National Borders and the Conservation of Nature

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Abstract

Tropical forests slow climate change, and their conservation is an international priority. We propose using finely grained satellite data at national borders, where one political jurisdiction ends and another begins, to evaluate the net impact of national policies on conservation. Using 30x30 meter satellite data along Brazil's 12,800 km border in the Amazon, we find dramatic changes in deforestation rates that match changes in Brazilian policies. Between 2001 and 2005, at the tail end of a pro-exploitation period, annual Brazilian deforestation was more than three times the rate across the border. From 2006 to 2013, as Brazil introduced policies to reduce deforestation, these differences at the border disappear. But they re-appear starting in 2014, amid a period of dismantling environmental regulation. National borders offer a means of evaluating the effectiveness of national conservation policies, which are now objects of international interest.

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1 Introduction

Conservation of nature is a relatively new idea (Friedman 1962; Krutilla 1967). An Environmental Protection Agency was not set up until 1970 in the US and only in 1989 in Brazil. Traditionally, forests were natural resources to exploit for a country's benefit, either for timber or for agriculture expansion. Benefits beyond future exploitation were seldom considered (Pigou 1920; Dasgupta and Heal 1979).

Climate change has changed all this. There is now a clear and defined benefit from *not* exploiting these natural resources as their conservation is critical to limiting future climate change. This has led to initiatives such as the 30 by 30 initiative, which aims to designate 30% of the world's land area as protected by 2030 (Dinerstein et al. 2019). Indeed, many climate change reports, from Stern (2007) to IPCC (2022), point to ecosystem conservation as a cost-effective means of tackling climate change. This new conservation objective conflicts with the traditional exploitation objective. A key problem is that the benefits of exploitation accrue to the country that contains the resource, whereas the benefits of conservation extend beyond it (Harstad 2020; Harstad 2022). This implies that there is international interest in the conservation policies of the countries that contain the vast ecosystems whose conservation or exploitation will impact the pace of climate change (IPCC 2022).

This paper explores whether national policies can exert regulatory control over conservation by examining whether deforestation changes discretely at national borders. We focus on forests, as they have become the central focus in these international conservation efforts. Here, the immediate value of extracting timber and of converting forest areas to expand agriculture land has to be balanced against their longer term conservation value. Tropical forests, in particular, are singled out for attention (Burgess et al., 2012; Hsiao 2021; Balboni et al. 2021, 2022). This is due to their vast extent, their power to influence the path of climate change, and the fact that they are being destroyed at a faster rate than other forest systems (IPBES 2018; IPCC 2022).[1] FAO (2020) estimates that across our study period, 2000 to 2020, about 90% of deforestation occurred in tropical areas. Indeed, there is a growing concern that if current rates of degradation are not stemmed, then the damage to these ecosystems will become irreversible, thus depriving the world of an important public good (Franklin Jr and Pindyck 2018; Araujo et al. 2020; Boulton et al. 2022). It is here, in these tropical forests, where the tension between conservation and exploitation is most acute.

The three major areas of tropical forest in the world are in the Amazon (predominately within the national jurisdiction of Brazil), the Congo Basin (predominately Democratic Republic of Congo) and South-East Asia (predominately Indonesia). As Figure 1 illus-

[1] The fact that tropical forests are the most biodiverse ecosystems on the planet is an added reason to conserve them (Dasgupta 2021).

