was a 2-year ban on soy produced in Amazon biome areas deforested after July 24, 2006. After being periodically renewed, in 2016 was extended indefinitely. At the end of 2014, to align with the 2012 Forest Code revision changes, the deforestation reference date became July 22, 2008.

Each year the agreement monitoring and enforcement are overseen by *Grupo de Trabalho da Soja* ("Soy working group" in Portuguese translation and hereafter GTS), which monitors municipalities entirely and partially covered by the Amazon Biome [3] which cultivated more than 5,000 hectares of soy in the previous harvest [4]. The monitoring detects areas where soy expansion occurred, comparing it with the mapping of the deforested areas in the reference date, which comes from PRODES satellite monitoring system [5]. The link between any detected violations and producers is made using the properties registry in CAR[6], which became mandatory for producers to sell soybeans to ASM trading firms.

Mato Grosso is the state that concentrates the majority of the municipalities, which, since 2006, have cultivated more than 5,000 hectares of soy. Figure 2 presents the geographic distribution of soybean cultivation across the legal Amazon municipalities in 2007, the first year of monitoring [7].

[3]The monitoring only takes place on the share of land within the biome.

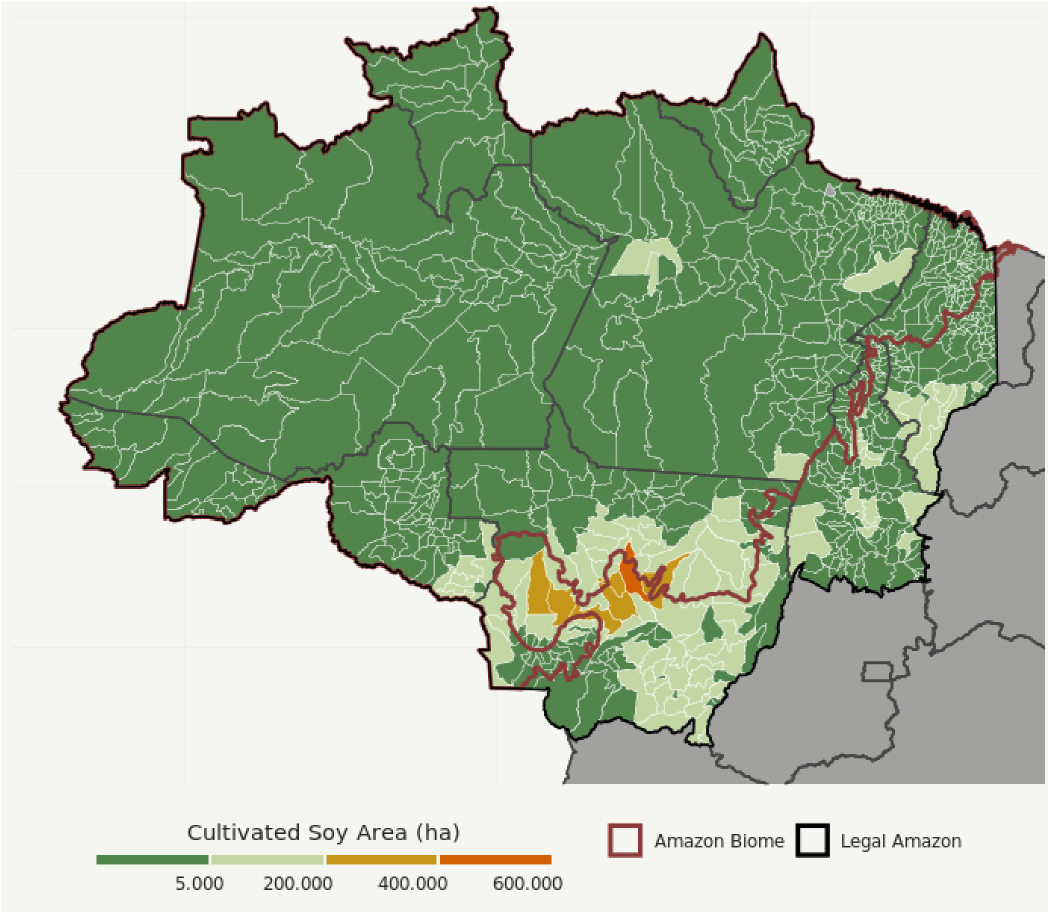
[4]The association also does not monitor localities within land settlements, indigenous lands, and protected areas.

[5]PRODES stands for *Projeto de Monitoramento do Desmatamento na Amazônia Legal por Satélite* in Portuguese

[6]In Portuguese, *Cadastro Ambiental Rural*, which is a mandatory registry for all rural properties in Brazil. The registry provides georeferenced information about the rural property for environmental regulation, as established in the 2012 Forest Code revision.

[7]It is pertinent to note that the distribution of these municipalities has not significantly changed since 2007. There is no sign of a change in the production threshold, meaning no municipality that cultivated above 5,000 hectares reduced the area in response to the enforcement.

Figure 2 – Cultivated soybean area (ha) in Legal Amazon municipalities: 2007 harvest



Source: PAM - IBGE. Author's elaboration.

Following ASM, in 2009, conservation agreements comprehending the Brazilian Amazon were made in the cattle industry. Gibbs et al. (2016) found that, although the agreements significantly reduced deforestation in supplying properties, the intervention had a limited geographic scope and left room for fraud since ranchers were able to move the cattle between properties.

Overall, market control policies' effectiveness depends on the agents' ability to dodge the ban, which varies according to the activity's nature and enforcement capacity. For example, Chimeli and Soares (2017) found evidence that the prohibition of mahogany exploration in the '90s increased violence in Amazon regions with natural occurrences of the variety due to the development of an illegal market. This evidence that the shutdown of a market under limited enforcement can be ineffective since it can lead to an illegal market's birth, generating negative social impacts as a byproduct.

Due to the ASM characteristics, there are significant differences between the two examples mentioned. Firstly, the Soy Moratorium leaves little room for fraud since the monitoring occurs at a property level using CAR registry information. Secondly, because soybeans are a recognizable and traceable product. The prohibitions on Amazon's Mahogony made it be smuggled out of Brazil classified as "other tropical species" (Chimeli and Boyd, 2010), which certainly could not be done with soybeans. Finally, the soy industry has a limited number of trading firms, and the Moratorium signing associations correspond to 90% of Amazon's soy trade (Zu Ermgassen et al., 2020), meaning that the limited number of buyers can exert control over the producers (Gibbs et al., 2015).

Considering ASM and the industry peculiarities, the market ban created incentives that could impact Amazon's land use dynamic and deforestation by different channels. First, farmers who believe in ASM's enforcement capacity will have no incentive to expand their production to forest-occupied areas since the most relevant market buyers would ban them. Secondly, the agreement could disincentive not only in-property soy-driven deforestation but also the overall Amazon deforestation dynamic. By excluding soy from the range of land-use activities, and therefore the expected returns from land-use of forest-covered areas, the agreement could decrease the speculative value of deforestation for cattle ranchers and investors (Heilmayr et al., 2020).

Notwithstanding, the agreement still accommodates indirect deforestation. First, farmers seeking to expand soy crops after 2006 could shift production to areas occupied by other activities - causing agricultural displacement. As mentioned before, this has been the main channel driving soy expansion in the Amazon. Further, If this displacement dislocates the agricultural activities to forest-occupied areas, then soy expansion would still be causing deforestation, but only indirectly. At last, the agreement could induce an expansion of soy crops to other biomes, increasing deforestation in the bordering Cerrado and Pantanal areas.

Considering these potential land-use implications, this dissertation is dedicated to investigating two channels of the commitment impacts. First, if it affected Amazon's soy-driven deforestation and, second, if it generated agricultural displacement in the Amazon.

Literature has found evidence of a decrease in overall deforestation following the commitment (Gibbs et al. (2015), Kastens et al. (2017), Macedo et al. (2012), Svahn and Brunner (2018)). Heilmayr et al. (2020) estimates that between 2006 and 2016, ASM has contributed with 18,000 $\pm$ 9,000 km^2 of avoided deforestation in the Amazon biome.

Observing ASM's impact on soybean farming in the Amazon, Ama et al. (2020) point that when the commitment was launched, direct soybean deforestation already represented a small deforestation impact. Still, ASM was a relevant reinforcement to the new trend in Amazon's agricultural production that arose following Brazil's more substantial environmental protection efforts.

The GTS monitoring system indicates that the agreement has a relevant enforcement capacity. In the 2007/2008 harvest, GTS detected no polygons non-compliant with ASM. However, in the subsequent years, and between 2009 and 2016, 54 municipalities were not in compliance. Soy-driven deforestation accounted for 12.45% of total deforestation in these municipalities, where 59,972 hectares were converted to soy (Silva and Lima, 2018).

Rausch and Gibbs (2016) discuss that the complexity of the Amazon region property ownership renders potential loopholes in the agreement. In Mato Grosso, producers use multiple properties to grow soy, which leaves room for laundering by claiming their production took place only in properties complying with ASM. Additionally, IBAMA's list of embargoed properties - producers who engaged in illegal deforestation and the law prohibits selling their production - often mismatches ASM verified properties list. Therefore, these properties can eventually find a way to sell soy.

Beyond non-compliance issues, an important aspect when discussing ASM's impacts is the possibility of cross-biome leakage to the Cerrado and Pantanal and indirect deforestation. In Mato Grosso, the agreement's spatial limitation led to the hypothesis of cross-biome leakage [8]. While Pantanal in the 2016/2017 harvest concentrated only 2,430 ha of the state's 10,281,938 ha of soy plantation, the Cerrado biome was responsible for 6,298,459 ha of the total (Silva and Lima, 2018). Moffette and Gibbs (2018) found that, in the Cerrado portion of Mato Grosso close to the biome boundary, ASM led to an additional 31% increase in soy production. However, it mainly took place on previously cleared land occupied by pasture and less on vegetation-covered areas.

Further, Noojipady et al. (2017) shows that since 2008 soy expansion shifted to the MATOPIBA region [9], accounting for 14% of cropland expansion during the latter half of the decade, with 30% in forest areas. The rising deforestation in the Cerrado since 2010

[8]Since ASM is limited to the Amazon biome, only a share of the state was subject to the commitment

[9]MATOPIBA is the acronym for the region comprehending the states of Maranhão, Tocantins, Piauí, and Bahia. The Cerrado biome mainly covers the region.

has open a discussion of expanding the Moratoria to the biome (Nepstad et al. (2014), Soares-Filho and Rajão (2018)). It is estimated that expanding the ASM to the Cerrado could prevent the direct conversion of 3.6 million ha of the biome to soybeans by 2050 [10] (Soterroni et al., 2019).