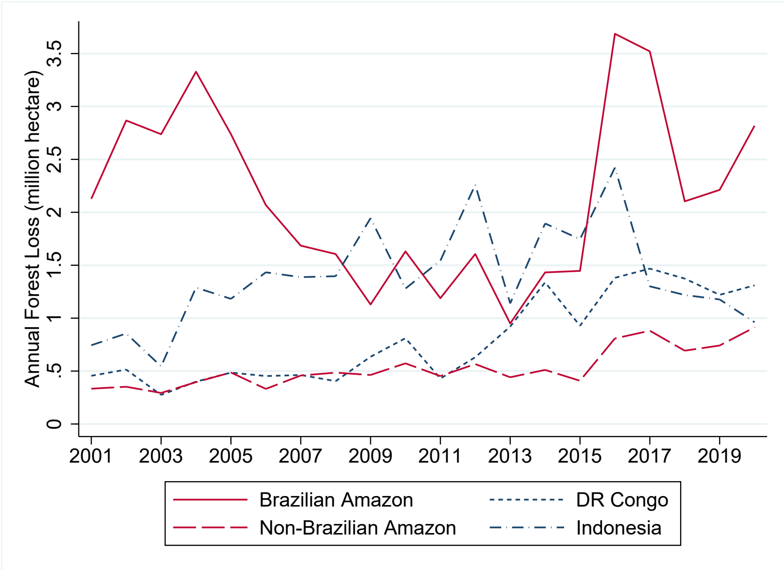


Figure 1: Forest Change in the Amazon, DR Congo and Indonesia, 2001-2020

This figure compares the annual forest loss in the Brazilian and non-Brazilian Amazon, the Democratic Republic of the Congo and Indonesia, using data from Hansen et al. (2013). Forest loss is the share of forest cover in each country that was lost in each year. The solid red line shows that the Brazilian Amazon had the only declining deforestation rate for almost a decade.

trates, these different areas have experienced radically different patterns of deforestation. Brazil – which contains 65 percent of the Amazon rainforest – moves from having almost the highest rate of deforestation in 2001 to having the lowest rate in 2013, and then converges back to the rates of deforestation seen in Indonesia and the Democratic Republic of Congo whose rates are rising steadily from 2001 to 2020. Even within the Amazon, what is happening in Brazil looks totally different from what is happening in the non-Brazilian Amazon where we do not see the same pattern of reversals.

How can we understand these patterns? How can we assess whether national conservation policies are influencing them? All these countries have *de jure* policies to conserve these ecosystems. The problem is that illegal extraction drives a wedge between *de jure* policies and their *de facto* enforcement. Indeed, this wedge distinguishes conservation challenges in developing countries from those in developed countries (Greenstone and Jack 2015; Balboni et al. 2021, 2022; Glennerster and Jayachandran 2023). Illegal extraction is facilitated by the remote nature of wilderness ecosystems, which cover about 20 percent of the world's land area (Allan et al., 2017) and state actors are often involved in this activity (Burgess et al. 2012).

In these weak institutional settings with complicit states, we need new tools to assess how well national conservation efforts are working on net. We propose a method that combines impartial monitoring via satellites with the use of national borders. Satellites obviate the need to use data collected by government, which may be patchy or nonexistent due to limited state capacity or manipulated to suit political needs (Donaldson and Storeygard 2016). National borders obviate the need for aggregating the effects of a range of imperfectly enforced policies. Because political and policy jurisdictions stop at the national border – but satellite data on conservation outcomes can be measured uniformly across the geography – by analyzing satellite data on deforestation at the international border, we can examine the effect of national policies. The aggregate patterns of deforestation we observe in Figure 1 can be driven by many factors – e.g., demand, costs of access, availability of labor, access to finance, weather, flammability – which fall outside the purview of conservation policies. Satellite images on the other side of the border (just) outside a country's jurisdiction serve as a control for (otherwise similar) satellite images which fall within a country's policy jurisdiction. This allows us to examine the net, equilibrium outcomes from a country's conservation efforts.

Building on Holmes (1998) and Turner et al. (2014), we write down a model to make precise when we can recover policy effects. Changes in national conservation policies can have a direct effect by changing the returns to illegal deforestation (and hence the propensity to engage in it) and an indirect effect by changing the investment behavior of potential users of forested land (including their location choice). The model makes it clear that for forestry where – (i) the share of capital in production is low, (ii) local supply of capital is likely elastic, and (iii) the key factor of production (land) is fixed in space – the direct effects are likely to dominate and the regression discontinuity is likely to recover the policy impact. This contrasts with other sectors like capital intensive manufacturing where the control group (pixels on the other side of the border) are affected by the land use regulation of the treatment group by the potential for people, firms, and capital to relocate across the border. The model also suggests how we can use the border effects to establish counterfactuals by comparing the coefficient on the border dummy to other cross-sectional determinants of forest extraction.

Our analysis focuses on the most important ecosystem on the planet – the Amazon rainforest. Covering more than two million square miles – larger than the size of the entire European Union – the Amazon plays a crucial role in the global carbon cycle and hosts an astounding amount of biological diversity. Its immense size implies that its deforestation rate will affect the pace of global warming (IPBES, 2018). Within the Amazon, we focus on Brazil. It contains the bulk of the Amazon rainforest and, between 2000 and 2020, 55% of global net forest area loss came from Brazil (FAO 2020). Hence, understanding whether Brazilian conservation efforts have been effective is an issue of international importance (Araujo et al., 2022). Indeed, if Brazilian national policies have no *de facto* bite, then this is likely to render meaningless both national and international accords to slow Amazonian deforestation.

To assess the effectiveness of conservation policies in Brazil, we apply a regression discontinuity design using 30x30 meter resolution Landsat 7 data in 27km bands on either side of Brazil's 12,800km border with seven other nations in the Amazon from 2000 to 2020 (Hansen et al., 2013). We show that areas on both sides of the border look similar in most important geographic respects, such as slope and distances to urban areas, water, and roads. While our focus is on results analyzing the entire border, we find similar results restricting attention to "artificial borders" – typically straight lines drawn in unknown territory by former colonizers and which do not correspond to any preexisting natural or institutional border (Alesina et al., 2011). For these borders, there is no geographic feature at the border – and indeed, usually not even so much as a fence.[2]

We document three striking facts. First, we show that until about 2005, the level and rate of deforestation were higher on the Brazilian side of the border than for its neighbors. These differences reflect a host of Brazilian policies to open up the Amazon (Pfaff 1999;). When our data starts in 2000, Brazilian land was 38 percent more likely to have been deforested than similar land located just a few kilometers away across the border. From 2001 to 2005, the annual deforestation rate was more than *three times* higher on the Brazilian side of the border than in neighboring countries. The deferentially higher deforestation is driven by higher land conversion from forest to agriculture in Brazil. These differences are concentrated on border segments where the so-called "Arc of Deforestation" intersects the international border – indicating that the differences are due to policies in Brazil, rather than in countries across the border.

Second, we show that the discontinuity in deforestation rates disappears precipitously in 2006 – just as Brazil implemented substantially tougher national policies targeting illegal deforestation – and stays low until 2013 – when Brazilian environmental policies start to be dismantled. In the mid-2000s, Brazil launched a new conservation agenda with the 2004 *Action Plan for the Prevention and Control of Deforestation in the Legal Amazon* (PPCDAm), which strengthened the legal penalties associated with illegal deforestation, particularly on unclaimed and private land outside protected areas (Nepstad et al., 2009). PPCDAm was bolstered in 2006 by the Law on Public Forest Management and by the Center for Environmental Monitoring becoming fully operational. Together, these enabled the Brazilian state to couple satellite-based detection of deforestation with police and army enforcement operations targeted at areas where illegal deforestation had been detected (MMA, 2008). These policies led to dramatic reductions in deforestation. However, this reduction was temporary, and starting in 2014, deforestation rates in Brazil (relative to countries just across the border) climbed again. This second reversal coincides with a period of economic crisis and growing lobbying from the agricultural sector, which is consistent with the hypothesis that environmental protection was undermined by political

[2] In fact, in one famous incident, President-elect Cardoso of Brazil went hiking near the border in 1994, and accidentally ended up in Bolivia – and was there for over an hour before anyone realized he was in the wrong country (Cardoso and Winter, 2006, pp. 218-219).

pressure (Azevedo et al., 2017; Freitas et al., 2018; Soterroni et al., 2018).

Third, we show that enforcement effort was particularly effective in areas with weaker *de jure* regulation and greater potential for exploitation. To examine what factors contribute to the state's ability to conserve its natural resources, we propose a novel approach for estimating heterogeneous effects, combining the spatial regression discontinuity with pixel-level pairwise propensity score matching. In this exercise, by conditioning on pixel-level observables and matched pair fixed effects, we can attribute the *conditional* difference in deforestation across the border to differences in conservation policy. We find that the reductions in deforestation following the mid-2000s policy changes in Brazil were most pronounced outside protected areas – precisely the areas where the Brazilian state increased its enforcement – and on pixels with greater potential for exploitation depending on their market access – measured by proximity to urban areas, villages, and roads. While the stronger Brazilian policies reduced the deforestation gap even in pixels further from markets, their effectiveness diminishes as we moved to pixels further from roads and urban areas. This suggests that the Brazilian state was able to enforce environmental regulations when there was the political will to do so, but only where there was enforcement capacity. We find, however, that the second reversal was mostly driven by lower enforcement of conservation policies in all areas, even in those with stronger de jure protection status and closer to markets. This underlines how fragile the pro-conservation agenda was when faced with pro-exploitation political leaders (Harstad 2020).

To quantify how much forest would have been preserved had the stronger Brazilian policies remained in place until 2020, we use our model combined with the discontinuity estimates to construct counterfactuals. Our results show that deforestation rates in the region we study would have been 30% smaller than what we observed had the environmental deregulation in Brazil not happened, that is, had the stronger policies implemented starting in the mid-2000s remained in effect until 2020.