In addition to cross-biome leakage, literature has opened a discussion of ASM's agricultural displacement effects. Arima et al. (2011) estimates soy's indirect land use impact in the Amazon, showing that soy expansion has displaced cattle production to forest areas, therefore, putting doubts on the Moratorium overall effectiveness. Observing Mato Grosso's property-level data, Gollnow et al. (2018) found that the conversion of pasture to soybeans declined between 2008 and 2010 in the Amazon biome. Such indirect deforestation was more dominant between 2004 and 2008, indicating there was not a strong displacement effect following ASM. In summary, due to Amazon's soybean expansion dynamic, these indirect effects are highly relevant to discuss ASM's global impact in reducing deforestation.

The following section presents the investigation of ASM's impacts on direct soy-driven deforestation. This research's contribution comes from exploring a regression discontinuity design, using the Amazon biome border as a multidimensional discontinuity on the policy validity, combined with data on soy-driven deforestation. Although Svahn and Brunner (2018) has explored the biome border as a regression discontinuity, their investigation observes overall deforestation rather than direct soy to forest conversion.

In sequence, in section 4, I estimate ASM leakage effects. Although Moffette and Gibbs (2018) have explored deforestation leakages to Cerrado in Mato Grosso, I explore a difference-in-differences approach to investigate leakage effects by looking at potential agricultural displacements. The contribution comes from investigating if ASM induced a shift of soy crops to pasture in the Amazon biome. Although Gollnow et al. (2018) was the first to discuss this secondary impact, the work is limited to a statistical description of such effects.

[10] A relevant challenge for targeting the biome is that the companies who have signed ASM only trade 46.5% of the cultivated soy (Zu Ermgassen et al., 2020).

3 Deforestation Impact

This section has the objective of investigating ASM's impact on soy-driven deforestation. The Soy Moratorium enforcement changes discretely at the boundary of the Amazon biome: on one side, farmers can no longer produce in areas deforested after 2006, while on the other, they face no restrictions. Such discrete change in the policy validity suggests a regression discontinuity (RD) for evaluating the commitment impact, with the biome boundary forming a multidimensional discontinuity.

For the RD design to be valid, factors impacting soy-driven deforestation and soy cultivation need to be homogeneous along the biome border. For this reason, the analysis will be restricted to Mato Grosso state. As displayed in Figure 2, it is the state that concentrates most of the municipalities which produce more than 5,000 hectares of soy. Therefore, it represents the region where the policy enforcement is effectively valid. Moreover, the state is entirely within the Legal Amazon, meaning that the study area shares a set of common environmental incentives, especially environmental law enforcement.

The empirical strategy objective is to investigate whether ASM impacted soy-driven deforestation, using the non-amazon Mato Grosso area as a counterfactual. Multiple authors have explored the use of geographical frontiers as a source of treatment discontinuity, including the literature investigating Amazon's deforestation (Crespo Cuaresma and Heger (2019), Burgess et al. (2018) and Anderson et al. (2016)). The strategy is only possible because observations occur at a pixel level rather than at a Municipal Level. Svahn and Brunner (2018) presented a similar approach to estimate ASM's deforestation impact, exploring the biome frontier as a discontinuity. However, they observe overall deforestation rather than soy-driven deforestation. Therefore, the empirical strategy contribution comes from combining the RD approach with data on soy-driven deforestation.

The analysis will observe soy expansion over forest-covered areas in the 2007-2014 period - restricting the study to the commitment initial deforestation date. The forest-occupied areas will consider the points entirely covered by forest at the end of 2006[1].

As in Keele and Titiunik (2015), consider that the geographical location of an observed share of land i is given by its latitude and longitude coordinates $(S_{i1}, S_{i2}) = \mathbf{S_i}$.

[1]The ideal setting would be to have the forest-covered localities on 24 July 2006, the Moratorium reference date. However, the yearly data which will be used does not allow this. For this reason, it will be considered the forested points at the end of 2006, which will give a conservative reference of the forest-covered points.

Consider $\mathfrak{B}$ as a set of boundary points. Let b be a boundary point, such that $b = (S_1, S_2) \in \mathfrak{B}$. Consider A^t and A^c as the sets of points that represent, respectively, treated and non treated areas. Treatment assignment, represented as $T_i = T(S_i)$, is a deterministic function of S_i, such that $T(s) = 1$ for $s \in A^t$ and $T(s) = 0$ for $s \in A^c$. Therefore, treatment has a clear discontinuity along border points $\mathfrak{B}$. Considering the two-dimensional nature of the score, the central continuity assumption for this Regression Discontinuity approach states that:

$$\lim_{s \to b} E\{Y_{i0}|S_i = s\} = E\{Y_{i0}|S_i = b\}$$
$$\lim_{s \to b} E\{Y_{i1}|S_i = s\} = E\{Y_{i1}|S_i = b\}$$

for all $b \in \mathfrak{B}$. Where Y_{i0} and Y_{i1} represent the potential outcomes of the observations i in the control and treatment groups. Therefore, the continuity assumption requires that the average potential outcomes under treatment and control be continuous at all points on the boundary (Keele and Titiunik, 2015).

In this investigation, this assumption represents that the potential land-use outcomes near the boundary observed in the Amazon Biome are very similar to the possible land-use outcomes on the other side (geographically defined as Cerrado and Pantanal biomes). Since the probability of the Soy Moratorium treatment jumps discontinuously along with the collection of border points, assuming equivalent potential outcomes and controlling for covariates, any differences after 2006 could be attributed to the Moratorium.

The score S_i is defined by i's shortest Euclidian distance to the Amazon biome in this design. If the continuity assumption is valid, it follows that units within a certain distance from the border but on opposite sides are valid counterfactuals for one another. Therefore, within a certain distance from the geographic frontier, the treatment can be considered a "quasi-experiment" (Lee and Lemieux, 2010).

This research's peculiarities point that all relevant factors besides treatment change smoothly at the Amazon biome border. Firstly, a relevant issue is whether the Amazon and Non-Amazon areas within Mato Grosso consistently differ in their ecological characteristics, directly affecting deforestation costs. The Amazon-Cerrado transition region is the world's largest Ecotone[2], which was not adequately considered when, in the '80s,

[2]Ecotone is a transition area between two biomes. The Amazon-Cerrado Ecotone is the world's largest and is considered to have 6 thousand square kilometers of extension (Marques et al., 2019).

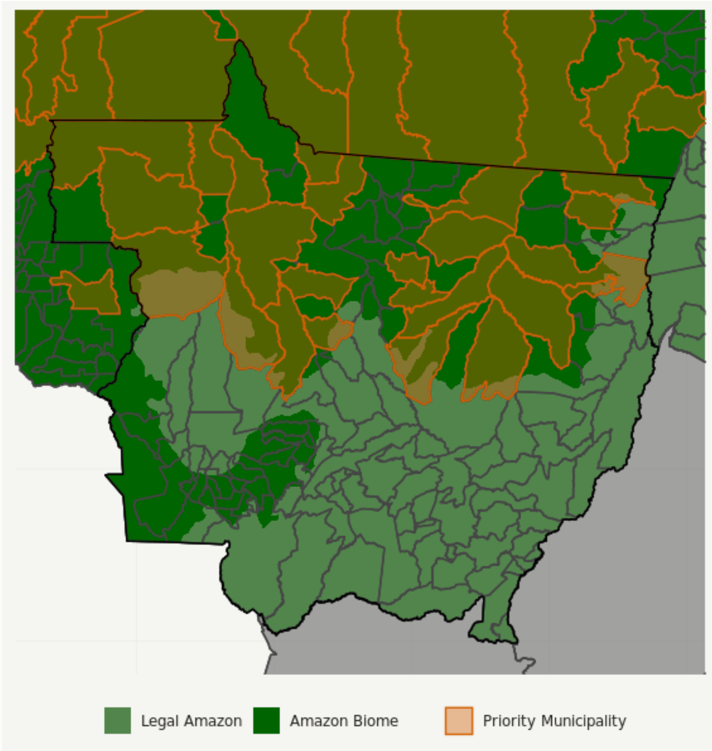
IBGE delimited the current geographical Biomes division (Marques et al., 2019). For this reason, the sharp division between the Amazon and the other biomes does not reflect reality [3]. Therefore, up to a certain distance from the biome border, it is reasonable to consider that both areas have very similar Ecological characteristics. Besides, since the Moratorium uses IBGE's geographical frontier as a reference, established before the agreement, there is no possibility of treatment attribution manipulation, which further motivates the RD design.

Considering that the physical aspects that could impact deforestation are sufficiently similar along the border, there remains a concern that the changes in conservation policies during the 2000s would impact the Amazon and non-Amazon biome areas differently. The most relevant policy, PPCDAm, had a significant impact on deforestation and effectively started in 2006, the same year of the moratorium signature (Assunção et al., 2017). However, since the plan comprehended the entire Legal Amazon, Mato Grosso state was entirely subject to it.

Another point of concern is Amazon's Blacklist of priority municipalities. Brazil's Environment Ministry clearly states that the list only targeted localities within the Amazon biome, potentially violating the assumption that the bordering areas have a mutual set of incentives. Since the municipalities' BBlocklistsignificantly impacted deforestation (Assunção and Rocha, 2014), a change in Amazon's land use after 2006 could be confounding ASM with the Blacklist impacts. However, as presented in Figure 3, some of Mato Grosso's municipalities included in the list are within both biomes since they lay within IBGE's frontier. Since the boundary does not follow the municipalities' division, all cities in the border, covered by both biomes, potentially could have been included. Therefore, since the Municipalities Blacklist had municipal enforcement, but ASM only monitors localities within the Amazon biome in such municipalities, I am secure that, controlling for the participation in the list, I will observe the impact of the commitment on soy-driven deforestation.

[3]Is estimated there is a miscalculation up to 245,5% in certain transaction areas (Marques et al., 2019).

Figure 3 – Mato Grosso's municipalities in Amazon's priority municipalities list



Source: IBGE and MMA.

With these considerations, it is reasonable to think that, in the period of analysis sufficiently close to the Amazon Biome border, the Moratorium was the only relevant policy change impacting Amazon points. The following section presents the empirical specification exploring the Discontinuity Design.

3.1 Estimation Framework

The Soy Moratorium enforcement is a deterministic and sharp function of a known variable, the latitude and longitude of the Amazon biome border frontier. Considering Mato Grosso's state, which is cut by the frontier, this suggests estimating ASM impacts on soy cultivation using a regression discontinuity research design, with the border as a multidimensional discontinuity in the geographic space.