Combined, these results – the sharp discontinuity in deforestation levels and rates at the border, the dramatic change in deforestation at the border following the government crackdown, and the reversal of deforestation rates exactly in the areas where environmental policies were previously firmly enforced – demonstrate the remarkable reach of the Brazilian state to exploit or conserve its natural resources. They suggest that the rapid deforestation in the Brazilian Amazon in the early 2000s was a consequence of a pro-exploitation policy environment, and that the temporary reversal, from 2006-2013, was indeed a consequence of the introduction and enforcement of laws to protect the Amazon rainforest, which unravelled in the subsequent 2014-2020 period as pro-exploitation political forces took hold.

To help us interpret these findings, we discuss the main drivers underlying reversals in national conservation policies based on a model of dynamic exploitation of an exhaustible resource (Harstad, 2020). This model clarifies that conservation policies are only implemented by governments with a strong inclination towards environmental issues. However, it also underlines how difficult it is to maintain a pro-conservation equilibrium when there are groups lobbying to take the short-term economic gains from exploiting natural resources (Harstad and Svensson, 2011). The insights from this model line up with the underlying political dynamics in Brazil and help us to understand the reversals in environmental policy in the Amazon.

Our analysis helps us to understand why in Figure 1 the Brazilian Amazon was the only major area of tropical forest that experienced falling rates of deforestation since the mid-2000s[3] and why this downward trend reversed in recent years. Identifying the role of Brazilian policies in these reversals is challenging, both because many other factors affect rates of deforestation and because a myriad of conservation policies were applied across the country. Many papers use variation within Brazil to study the role of specific policies – such as the satellite-based deforestation detection system (DETER),[4] the creation of protected areas,[5] targeted enforcement efforts in priority municipalities,[6] and conditioning access to subsidized rural credit on land registration and environmental compliance.[7]

While each of these studies focuses on identifying the effects of a particular policy, it is difficult to aggregate their impact. The contribution of this paper is to identify the net 'Brazil policy effect' – the combined effect of all Brazilian policies aimed at reducing deforestation – by studying the overall effect of being in Brazil compared to being just across the border. The band of forest just across the border is similar in many respects but falls under a different policy jurisdiction. Many policy makers, both national and international, want a handle on how effective, in aggregate, national conservation policies have been, and our approach fills this gap.

This paper fits within a rich literature using borders to study policy effects. While borders have been associated with policy outcomes in developed countries (Holmes, 1998; Black, 1999; Turner et al., 2014) where regulations are tightly enforced, evidence from developing countries is more mixed. Some papers use state or city borders to estimate the effects of policies such as minimum wage, carbon subsidies, and decentralization of water quality management.[8] Others argue that in many developing country contexts, governments can project some authority in national or regional capital cities but have much weaker powers in remote, frontier areas.[9] Our results are consistent with the nuanced evidence for developing countries. Despite substantial *de jure* policies that restrict

[3]Nepstad et al. (2009); Hargrave and Kis-Katos (2013); Assunção et al. (2015).
[4]Assunção et al. (2023); Ferreira (2021).
[5]Soares-Filho et al. (2010); Nolte et al. (2013); Harding et al. (2021).
[6]Arima et al. (2014); Assunção and Rocha (2019); Cisneros et al. (2015); Assunção et al. (2022).
[7]Alix-Garcia et al. (2018); Assunção et al. (2019).
[8]Magruder (2013); Chen et al. (2013); Lipscomb and Mobarak (2016).
[9]Michalopoulos and Papaioannou (2014); Pinkovskiy (2017).

development and promote conservation, *de facto* enforcement seems to depend critically on national political will.[10]

Extending these methods into wilderness areas is important given the new and urgent attention being paid to the value of conserving them and the difficulties associated with assessing this. In these far flung wilderness areas, national interests may diverge from international interests and new policy instruments may be needed to align them (Harstad 2022). In effect, many who care about conservation of wilderness ecosystems such as the Amazon do not reside in the political jurisdictions where they are located.

The remainder of this paper is organized as follows. Section 2 presents the theoretical framework that guides our main empirical strategy. Section 3 discusses the major policy changes in Brazil and in the other countries in the Amazon region. Section 4 sets our empirical specification and data. We present our main results in Section 5. Section 6 presents the counterfactual exercises. Section 7 discusses the factors influencing the dynamics of conservation and exploitation in the Brazilian Amazon. Section 8 concludes.

2 Theoretical framework

Model setup. We build on Holmes (1998) and Turner et al. (2014) and consider a static model of land use. We assume a space covered with forest consisting of pixels, i, distributed over a line segment, such that $i \in [-1, 1]$. Pixels are of equal size but heterogeneous in their productivity $a_i > 0$. Productivity captures agronomic characteristics of the land parcel, such as soil suitability for crops, distance to roads, and access to water. For each pixel i, an agent chooses the fraction of land to be preserved and the fraction to be deforested and used for agriculture, l_i. The gross production using land l_i and capital k_i (a mobile factor of production) in pixel i is $A(a_i, l_i, k_i)$. We assume a CES production function: $A(a_i, l_i, k_i) = a_i(\alpha l_i^\rho + (1-\alpha)k_i^\rho)^{\frac{\phi}{\rho}}$, where $\alpha \in [0, 1)$, $\phi < 1$, and $\rho < 1$. As a normalization, the value from preserving the land in each pixel is zero.

Land use is subject to different regulations, policies, and enforcement capacities. The model embeds this heterogeneity by allowing each pixel to be subject to a pixel-specific land use regulation $v_i \in [-1, 0]$. The pixel productivity net of regulation is given by $A(a_i, l_i, k_i)\, e^{v_i}$.

For each pixel, the individual chooses the optimal input levels – the share of land used l_i^* and capital k_i^* – to maximize their private returns: $\Pi(a_i, l_i, k_i) = A(a_i, l_i, k_i)\, e^{v_i} - rk_i - cl_i$. The price of capital is denoted by r, and c is the cost of converting forest to productive land. Implicitly, we assume an elastic global market for output with the price normalized

[10] A large literature uses borders to study the legacies of colonial or pre-colonial institutions (e.g., Dell, 2010; Cogneau and Moradi, 2014; Fujiwara et al., 2017; Dell et al., 2018; Dell and Olken, 2020), and estimate trade costs by looking at across-borders price gaps (Gopinath et al., 2011; Aker et al., 2014).

to 1. The optimal share of land used in each pixel is given by:

$$l_i^* = \begin{cases} \min\left\{ [a_i e^{v_i} \Phi(r)]^{\frac{1}{1-\phi}} \text{ , } 1 \right\} & \text{if } \Pi\left(a_i, l_i, k_i\right) \geq 0 \\ 0 & \text{if } \Pi\left(a_i, l_i, k_i\right) < 0 \end{cases} \tag{1}$$

$$\text{where } \Phi(r) = \frac{\phi}{c}\alpha^{\frac{1-\phi}{1-\rho}} \left[\alpha^{\frac{1}{1-\rho}} + (1-\alpha)^{\frac{1}{1-\rho}} \left(\frac{c}{r}\right)^{\frac{\rho}{1-\rho}} \right]^{\frac{\phi-\rho}{\rho}}.$$

From this equation, we observe that regulation may lead to different land use choices in pixels with similar productivity levels. The weaker the regulatory levels in pixel i (i.e., v_i closer to zero), the larger the share of land deforested and used for agriculture.

What do we learn from looking at borders? Suppose that the land is spread across two countries: *Left* (L) and *Right* (R). All land $i < 0$ belongs to country L, and $i \geq 0$ belongs to country R. Each country imposes different land use regulations and has different enforcement capacities. Likewise, the cost of capital may also differ in the two countries if markets are not integrated around the border.

Consider a researcher who observes land use in each pixel, l_i^*, but does not perfectly observe land productivity, a_i. For the interior solution case, when comparing the logarithm of land use in pixels sufficiently close to the border in both countries, we have

$$\delta_i \equiv \lim_{i \to 0^+} \ln l_i^* - \lim_{i \to 0^-} \ln l_i^* = \frac{\lim_{i \to 0^+} \ln a_i - \lim_{i \to 0^-} \ln a_i}{1-\phi} + \frac{\ln \Phi\left(r_R\right) - \ln \Phi\left(r_L\right)}{1-\phi} + \frac{\lim_{i \to 0^+} v_i - \lim_{i \to 0^-} v_i}{1-\phi}. \tag{2}$$

The first term represents the difference in pixel productivity on each side of the border. Under the standard assumption that land productivity a_i is continuous around the border (e.g., as in Holmes, 1998; Turner et al., 2014), this term converges to zero. Intuitively, this assumption means that pixels very close to each other have similar characteristics, and this can be empirically verified. The second term captures the difference in land use due to different capital costs in each country. The third term captures the difference in land use due to differential (local) costs imposed by land regulation.