As first discussed by Dell (2010), the identifying assumptions are identical to those in a single-dimensional RD. Consider the regression form:

$$S_{ib} = \alpha + \gamma \text{Amazon}_i + f\left(\text{geographic location}_i\ \right) + X_i'\beta + \boldsymbol{\phi}_b + \varepsilon_{ib}$$
$$for - h < \text{ geographic location}_i < h \tag{1}$$

where S_{ib} is the average soy area between 2007 and 2014 in pixel i, located along the segment b of the Amazon biome boundary. Each observed pixel comprehends and area of 100 hectares (1km resolution). The high resolution data comes from MapBiomas and Appendix A2 explains in details how the information was built.

$Amazon_i$ is equal to 1 if point i is within the biome and is equal to 0 otherwise. As suggested by Dell (2010), ϕ_b is a set of boundary segment fixed effects. The Amazon boundary was divided into ten segments, and each segment fixed effect denotes the boundary fraction pixel i is closest to. Due to the frontier unevenness, the segmentation assures that points within a given part of the border are used as counterfactuals for one another. The border fixed effects also control for shared characteristics, such as market access. Figure A3 plots the geographic distribution of the boundary segmentation.

$f($ geographic location) is the regression discontinuity polynomial, a smooth function of each point i geographical location. Shortly it will be presented which functions are considered. Finally, X_{id} is a vector of covariates that control for factors impacting soy cultivation that are likely non-homogeneous across the biome border and, therefore, are not controlled by the boundary segment fixed-effect. It includes the average pixel soil suitability, which comes from Soares-filho et al. (2014), and a binary control equal to 1 if i was within a priority municipality in the study period and zero otherwise. Appendix A2 has an overview of the data sources and how these covariates were constructed.

Observations i are limited to the set of points entirely covered by forest in 2006. Since ASM prohibits soy expansion to forest-occupied areas, it was necessary to restrict the analysis to forest-covered points to comprehend if the policy effectively impacted the conversion of forests in soy. The explained covariate, the mean soy area, is restricted to the 2007-2014 period to limit the research to 2006's deforestation reference. All of the observed pixels i are outside Indigenous Lands, conservation units, and land settlements, where the moratorium rule does not hold. The observations are restricted to municipalities that produced more than 5,000 hectares in any year of the 2007-2014 period. Finally, the pixels' geographic location is limited to a band $[-h, h]$ across the biome border.

In the baseline specification, a first-order polynomial approximation in $f()$ is used. Although it has become usual in the RD analysis to control high-order polynomials (thirdorder or higher), literature has shown that it renders misleading causal effects and should not be used (Gelman and Imbens, 2014). The lower-order polynomials are more intuitive approximations and are less sensitive to outliers. To control for the potential misspecification of the functional form of the regression function near the cutoff, I explore different observation weighting schemes (Cattaneo et al., 2019). A Kernel function gives the weights. I will explore the simple uniform kernel, which gives equal weight to all observations inside the band $[-h, h]$ [4], and the triangular kernel function, which maximizes the weight in the cutoff, declining symmetrically and linearly as the observation gets farther from it.

In the ideal RD setup, the treatment effect is identified using all observations around the cutoff and fitting a polynomial of the observed outcome on the score (Cattaneo et al., 2019). Thus, as in Dell (2010), I follow a non-parametric approach by limiting my sample to points within distance h from the Amazon boundary. This is done for methodological and empirical reasons. As discussed by Cattaneo et al. (2019), global approximations can induce counter-intuitive weighting schemes, with estimators being heavily influenced by observations far from the boundary, leading to misleading results. Therefore, it has been a practice in RD to work with local polynomial methods, which localize the polynomial fit to the cutoff, not including observations sufficiently far. Restricting the analysis to a band across the border makes it substantially more robust and less sensitive to boundary and overfitting problems (Cattaneo et al., 2019).

Additionally, this study's peculiarities suggest that it is reasonable to restrict the RD analysis to a band across the cutoff. Firstly, it is evident that the geographic characteristics of Mato Grosso are very different across the entire state, which would invalidate the underlying assumption that the treated and non-treated areas are valid counterfactuals.

The band $[-h, h]$, the neighborhood's width around the border cutoff, was selected by choosing the distance which minimized the mean square error (MSE) of the local polynomial RD estimator[5]. Using the MSE, considering the linear polynomial and uniform kernel specification, I found an optimal bandwidth h of 56 kilometers across the border. To give my results robustness and assure they do not arise from the bandwidth choice, I present my estimations considering half (28 km) and double (112km) of the optimal band-

[4]Employing the uniform kernel is equivalent to estimating a non-weighted linear regression with the observations within the cutoof

[5]The MSE of an estimator is the sum of its squared bias and its variance. Therefore, the optimal choice of h seeks to minimize the bias-variance trade-off (Cattaneo et al., 2019). The MSE of an estimator γ is given by $\text{MSE}(\hat{\gamma}_{\text{SRD}}) = \text{Bias}^2(\hat{\gamma}_{\text{SRD}}) + \text{Variance}(\hat{\gamma}_{\text{SRD}})$.

width. Figure A4 plots the selected bands and how they are geographically distributed across the Amazon biome boundary.

3.2 Data sources and Descriptive Statistics

Before presenting the results of the estimations, this section presents data sources and descriptive statistics. The main objective is to examine whether there are significant differences between treated and non-treated areas, which could invalidate the covariates continuity assumption.

The Forest and soy-cover data come from MapBiomas collection 5. MapBiomas uses Landsat mosaics and a random forest classifier to produce yearly classified land-use maps. For this investigation, I took advantage of the Collection 5 feature of mapping soy crops. Further, I also used the vegetation classification to select the points covered by forest in 2006. Appendix A2 presents in detail how Mapbiomas data was handled.

Table 1 presents an overview of the data and variables of interest considering the optimal 56 kilometers band. Although equal distances from the biome border are considered, the number of pixels differs since only points outside indigenous areas, conservation units, land settlements, and inside municipalities that produced more than 5,000 hectares of soy are considered. Considering all border observations, it is interesting to note that, although the mean forest cover in the 2007-2014 period was similar between the two areas, the average soy cover in the Amazon was almost 50% smaller.

Further, observing the points covered by forest in 2006, it is interesting that the average forest cover had an approximate 1.5% and 2.5% percentage reduction outside and inside the Amazon biome between 2007 and 2014, respectively. The mean soy cover, representing soy expansion over forest areas after 2006, was minimum - less than 1% in both treated and non-treated areas.

Table 1 – Mato Grosso's land use summary statistics

	Main Band: 56 km	
	Outside Amazon	Amazon
All Border Points		
Mean Forest Cover in 2006/100 ha	57.28 (42.53)	57.63 (42.09)
Mean Forest Cover/100 ha: 2007-2014	56.29 (42.21)	56.07 (41.44)
Mean Soy Cover in 2006/100 ha	21.32 (37.95)	7.87 (24.01)
Mean Soy Cover/100 ha: 2007-2014	22.23 (37.63)	11.34 (26.89)
2006's Forest Covered Points		
Mean Forest Cover/100 ha: 2007-2014	98.48 (7.59)	97.51 (10.37)
Mean Soy Cover/100 ha: 2007-2014	0.22 (2.71)	0.24 (2.85)
Observations: All points	269,527	373,649
Observations: 2006's Forest Covered Points	89,453	125,499
Municipalities	44	48

Note: Table presents the variables' average coverage in each 100 ha pixel, with the sample standard deviations in parenthesis. Both sets of points consider observations within the 56 km band that are outside indigenous lands, conservation units, land settlements, and within municipalities which produced more than 5,000 hectares of soy.

To compare if treated and non-treated points characteristics systematically differ in the pre-treatment period, Table 2 presents selected variables [6] normalized difference in means, as suggested by Imbens and Wooldridge (2009), within the 56 kilometer optimal band across the border [7]. The choice of the normalized difference rather than the t-statistic is due to the difference in sample size between the two groups. Imbens and Wooldridge (2009) suggest as a rule of thumb that a difference exceeding one quarter should be an alert. Table A1 presents the difference considering the additional border bands.

Although in Equation 1 is implicitly assumed that any time-invariant infrastructure covariates impacting soy expansion are controlled for in the boundary fixed-effects, to support the continuity assumption, I examine the difference in the mean distance to a paved road since it is a relevant aspect impacting market access.

[6] The variables data sources and handling are discussed in Appendix A2

[7] The normalized difference is means is given by $\Delta_X = \frac{\bar{X}_1 - \bar{X}_0}{\sqrt{S_0^2 + S_1^2}}$, where 1 and 0 represent the treated and untreated groups. $\bar{X}_i$ and S_i^2 are each group mean and sample variance.

The difference between treated and untreated areas' soil aptitude and mean forest cover does not exceed one quarter across all border distances. However, there is a significant difference in the mean distance between treated and non-treated areas observing the distance to a paved road. Although that is the case, in absolute terms, the difference in means is approximately 12 kilometers which, given Mato Grosso's magnitude, is considerably small.

Table 2 – Selected variables standardized mean differences

	Main Band: 56 km	
	Outside Amazon	Amazon
Distance to Paved Road	27.1 (27.5)	39.3 (32.3)
SMD	*0.407*	
Soil Aptitude	1.40 (0.67)	1.33 (0.66))
SMD	*0.095*	
Mean Forest Cover in 2006 (ha)	57.28 (42.53)	57.63 (42.09)
SMD	*0.008*	
Observations	269,527	373,649
Municipalities	44	48

Note: Table presents the variables average covarage in each 100 ha pixel, with the sample standard deviations in parenthesis.

In conclusion, Table 2 demonstrates that the geographic and infrastructure characteristics which potentially impact land use are reasonably similar between the treated and non-treated areas, further encouraging the Regression Discontinuity approach. The following section presents the results.

3.3 Results

Table 3 presents Equation 1 baseline estimation results. The first column presents $Amazon_i$ coefficient estimates for the main bandwidth h using different polynomial and kernel specifications. Across all specifications and border distances, I find no statistically significant estimate for the $Amazon_i$ coefficient of interest.

Table 3 – Regression discontinuity estimates: 2006's forest-covered points

	Dependent variable: Average Soy Cover/100 ha		
	(I)	(II)	(III)
Points Within:	56 km	28 km	112km
Amazon coefficient estimates:			
Linear	−0.053	−0.062	−0.016
	(0.122)	(0.224)	(0.087)
Quadratic	-0.0276	-0.077	-0.0525
	(0.148)	(0.093)	(0.173)
Linear (triangular kernel)	-0.0772	-0.062	-0.0591
	(0.081)	(0.064)	(0.133)
Quadratic (triangular kernel)	-0.0596	-0.075	-0.1317
	(0.144)	(0.122)	(0.144)
Observations	214,952	115,423	347,724
Linear Uniform Kernel Specification Statistics			
R^2	0.006	0.009	0.005
F Statistic	96.797***	74.259***	131.347***

Note: Robust standard errors clustered at the boundary-segment level. To check significance: *p<0.1; **p<0.05; ***p<0.01

The lack of a statistically significant difference between treated and non-treated areas, in conjunction with information presented in Table 2, points that the direct soy to forest conversion is, in both areas in Mato Grosso, a minor deforestation driver. As presented in Table 2, between 2007 and 2014, less than 1% of the treated and non-treated forest-covered points were converted to soy.

Additionally, it is interesting that I find no indication of a shift of soy crops over non-treated forest-covered areas within Cerrado and Pantanal. This finding is in line with Moffette and Gibbs (2018), which found that following ASM, although soy expanded in the neighboring Cerrado area in Mato Grosso, this mainly occurred in areas occupied by pastures.

As a robustness check, I estimated Equation 1 considering only the points within Priority Municipalities. Results are presented in Table A2 and corroborate the lack of statistically significant difference in soy-driven deforestation. Additionally, I estimated

Equation 1 considering the yearly soy cover for each year of the 2007-2014 period as the explained variable. Results for the $Amazon_i$ coefficient are presented in Table A3. Overall, results again point to a lack of statistically significant difference in soy expansion in the Amazon after the Soy Moratorium.

3.3.1 Soy Increment Impact

Considering I found no evidence pointing to a reduction in direct soy-driven deforestation following ASM, to complement the analysis, I estimate Equation 1 considering all frontier observations instead of only 2006's forest-covered points. Further, in place of looking at the average soy cover in the 2007-2014 period, my variable of interest is now the average soy-increment in the period [8]. Results considering the optimal border and the complementary distances are presented in Table 4.

[8] I estimate the increment as the difference between the average soy cover in the 2007-2014 period and the soy cover in 2006.

Table 4 – Regression discontinuity estimates: all border points

	Dependent variable: Soy Cover/100 ha		
	(I)	(II)	(III)
	56 km	28 km	112km
Amazon coefficient estimates:			
Linear	1.772**	1.995*	2.798***
	(0.691)	(1.118)	(0.912)
Quadratic	1.3606 **	1.4034 ***	1.7638 *
	(0.601)	(0.46)	(0.919)
Linear (triangular kernel)	1.6299 ***	2.3399 ***	1.8783 ***
	(0.426)	(0.458)	(0.691)
Quadratic (triangular kernel)	1.6337 **	1.2299 ***	1.5013 *
	(0.723)	(0.446)	(0.847)
Observations	643,176	368,908	991,362
Linear Uniform Kernel Specification Statistics			
R^2	0.036	0.034	0.031
F Statistic	1,872.735***	998.040***	2,447.774***

Note: Robust standard errors clustered at the frontier-segment level. To check significance: *p<0.1; **p<0.05; ***p<0.01

As presented in column I, the linear specification points to a statistically significant difference in the soy increment of 1.772 hectares per 100 hectares in Amazon points between 2007-2014. Across all specifications of the RD polynomial, the $Amazon_i$ coefficients are reasonably similar. The linear coefficient estimate represents roughly 6,621 additional square kilometers of soy in the Amazon biome in the 56 km border between 2007 and 2014. Observing the 28 km and 112 km distances from the border (Columns II and III), the results remain statistically significant with a similar magnitude.

Overall, the results, in conjunction with the lack of statistically significant impact on soy-driven deforestation, indicate that following ASM, soy expansion continued to take place in the Amazon biome over previously deforested areas.

3.3.2 Discussion and Limitations

The presented findings complement the discussion of Macedo et al. (2012) and Ama et al. (2020), which comment that direct soy-driven deforestation has been a minor deforestation driver in the Amazon forest. Therefore, it is not a surprise that following ASM, there was no significant reduction in soy-driven deforestation in Mato Grosso. Moreover, the results evidence that the ASM agreement design allows the existing soy expansion dynamic to continue, as seen in the soy-cover increment in the Amazon biome portion.

It is worth noting that, although soy is not the main direct deforestation driver, ASM is still an appropriate buffer against future soy expansion over forest-occupied areas, making it a potential complement to the public conservation policies. Further, it is essential to recall that the Regression Discontinuity estimations only render a local effect. Therefore, the results are not comparable to previous literature findings pointing that ASM led to a reduction in deforestation (Heilmayr et al. (2020), Gibbs et al. (2015)).

With these considerations, even though the RD estimates render only a local effect, these findings open to interesting questioning regarding the Soy Moratorium's overall effectiveness. Since GTS only monitors municipalities that produced more than 5,000 hectares of soy, the enforcement takes place only in areas with developed agriculture and, consequently, significantly deforested. Considering such localities have areas cleared before 2006, farmers could continue to expand to these localities despite the agreement - exactly what my results indicate. Therefore, the deforestation impact in the monitored areas is significantly reduced.

Finally, future work can improve the presented research. An explicit limitation is that I did not precisely observe ASM's deforestation reference date and only observed the forest-covered points by the end of 2006, meaning the results represent a conservative estimate. Moreover, the time frame of analysis was limited to 2007-2014, a period of overall decreasing deforestation. It would be interesting to expand the investigation incorporating recent years, when Amazon's deforestation rates started to rise again, and overall environmental protection efforts have lost strength, putting the Moratorium enforcement capacity to the test.

4 Leakage effect

Following the investigation of ASM's impact on soy-driven deforestation, this section presents an analysis of ASM's secondary effects. Considering Amazon's land-use dynamic and the agreement rules, it is evident that farmers could strategically respond to the Soy Moratorium. Beyond the possibility of dodging the policy, a possible response is that farmers seeking to expand soy cultivation would do so in the areas deforested before 2006 and occupied by other agricultural activities, primarily cattle grazing. Since the policy is valid within the Amazon biome, this strategic response would occur in farms within the geographic area.

To investigate if the Moratorium induced this response, I use land-use transition data from MapBiomas. The data set allows the yearly land-use transition from pasture to soy (hereafter P2S) to be precisely identified at a high-resolution pixel level. In conjunction with the empirical strategy to be presented, this data's use is the most significant contribution of this research.

As in section 3, the analysis will be limited to Mato Grosso state since it is the Legal Amazon state with the most developed and dynamic agriculture and which concentrates a considerable number of soy-producing municipalities in the Amazon. By comparing areas in Mato Grosso, inside and outside the Amazon biome, the objective is to estimate if the commitment induced an increase in P2S conversions inside the ruling area.

4.1 Empirical Strategy

The empirical strategy follows a differences-in-differences approach, exploring that the state is entirely within the Legal Amazon but only partially covered by the biome. The underlying assumption is that, before ASM, areas inside and outside the biome had similar land-use trends. Hence, they are valid counterfactuals for one another. Therefore, the Moratorium effect can be identified by comparing these areas before and after the treatment, suggesting a differences-in-differences strategy.

The analysis will consider yearly 1.8 kilometer-pixel observations within Mato Grosso state between 2000 and 2014. The analysis is limited to the period to restrict to ASM's initial 2006 deforestation reference date. Data on land-use conversion in each pixel comes from MapBiomas yearly land-use transition data. Appendix A2 presents an in-depth explanation of how the information was handled and aggregated in a 1.8-kilometer pixel resolution.

The empirical strategy consists in estimating the main equation:

$$Y_{imt} = \beta_0 + \beta_1 Amazon_i + \beta_2 M_t + \beta_3 Amazon_i * M_t + \gamma X_{it} + \delta_t + \alpha_m + \epsilon_{imt} \tag{2}$$

where the dependable variable is the average P2S conversion per 100 hectares in each pixel i between year t and $t+1$.

$Amazon_i$ is equal to 1 if pixel falls within the Amazon biome, and 0 otherwise. M_t equals 1 for the post-2006 period, therefore, representing the Moratoria period. The OLS estimates of β_3 render the parameter of interest, presenting ASM's impact on Amazon.

δ_t is a time fixed effect that controls for common yearly trends within the Mato Grosso state. α_m is a municipality-specific fixed effect that controls for unobserved time-invariant municipality characteristics. X_{it} is a set of covariates. It was considered if the observation i was within a municipality in the Priority Municipalities list in that year. It was also considered each pixel distance to a paved road, navigable water, and soil aptitude. Appendix A2 presents maps of these attributes' geographic distribution and explains how the explained variables were built.

The analysis considers only pixels i located outside Indigenous Areas, conservation units, and land settlements since GTS does not monitor these points. Finally, the observations are limited to municipalities that produced more than 5,000 hectares in any year of the 2007-2014 period. To account for potential spatial correlation, standard errors are clustered at the municipal level.

As a robustness check, Equation 2 is modified considering to consider a triple differences specification. The triple differences compare not only areas inside and outside the Amazon biome but also high and low soil aptitude. Appendix A2 explains in detail how the differentiation between high and low soil aptitude points was made.

4.2 Descriptive statistics and difference-in-differences validity

Table 5 presents the variable of interest summary statistics for points inside and outside the Amazon biome. I compare the difference in the mean and standard deviation between the 2000-2006 and 2007-2014 periods, the first period corresponding to the premoratorium. It is worth noting that while outside the Amazon, the average P2S conversion had a significant decrease, in the Amazon remained almost constant.

Table 5 – Variables of interest descriptive statistics

	Amazon Biome		*Outside Amazon Biome*	
	2000-2006	2007-2014	2000-2006	2007-2014
P2S/100 ha	0.149 (1.67)	0.147 (1.67)	0.257 (2.33)	0.180 (1.82)

Note: Variable means and, in parenthesis, standard deviation.

Table 6 presents covariates' and the variable of interest distribution in the pixels inside and outside the Amazon Biome in Mato Grosso. The Table presents the covariates' means, standard deviation, maximum and minimum values. Considering only the pixels used in the estimands, there are 171,130 observed points inside the state, 85,224 pixels in the Amazon Biome, and 85,906 pixels outside the biome. The control variables that measure distance exhibit different mean values between the two groups, a natural consequence of Mato Grosso's Biome's geographic division not being uniform in space and neither the infrastructure variables. The mean Soil Suitability is relatively equal across the two regions.