When comparing land use very close to the border, researchers are interested in learning about the third term: the differential share of forested land converted into crop or pasture land due to the difference in environmental regulations of the two bordering countries. Equation (2) clarifies that the spatial discontinuity identifies the combination of differences in land use due to different input use at the border (the second term) and differences in land use due to regulatory changes at the border. The regression discontinuity only identifies the local effects of regulation if this second term is equal to zero. This condition is satisfied in two cases: (i) when the capital share in the production function is equal to 0 ($\alpha = 1$); or (ii) when the capital market is locally competitive, such that capital is supplied elastically at a constant price r on both sides of the border. If one of these conditions is satisfied, the regression discontinuity in equation (2) identifies the local differential effect of regulation on land use (the third term).

In the forestry case we consider here, it seems that both of these conditions are likely to hold. Most of the land deforested in the Amazon hinterlands is driven by cattle ranching, an activity with very low capital investment.[11] As we argue in Section 4, the local economies of the areas across the border seem to be substantially integrated, with easy cross-border movement of people and goods. Most importantly, the key factor of production (land) is completely fixed in space, so concerns about cross-border spillover are unlikely to be of the first order. Thus, in our setting – land use in the fringes of the Amazon – $\ln \Phi(r_R) - \ln \Phi(r_L)$ is likely small, and the regression discontinuity likely identifies the direct impact of land use regulations.

Extrapolating from borders The model also provides guidance on how to conduct counterfactuals based on estimated discontinuities. Specifically, the discontinuity in land use that we will estimate below corresponds to Equation (2). We can use equation (1) to help determine the net effect of an estimated change.

To do so, we need to parameterize equation (1). First, we assume that land productivity is represented as $a_i = \exp^{\mu(X_i)+u_i}$, where μ is a country-specific function of a vector of observable pixel-specific characteristics,X_i, and u_i is an unobserved productivity term with mean zero. We also assume that for all pixels in Brazil, environmental regulation takes the form of $v_i = \delta + \nu_i$, where δ is a common environmental cost, and ν_i are pixel-specific environmental regulation and enforcement.

We can then estimate the optimal land use in each pixel using a linear regression:

$$\ln l_i^* = \frac{1}{1-\phi}\left[\kappa + \mu(X_i) + \delta \mathbf{1}\left\{i \geq 0\right\} + u_i + \nu_i\right] \quad (3)$$

where κ is a constant, $\mu(X_i) = \mu_{Brazil}(X_i).\mathbf{1}\left\{i \geq 0\right\} + \mu_{Abroad}(X_i).\mathbf{1}\left\{i < 0\right\}$, and $u_i + \nu_i$ is the structural residual. The coefficient δ captures the average direct effect of Brazilian regulation on land use. The key point in (3) is that, having estimated δ using the discontinuity design, we can compute counterfactual land uses for different regulatory scenarios (i.e., different values of δ). We perform this exercise in Section (6).

[11] For cattle ranching, which represents 73% of the productive land use in Amazonian states of Brazil, the 2006 Census of Agriculture records the average value of tractors and machines employed as \$29 per hectare; for agriculture, it is \$71 per hectare. Even logging, which requires some machinery to cut and process wood, does not invest capital in the land as all equipment is carried to the next forested plot.

3 Environmental regulation in the Amazon

Countries in the Amazon region share the responsibility of regulating land use, but they often have different economic and conservation goals and policies. In this section, we provide an overview of the main conservation policies implemented in the Amazon region over the past two decades. We begin by examining the environmental regulation and land use dynamics in Brazil, which contains the majority of the Amazon forest and has been responsible for most of its historical deforestation. This context will help frame the empirical results we present later. We then discuss the main conservation policies in the non-Brazilian Amazon, highlighting the significant policy variation across countries and over time. Additional details are provided in Appendix C.1.

3.1 The Brazilian Amazon

Early days. Prior to the 1960s, the native vegetation in the Brazilian Amazon was largely intact, with a population consisting mainly of indigenous people and a small non-native population. The primary economic activity during this period was rubber extraction. From 1964 to 1985, the military government encouraged immigration to the region through large-scale infrastructure projects, such as road construction and hydroelectric power plants, as well as land titling for productive use (Pfaff, 1999). This led to a surge in migration and cattle ranching in the area.

Environmental concerns were not a priority for the government at that time. The Ministry of Environment (MMA) and the Brazilian Environmental Agency (IBAMA) were established only during the process of re-democratization in 1985 and 1989, respectively. However, environmental regulation remained weak until 2004, when deforestation rates reached their peak in the region. Between the 1980s and 2004, the deforested area in the Brazilian Amazon increased from 6% to 16% between the 1980s and 2004 (MMA, 2013).