Table 6 – Descriptive statistics - Mato Grosso: 2000-2014

	Outside Amazon Biome			
	Mean	St. Dev.	Max	Min
P2S/100 ha	0.2	2.1	95	0
Distance to Paved Road (km)	32.9	31.1	182.1	0.004
Distance to Water(km)	116.3	75.2	530.7	0.01
Soil Suitability	1.1	0.7	2.0	0.0
	Amazon Biome			
	Mean	St. Dev.	Max	Min
P2S/100 ha	0.1	1.7	92	0
Distance to Paved Road (km)	47.7	34.9	158.3	0.02
Distance to Water(km)	211.8	113.0	523.2	0.03
Soil Suitability	1.3	0.5	2	0

Although the control and treated areas appear to have reasonably similar geographic characteristics, a couple of additional assumptions need to be satisfied for the difference-in-differences estimation to retrieve a valid causal effect. A first concern is the validity of the exogeneity assumption. For this to be valid, there must be no relevant factors coincident with ASM not included in the regression. As discussed in section 2, several other conservation policies were implemented in the analysis time frame. The most relevant, PPCDAm, was launched in 2004 and followed by the Municipalities Blacklist in 2007. The fact that I limit my study to Mato Grosso is a crucial factor since PPCDam targeted the entire Legal Amazon. Therefore, by only observing Mato Grosso and controlling for the participation on the Municipalities Blacklist, it is reasonable to believe that all the contemporaneous factors impacting the variables of interest are being considered.

Further, the independence between treatment and unobserved effects also requires that treatment was not manipulated or anticipated. Section 3 presented a discussion on how the policy validity within the Amazon Biome, a boundary established by IBGE in the 80s, makes ASM a completely exogenous treatment. Finally, since the policy's deforestation reference date coincided with the policy signature, there is no reason to suspect an anticipated treatment response. Considering these aspects, I trust the assumption of exogeneity between treatment and unobserved factors is satisfied.

Another central assumption for the differences-in-differences approach to be valid is that, in the absence of treatment, treated and non-treated units would have experienced parallel trends in the outcome of interest. If that is valid, then the untreated units are valid counterfactuals. Hence, before the Soy moratorium, units in Mato Grosso, outside and inside the Amazon biome, had similar land-use dynamics paths.

As an initial analysis, Graph 4 plots the trends in the outcome of interest between treated and untreated units[1]. The graph points to similar trends in P2S conversion before 2006.

[1] I present only the points considered in the estimates: Outside Indigenous Lands, Conservation Units, Land Settlements, and in municipalities produced more than 5,000 ha of soy.

Figure 4 – Land-use transition trend

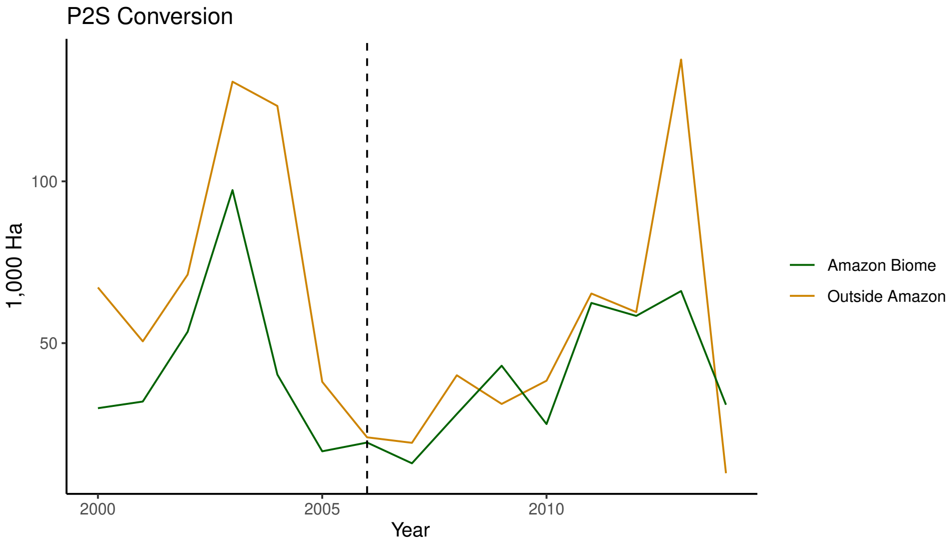


Figure 4 is simply a visual interpretation; therefore, I follow the common practice of testing the parallel assumption in the pre-treatment period. To test if distinct pre-treatment dynamics existed between Amazon and non-Amazon areas, I introduce a preintervention treatment (placebo intervention). I include a pseudo-treatment in the 2002-2004 period interacted with the *Amazon* dummy. This exercise has the objective of detecting if the land-use change dynamic was already different in the pre-intervention period.

Table 7 presents the results on the parallel trends testing. The pre-intervention placebo, given by $Amazon * Placebo$ is not statistically significant. Therefore, there is no evidence suggesting that there were different dynamics in P2S conversion before the intervention, meaning Equation 2 results are not capturing any pre-treatment difference in behavior.

Table 7 – P2S Conversion: parallel trends testing

	Dependent variable:
	P2S/100 ha
	(I)
Amazon	0.034
	(0.045)
Placebo	0.231***
	(0.046)
Post 2006	0.021
	(0.038)
Amazon * Placebo	−0.089
	(0.058)
Amazon * Post 2006	0.038
	(0.042)
Fixed Effects	Yes
Observations	2,566,950
R^2	0.015
F Statistic	381.570***

*Note: Robust standard errors clustered at the municipal level. Placebo represents a preintervention treatment in the 2002-2004 period. To check significance:*p<0.1; **p<0.05; ***p<0.01*

4.3 Results and discussion

Table 8 presents the main results. Estimations included municipal and year fixed-effects and other point-specific controls. Results indicate no statistically significant difference in P2S conversion following ASM in the Amazon biome area (*Amazon * Post 2006*). The absence of a statistically significant difference in the P2S conversion following ASM can arise from different reasons. First, it can be a consequence of the high cost of shifting the production technology. Although land available for soy became scarce following the agreement, farmers dedicated to cattle grazing have another specialization and a much less capital-intensive activity. Additionally, it might be the case that, although ASM produced incentives to expand soy crops over pastures in the Amazon, the non-favorable market condition between 2005 and 2010 discouraged farmers from expanding soy cultivation.

Table 8 – Land-use conversions: main results

	Dependent variable:
	P2S/100 ha
	(I)
Amazon	0.003
	(0.053)
Post 2006	-0.142^{**}
	(0.057)
Amazon * Post 2006	0.064
	(0.048)
Fixed Effects	Yes
Observations	2,566,950
R^2	0.017
F Statistic	382.470^{***}

Note: Robust standard errors clustered at the municipal level.
To check significance: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

As a robustness check, I performed a triple differences estimate, comparing the areas outside and inside the Amazon and the areas suitable and not suitable for crop cultivation. Appendix A2 presents how the differentiation between suitable and non-suitable areas was made. Table A4 presents the results. As in the baseline estimation, I found no statistically significant difference in the P2S conversion following the agreement.

To complement the findings of Section 3, I estimate Equation 2 restricting it to the observations around a 56 kilometer band across the Amazon Biome border in Mato Grosso. Results are presented in Table 9.

Table 9 – P2S Conversion: 56 km distance from Amazon biome border

	Dependent variable:
	P2S/100 ha
	(I)
Amazon	0.121***
	(0.044)
Post 2006	-0.014
	(0.024)
Amazon * Post 2006	0.661***
	(0.038)
Fixed Effects	Yes
Observations	1,018,110
R^2	0.018
F Statistic	257.157***

Note: Robust standard errors clustered at the municipal level. To check significance: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

In contrast to the previous results, observing the points close to the boundary, I find that ASM had a statistically significant impact on P2S conversion. The coefficient of interest $Amazon * Post2006$ estimate is 0.661, meaning that after 2006 there was a relative increase of 0.661 hectares of P2S conversion per 100 hectares of land in the Amazon biome.

Results contribute to the discussion brought by Arima et al. (2011) that since soy expansion occurs mostly into pastures, the Moratorium would encourage this shift even further by restricting the areas available for soy cultivation.

Table 2 results, in conjunction with the findings of Section 3, evidence that the Soy Moratorium still left room for the existing Amazon soybean dynamic to continue. The continued expansion of soy into pastures raises doubts about the policy's concrete effectiveness since, while properties deforest before 2008 (the post-2014 reference date) remain available for soy cultivation, there is room for this land-use shift to continue. At the same time, the restriction can discourage future deforestation if land markets incorporate that soy producers would not be able to cultivate in such areas. It is difficult to understand which of these movements will prevail and, therefore, comprehend if the Moratorium will have any long-term impact on Amazon's deforestation.

Overall, Amazon's land use and farmers' behavior are complex phenomenons. Besides, the Soy Moratorium incentives are mixed with other conflicting incentives. Therefore, it is no surprise that the findings do not conclude the Moratorium's effectiveness. Future research could improve this discussion, exploring if the increase in P2S conversion was accompanied by a displacement of pastures to forest areas, increasing deforestation. The idea is that ranchers would transfer their lands to soy producers once land available for soy became more scarce and shift to new areas.

Finally, it is important to highlight that a limitation of this section estimates is that it did not consider any property-level information. It would be interesting to incorporate CAR property data to comprehend each in-property farmer's behavior. In this sense, Gollnow et al. (2018) has contributed by observing on-property land-use change information, including P2S. Future research can improve this section's investigation by combining in-property information as in Gollnow et al. (2018) with the presented econometric strategy.

5 Concluding remarks

This dissertation proposed an investigation of the direct and secondary impacts of the Soy Moratorium, a pioneer zero-deforestation agreement. To investigate its impacts on soy expansion, I took advantage of the commitment constraint to the Amazon biome, which creates a quasi-experiment set up in the border area. Using a regression discontinuity, I found no statistically significant change in soy expansion over Amazon forest-covered areas between 2007 and 2014. However, observing the increment in soy cover along the border, I found a significant increment of up to 2.798 hectares per 100 hectares in the Amazon. Overall, the regression discontinuity results confirm literature evidence that direct forest to soy conversion is not a significant deforestation driver (Richards et al. (2014), Macedo et al. (2012)). Further, the increase in soy cover in the Amazon region even after ASM evidences the agreement limitations and demonstrates that it allows the previous dynamic of soy expansion in the region to continue.

It's important to recall that this study's limitation is that the Regression Discontinuity approach renders only a local estimation. Meaning the results presented in Section 3 are by construction local evidence and are not informative about ASM's global impact.

Considering the agreement incentives, the second part of the dissertation presented a difference-in-differences estimation investigating if ASM encouraged soy expansion into pastures in the Amazon. Observing points near the biome boundary, I found a relative increase of 0.661 hectares per 100 hectares in P2S conversion in the Amazon. Although I find no statistically significant result observing the entire state, the findings support literature discussion on ASM's indirect land-use change implications (Arima et al. (2011), Heilmayr et al. (2020)).

Future research can improve the presented investigation by incorporating Mato Grosso's property CAR georeferenced information, which would allow discussing the land-use impacts at a property level. On the soy-driven deforestation impacts, another improvement would come from using GTS's deforestation reference date. Instead of observing the areas covered by forest at the end of 2006, comparing the exact forest-covered points the enforcement has been using as a reference would be interesting.

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Appendix A1 – A review of Amazon's conservation policies and relevant events

This section presents background information about the most relevant changes in Brazil's environmental protection law and technological developments in the Brazilian soy sector during the early 2000s. Figure A1 presents a timeline of the events detailed below.

A1.1 Environmental Legislation Changes

PPCDAm - 2004

The Action Plan for the Protection and Control of Deforestation in the Amazon (PPCDAm) was launched in 2004 following a period of rising deforestation rates. It remained in an experimental state through 2005, setting on complete operation in 2006.

The plan encompassed multiple policy interventions, with three sets of actions: land tenure regularization and creation of new reserves, promotion of more sustainable agricultural production systems, and increased monitoring and enforcement (Godar et al., 2014). The last was the fundamental part of the plan due to the adoption of high-frequency remote sensing of forest clearing. The satellite images were used to form the Real-Time System for Detection of Deforestation (DETER), which used digital maps of deforestation to set deforestation alerts that indicated areas in need of urgent attention. The DETER system became Ibama's enforcement's most crucial tool (Assunção et al., 2017).

Priority Municipalities - 2008

In January 2008, Brazil's Ministry of the Environment released a list of 36 municipalities in the Amazon Biome in which urgent actions for prevention, monitoring, and control of illegal deforestation would be in place (Ministério do Meio Ambiente, 2008). These municipalities had accounted for 45% of Amazon's total deforestation in the previous year (Assunção and Rocha, 2014).

With the list, Ibama started focussing its law enforcement activities in the localities, issuing fines and embargoing farms. Beyond, the list motivated actions not explicit in the Decree, such as political commitments led by local governments to detain deforestation and the refusal of meatpacking plants to buy cattle from embargoed farms (Assunção and Rocha, 2014).

In 2009, seven new municipalities were included, and in 2011 another seven. Mato Grosso comprehends most of the municipalities, accounting for 19 of the 36 from the initial list. The list continues to exist and sporadically includes and excludes municipalities. Assunção and Rocha (2014) found that the Decree significantly reduced deforestation in the targeted localities between 2009 and 2011.

National Monetary Council Resolution 3.545

In February 2008, Brazil's Central Bank established the resolution Nº 3545, altering the criteria for the concession of rural credit for agricultural activities in the Amazon Biome. The credit concession became conditioned to borrowers' compliance with environmental legislation, requiring proof that the properties were not under embargo due to deforestation and in compliance with the environmental law. Conditions applied to properties located in the municipalities in the Biome.

Assunção et al. (2013) shows that conditioning rural credit concession was an effective policy instrument to combat deforestation. However, it highlights that it is a complement rather than a substitute to other conservation efforts.

Decree 6.514, 22nd July 2008

The DecreeDecree established new directives for the investigation and sanctions of environmental crimes. Overall, the DecreeDecree defined in more detail the administrative process for persecuting and punishing environmental law offenders. It regulated and introduced new instruments to punish environmental crimes. For example, it facilitated the sale of confiscated assets and the destruction of production goods, tools, and materials (Chimeli and Soares, 2017) .

Finally, the DecreeDecree established the public release of a list identifying landowners of areas under embargo. The law prohibited economic activities in such sites, including producing, buying, and selling products originating from them (Rausch and Gibbs, 2016). According to Assunção et al. (2017), beyond increasing the robustness of sanctions, the

DecreeDecree brought more excellent regulatory stability to the investigating and punishment process.

New Forest Code - 2012

Brazil's Forest Code is the country's central piece of legislation regulating land use and on-property conservation. The Code exists since 1965 and, before 2012, established severe restrictions on deforestation in private properties. However, in the Amazon region, it suffered from poor monitoring and enforcement capacity (Soares-filho et al., 2014).

The 2012 Forest Code revision presented relevant changes. Although it did not change the share of property area (80%) that should be kept as native vegetation in Amazon's rural properties, it eliminated small properties' obligation to restore previously deforested areas. With this, areas deforested before 2008 no longer had to be restored by landowners.

As mentioned by Soares-filho et al. (2014), the 2012 revision introduced interesting new mechanisms with the potential to reduce environmental degradation. For example, the Environmental Reserve Quota (in Portuguese stands as CRA) is a tradable title of preserved areas above the code requirements. This title can be traded to compensate properties not following the Code, opening the possibility of a market for preserved lands.

Finally, the central instrument for implementing the new Forest Code success is the National Rural Environmental Registry System (SICAR), following state-level registries (CAR) in Pará and Mato Grosso Azevedo et al. (2017). The registry aimed to georeference property boundaries and remaining forest areas, making it possible to link any violations of the Forest Code with property owners.

A1.2 Soy Industry Landmarks

A fundamental change in the soy market occurred in the '90s, with the introduction of Genetically Engineered (GE) Seeds. The first generation was commercially released in the United States by the biotechnology firm Monsanto in 1996. The introduction of such seeds represents a fundamental industry landmark since they were a variety of glyphosate-tolerant seeds. Glyphosate-based herbicides are a type of herbicide that, beyond dealing with unwanted weeds, require fewer applications. Therefore, with the GE seeds, glyphosate could be applied directly without harming the crops. Further, the seeds also improved productivity by not requiring land tillage, a technique of agitating the soil to mix organic matter and nutrients (Dias et al., 2019).

Brazil adopted the seeds later than other important global producers, such as the USA and Argentina (Meyer and Cederberg, 2010). In 2003, commercialization was permitted for one harvesting season, and farmers were required to burn unsold stocks after harvest. The same permission was given in 2004. In 2005, the Bio-Safety Law indefinitely authorized the commercialization and production of GE soybeans. The adoption rate reached 93 percent in the 2010's (Dias et al., 2019).

Bustos et al. (2016) found that the adoption of GE seeds resulted in a sharp increase in productivity. Soy production per worker went from 100 tones per worker in 2003 to 300 tonnes per worker in 2011. The result partially arises from the fact that there was a relevant expansion in the planted area, which was not accompanied by an increase in workers.

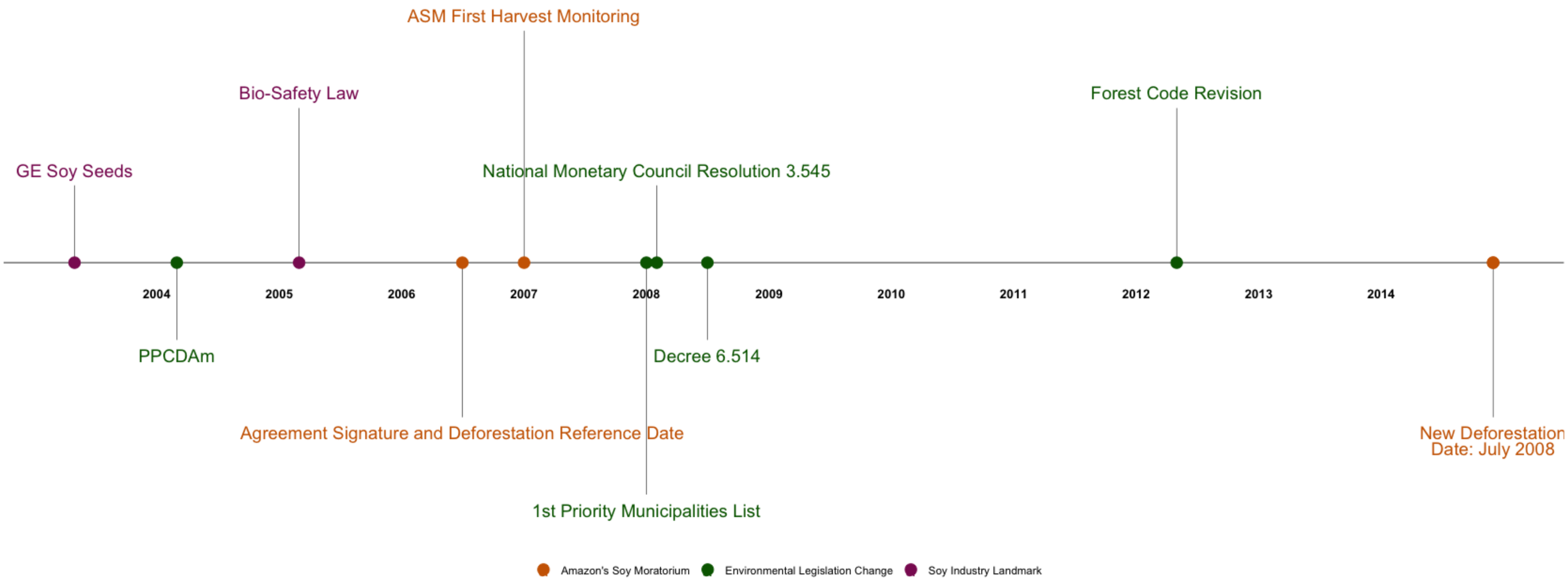
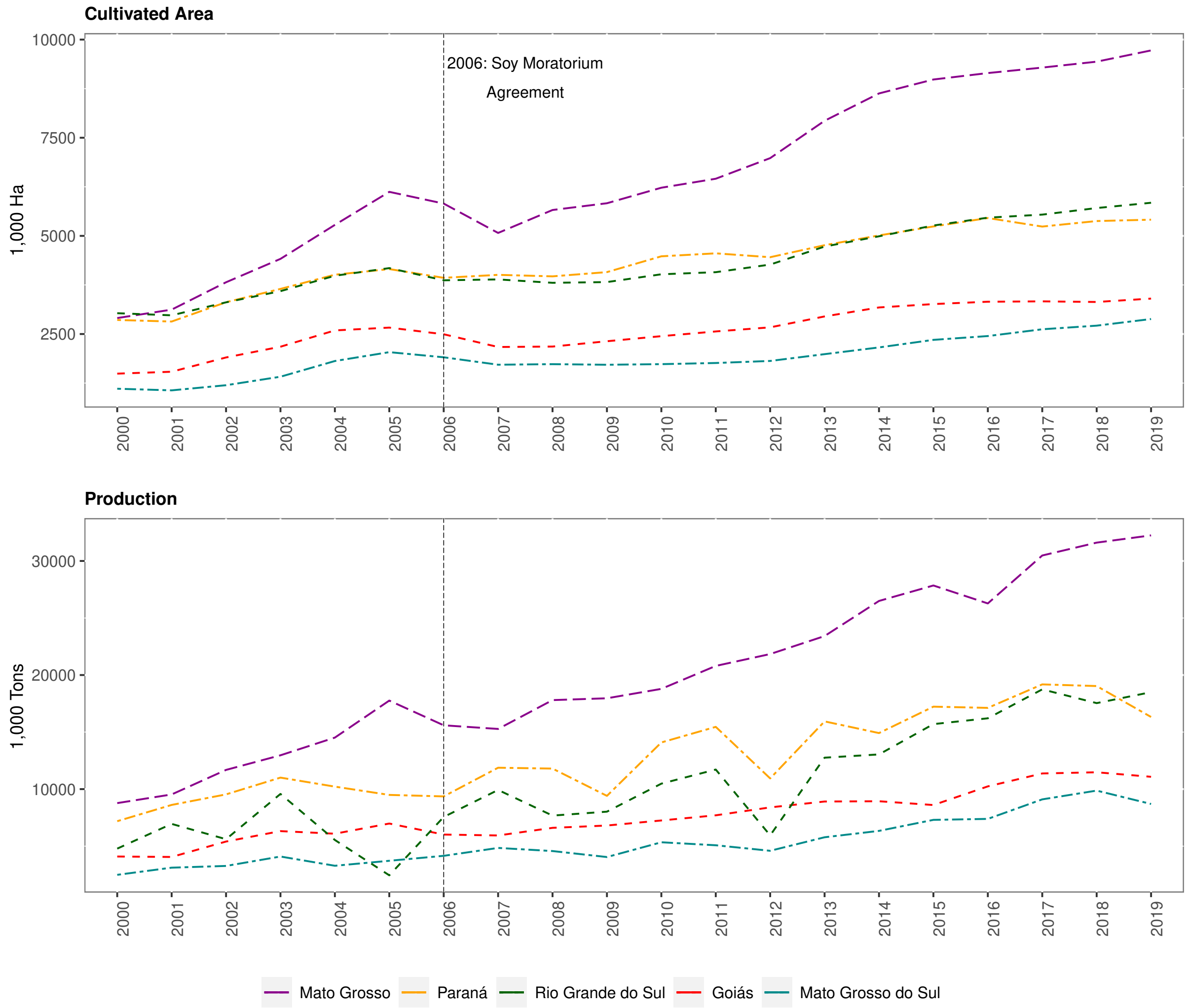