A new environmental agenda. In 2003, President Lula appointed Marina Silva as Minister of the Environment, signaling a shift in focus from exploitation to conservation of the Amazon. Silva, a union leader and the daughter of Amazonian rubber tappers, had already been involved in efforts to protect the Amazon from encroachment by ranchers and farmers, collaborating with Chico Mendes. In November 2004, the federal government launched the *Action Plan for the Prevention and Control of Deforestation in the Legal Amazon* (PPCDAm) to combat deforestation in the Amazon. The action plan outlined a series of policy changes to be implemented gradually. The main policies implemented during this period are summarized in Table A1.

For environmental regulatory purposes, the land in the Brazilian Amazon can be classified into two categories: protected areas for conservation (such as national parks and indigenous land), and unprotected areas (which include privately owned land and untitled and unclaimed areas). PPCDAm imposed stricter regulations on land use in both types of land. The government paired technology and intelligence missions to enhance environmental monitoring and enforcement in the Amazon. In particular, it developed a remote-sensing system (DETER) which generated biweekly heat maps used to inform coordinated enforcement actions between IBAMA, the Army, and other government institutions. In 2006, IBAMA's Center for Environmental Monitoring (CEMAM) became fully operational, providing near real-time satellite data to local IBAMA offices for enforcement purposes.[12] Additionally, the government created a list of priority municipalities with historically high deforestation rates that would receive special attention.[13]

PPCDAm also included land-specific policies. Harming native vegetation in Protected Areas (PAs) had been considered a felony subject to potentially severe legal punishments, including imprisonment, since 1998. Throughout the period, this category of land faced the highest level of *de jure* sanction. In contrast, PPCDAm made several *de jure* changes to increase enforcement outside PAs. Prior to 2005, deforesting untitled or unclaimed land outside PAs was considered an infraction punishable, at most, with fines. PPCDAm elevated the deforestation of unclaimed land to a felony and legislated that authorities could seize the equipment of violators, such as trucks and chainsaws used for clearing the land. Similarly, until 2005, private properties outside PAs were required to maintain at least 80 percent of their area as native vegetation, making it illegal to deforest more than 20 percent of the property. However, non-compliance with this threshold was considered only an infraction. Starting in 2008, PPCDAm linked access to subsidized agricultural credit lines to stricter environmental compliance (Assunção et al., 2019).

In sum, prior to 2005, the majority of deforestation in the Amazon was illegal, but enforcement and the *de jure* sanctions associated with deforestation substantially increased that year. The significant reduction in deforestation rates in Brazil, as depicted in Figure 1, coincides with the implementation of this new environmental agenda in the region.

Dismantling of the environmental agenda. In the subsequent decade, the 2010s, the Brazilian government's focus on maintaining a strong environmental agenda began to weaken. The increasing political influence of the rural caucus in the Federal Congress (Rochedo et al., 2018), backed by the agriculture sector, exerted pressure to deregulate certain land use restrictions introduced in previous years (e.g. Crouzeilles et al., 2017; Rochedo et al., 2018; Freitas et al., 2018).[14] Simultaneously, the government shifted

[12] Studies by Assunção et al. 2023 and Ferreira (2021) demonstrate that the remote-sensing system led to increased fines and contributed to a reduction in deforestation.

[13] Two of these municipalities are located on the border with Bolivia.

[14] The number of rural caucus members in the Federal Congress rose from 79 in the 2002-2006 legislature to 142 and 207 in the 2011-2014 and 2015-2018 legislatures, respectively.

its focus in the Amazon region towards promoting economic development through large infrastructure investments and subsidies for industries such as livestock grazing. Table A2 presents the key events during this period.

The most significant policy change was the controversial approval of the New Forest Code (Law 12.651/2012) in 2012. The amnesty provided to "small" private properties (those with less than 440 hectares in the Amazon) that had exceeded the legal deforestation limit before 2008 was particularly contentious.[15] Beyond the *de jure* impact, the “amnesty afforded by the New Forest Code could lead to the perception that illegal deforesters are unlikely to be prosecuted and may even be exonerated in future law reforms” (Soares-Filho et al., 2014, pg.364). Subsequently, the Federal Congress made repeated attempts to roll back key aspects of the regulatory framework established under PPCDAm, including streamlining the land titling process for occupied public land and simplifying environmental licensing for infrastructure projects.