Figure A1 – Timeline of Amazon's conservation policies and other relevant events

Appendix A2 – Tables and Figures

Figure A2 – Brazil's leading soy-cultivating states: Cultivated Area (1,000 ha) and Production (1,000 ton)



Source:IBGE.

Figure A3 – Amazon's border segments

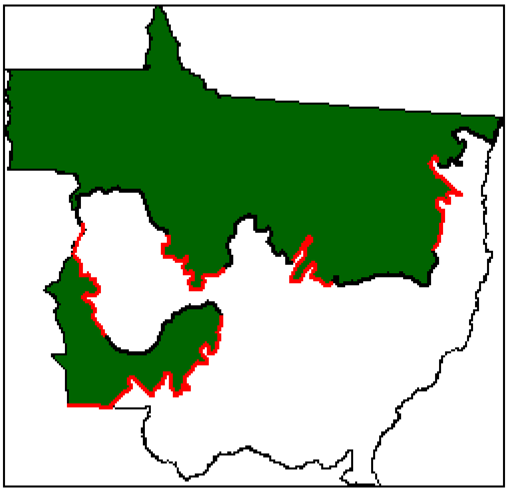
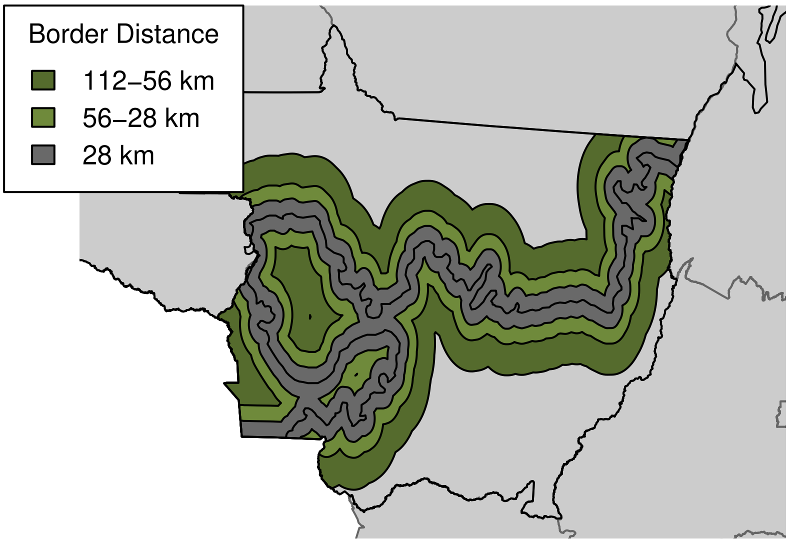


Figure A4 – Gradual distance from Mato Grosso's Amazon biome border: selected bandwidths



Source: IBGE.

Table A1 – Covariates Summary Statistics: 112 km and 28 km bands

	112 km		*28 km*	
	Outside Amazon	Amazon	Outside Amazon	Amazon
Distance to Road	31.8 (28.9)	42.6 (31.2)	23.6 (25.8)	36.8 (32.3)
SMD	*0.357*		*0.451*	
Soil Aptitude	1.26 (0.74)	1.33 (0.67)	1.40 (0.67)	1.37 (0.62)
SMD	*0.104*		*0.049*	
Mean Forest Cover in 2006 (ha)	60.06 (41.75)	59.48 (42.06)	56.27 (42.78)	55.16 (42.08)
SMD	*0.014*		*0.026*	
Observations	438,089	553,273	148,304	220,604

Note: Variables means and, in parenthesis, standard deviation. SMD stands for the variables standardized mean differences between Amazon and non-Amazon areas.

Table A2 – Regression discontinuity estimates: 2006's forest-covered points and within priority municipalities

	Dependent variable: Soy Cover/100 ha
	(I)
	56 km
Amazon coefficient estimates:	
Linear	-0.202
	(0.349)
Quadratic	-0.2657
	(0.34)
Linear (triangular kernel)	-0.2709
	(0.26)
Quadratic (triangular kernel)	-0.2149
	(0.348)
Observations	94,559
Linear Uniform Kernel Specification Statistics	
R^2	0.007
F Statistic	63.689***

Note: Robust standard errors clustered at the frontier-segment level. To check significance: *p<0.1; **p<0.05; ***p<0.01.

Table A3 – Regression discontinuity yearly estimates coefficients: 2006's forest-covered points

	Amazon Coefficient - 56 km band
2007	-0.00012 *
	(7e-05)
2008	-0.0031
	(0.00293)
2009	0.01871
	(0.03507)
2010	-0.03009
	(0.12122)
2011	-0.02012
	(0.20383)
2012	0.04373
	(0.21488)
2013	-0.06435
	(0.25868)
2014	-0.27797
	(0.37954)
Observations	214,952

Note: In each yearly estimation standard errors were clustered at the municipal level.To check significance: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$.

Table A4 – Land-use conversions: triple differences estimates

	Dependent variable:
	P2S/100 ha
	(I)
Amazon	0.111*
	(0.060)
Post 2006	−0.109***
	(0.033)
Aptitude	0.241***
	(0.050)
Amazon * Post 2006	0.031
	(0.022)
Amazon * Post 2006 * Aptitude	0.053
	(0.063)
Fixed Effects	Yes
Observations	2,566,950
R^2	0.017
F Statistic	381.819***

Note: Robust standard errors clustered at the municipal level.
To check significance: $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Appendix A3 – Data Sources

A3.1 Land Use Data

In both section 3 and 4 I used Mapbiomas Collection 5 land use maps. Mapbiomas uses Landsat imagery to produce two types of maps, cover maps and transition maps. While the cover maps display a picture of land use in a given year, the transition data informs whether a pixel went from a category of land use from year t to another in year $t+1$.

In Section 3, MapBiomas Collection 5.0 land-cover data was used to build 1 km resolution grid maps of Mato Grosso's Soy Cover and Mato Grosso's 2006 forest cover. In Section 4, I used MapBiomas Collection 5.0 land-use transition maps to build the Pasture to Soy (P2S) variable 1.8-kilometer pixel resolution.

Mapbiomas uses annual Landsat mosaics and a random forest classifier algorithm to create maps in a 30-meter resolution, classifying each pixel into a land-use category. Table A5 presents the categories of MapBiomas considered in each land-use variable. I took advantage of the fact that MapBiomas collection 5 was the first to identify soybean crops.

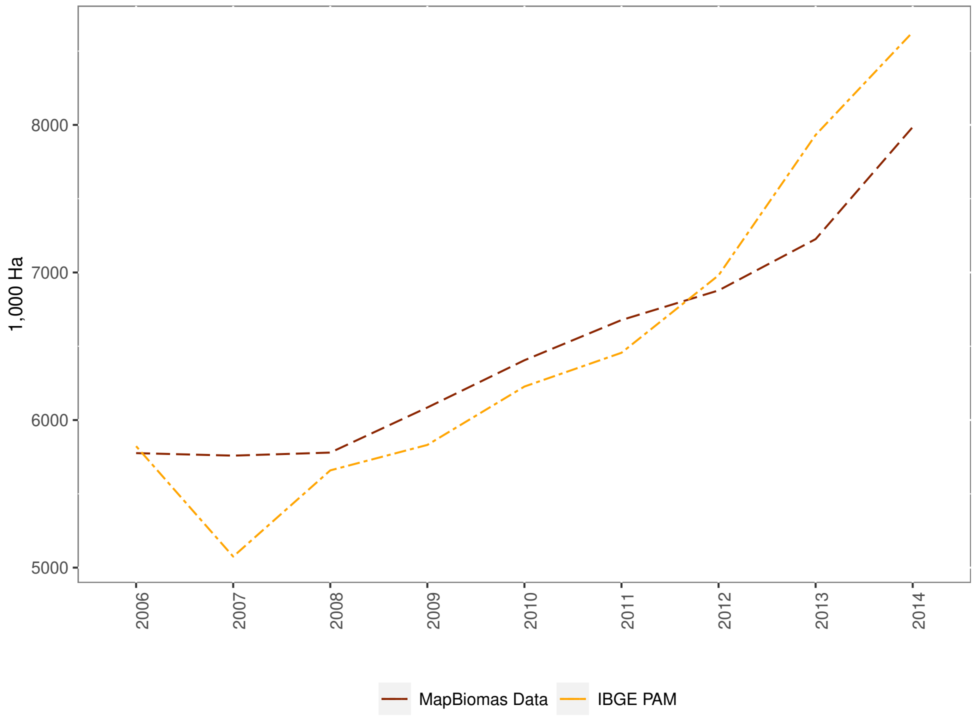
Table A5 – MapBiomas selected land-use categories

Land-use Transition Variable:	From:	To:
P2S	Pasture (15)	Soybean (39)
Land-use Variables:	Classes Considered:	
Soy Cover	Soybean (39)	
Forest Cover	Forest Formation (3), Savanna Formation (4), Wetland (11), Grassland Formation (12)	

Note: The numbers in parenthesis present each category MapBiomas ID.

The classification of the agricultural variables has an accuracy of approximately 97% in the Amazon, 75% in Cerrado, and around 80% in Pantanal. Since soy is this dissertation's primary variable of interest, in Figure A5 I compare MapBiomas classification of soy crops versus IBGE-PAM information on Mato Grosso's cultivated area. Although the datasets' information in some years does not precisely match, they both indicate similar trends. Further, considering that PAM is built from self-declaratory forms, it probably suffers from imprecise information.

Figure A5 – Mato Grosso's cultivated soybean area



To build the 1-kilometer resolution soy land-use map, I attributed one to pixels classified as soy-covered and zero otherwise. Then, I aggregated the classified information in 1km grid cells, estimating the pixel's mean soy-cover value. Therefore, in each pixel, I have the percentage of the area covered by soy crops. The same was done to built 2006's forest cover map. In Section 3 I considered only points 100% covered by vegetation as the forest points.

Finally, the land-use transition data was built in the same way. For each land-use transition category, the 30-meter resolution pixels were reclassified as one if they presented the land-use transition of interest or zero otherwise. Then, for each category, the pixels were aggregated in a 1,800m pixel resolution. Again, each land-use change category's annual rate was calculated as the mean change, that is, by dividing the total number of occurrences (taking value of 1) by the number of pixels.

A3.2 Control Variables

Soy-suitability

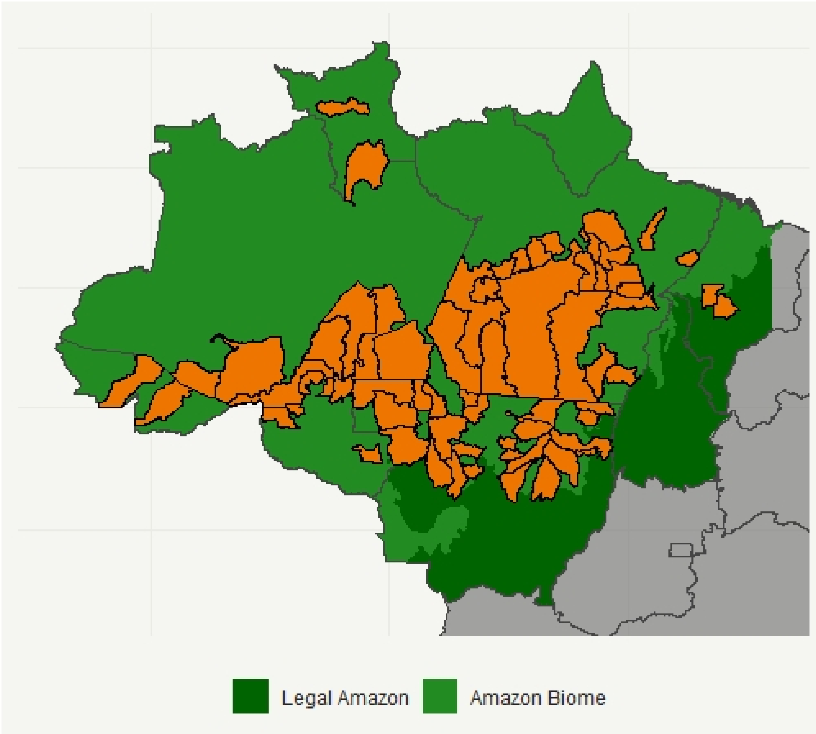
As in Heilmayr et al. (2020) to identify locations suitable for soy cultivation, I used data from Soares-filho et al. (2014).Soares-filho et al. (2014) used information on soil quality, from Embrapa, and declivity to create 60 m resolution map on terrain suitability for mechanized cropping. The map classifies as very suitable, suitable, or unsuitable. In section 4 the binary variable for soil-suitability was created considering points classified as very suitable and suitable as the soy-suitable locations (equal to 1) or unsuitable (equal to 0).

It is important to note that the source does not classify the soil suitability exclusively for soy cultivation. However, I consider this a minor issue since the topography is the most relevant variable impacting soy cultivation. Brazil's high agriculture technology adoption, especially in the soy sector, makes soil correction and fertilization a minor issue.

Municipalities Blacklist

In the estimations, I considered if observations fell within a municipality listed in Amazon's municipalities' Blacklist. The year of inclusion and removal of municipalities from the Blacklist came from Brazil's Environment Ministry. Figure A6 presents the distribution of municipalities within the Legal Amazon, that between 2007 and 2018 were included in the list.

Figure A6 – Amazon's Priority Municipalities



Source: IBGE and MMA.

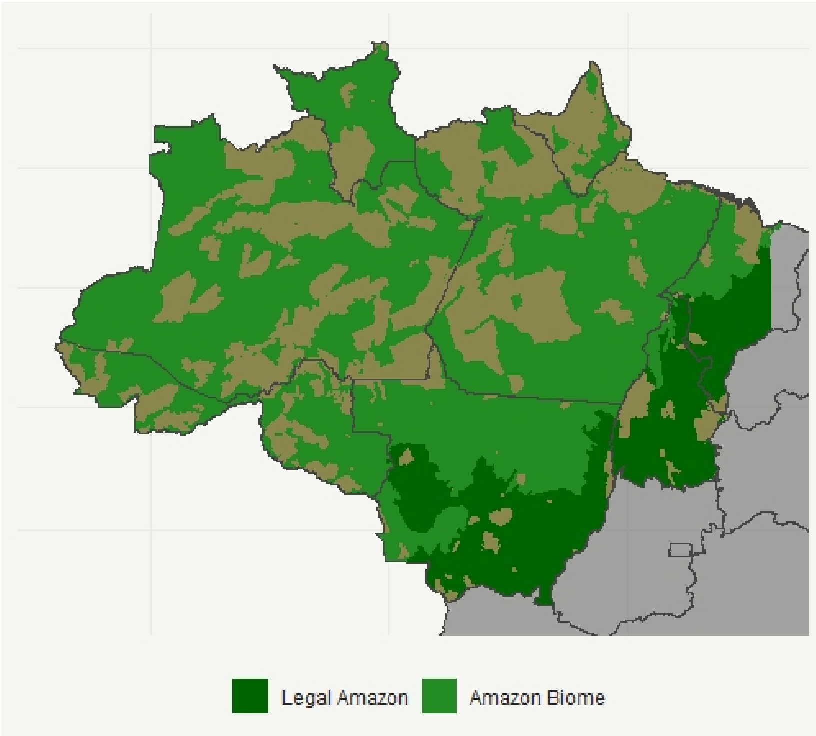
Other Covariates

To consider if an observation was within a municipality that produced more than 5000 hectares of soy in a given year, I used yearly information on soy cultivation from IBGE's PAM.

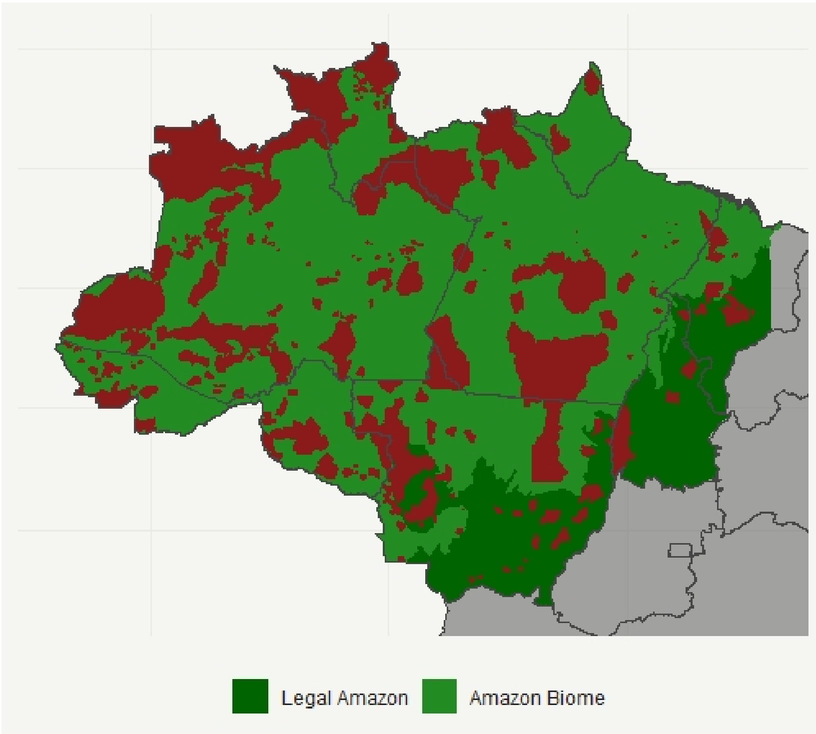
The georeferenced information on Land Settlements came from INCRA, the data on Indigenous Reserves and Conservation Units came from the Mato Grosso state government. Figure A7 plots the geographic distribution of these areas in the Legal Amazon. The distance variables, such as the distance to paved roads or navigable water bodies considered the shortest Euclidean distance. Paved roads included state and federal roads and also came from the Mato Grosso state government. The same source was used to map the navigable water bodies.

Figure A7 – Legal Amazon Conservation Units and Indigenous Reserves

I: Conservation Units



II: Indigenous Lands



Sources: IBGE and Mato Grosso State government.