The perception that environmental crimes would go unpunished was reinforced by the weakening of the government’s enforcement apparatus. An audit conducted by the Office of the Comptroller General (CGU, 2016) revealed a 34.2% reduction in IBAMA’s budget between 2013 and 2014. The report also documented a 24% decrease in the number of IBAMA’s enforcement officers from 2010 to 2014. Budget cuts persisted in subsequent years, resulting in a nominal value of only 57% of the 2013 budget by 2016.

In 2018, Jair Bolsonaro, a presidential candidate openly hostile to environmental issues, was elected with significant support from the rural caucus. The government initiated an unprecedented process of environmental deregulation, which involved dismantling the bureaucracy and dismissing experts in government environmental agencies, as well as scrapping environmental regulations on various fronts. As summarized by the Minister of Environment in an April 22, 2020, cabinet meeting, the objective was to “(...) run the cattle trough and change all the rules and simplify norms”.

As Figure 1 shows, after eight years of relatively low deforestation rates, there was a reversal in the trend with increased deforestation in the second half of the 2010s, coinciding with the gradual dismantling of the environmental agenda established by PPCDAm.

3.2 The non-Brazilian Amazon

Environmental governance in the non-Brazilian region was less developed than in Brazil. Perhaps because deforestation rates in the non-Brazilian Amazon were considerably lower than in Brazil throughout most of the 2000s, as shown in Figure 1, other countries in the region did not implement a comprehensive set of policies like Brazil did

Table A1 presents the timeline of environmental policies in the region during the

[15] Soares-Filho et al. (2014) estimate that this amnesty effectively forgave illegal deforestation inside private properties for 90% of Brazilian rural properties.

2000s. Peru, Colombia, Suriname, and Guyana developed their legal frameworks for forestry and regulated economic activity in the region. In 2004, Peru established the Alto Purus national park on the border with Brazil, and later, in 2008, created the Peruvian Ministry of Environment and the Environmental Agency. Colombia passed a New General Forestry Law in 2006, but it was declared unconstitutional in 2008. Bolivia and Venezuela had a less active environmental agenda during this period. Bolivia's main land use policy was the 2006 Law on Community Redirection of the Agrarian Reform, which aimed to facilitate land titling of public lands to indigenous communities.

Table A2 summarizes the key events during the 2010s. A trend observed in the region was the adoption of policies within the United Nations' REDD+ framework. These policies included economic and ecological zoning, demarcation of protected areas and national parks, and regulation of payment for environmental services. Despite these efforts, the annual deforestation rate in these countries continued to increase in the last decade. Bolivia and Venezuela pursued a resource nationalism agenda that opposed market-based mechanisms such as REDD+.[16]

In sum, Brazil's environmental efforts between 2004 and 2011 were unmatched by other countries in the region. While deforestation rates in Brazil dropped by 70% within a few years, deforestation in the non-Brazilian Amazon increased, as depicted in Figure 1. In the following decade, as Brazil reversed its environmental agenda and deforestation resumed its upward trend, most countries in the region continued to make progress in environmental governance. Nevertheless, the annual deforestation rate in the non-Brazilian Amazon also increased, albeit at a more moderate pace than in Brazil.

4 Empirical method and data

Although Figure 1 demonstrates a correlation between changes in deforestation and the discussed environmental policies in the previous subsection, we cannot establish a causal relationship between these national policies and conservation. The framework outlined in Section 2 clarifies that by examining forest cover in plots of land near the border between two countries, we can identify the differential effects of national policies on forest conservation. This section describes how we apply this framework to the data to estimate the differential effect of policies implemented in the Brazilian Amazon on deforestation compared to policies implemented in the non-Brazilian Amazon.

[16]Bolivia enacted the Rights of Mother Earth Law in 2010, which declared Mother Earth the title holder of inherent rights of the land. Venezuela, despite enacting a New Forest Law in 2013, created an economic strategic zone to enable mining in the forest.

4.1 Method

We estimate a spatial regression discontinuity design using as the main outcome variable the share of forest cover lost in each year between 2001 and 2020 at the 120-meter pixel resolution level. Our running variable is the distance to the Brazilian international border: D_i. Positive distances represent pixels in the Brazilian Amazon, while negative distances represent pixels in the Amazon outside Brazil. Our main estimating equation is:

$$Y_i = \alpha + \gamma B_i + f(D_i) + \delta X_i + \varepsilon_i \tag{4}$$

Y_i represents the outcome of interest (forest cover in 2000 or forest loss in a given year) in pixel i. B_i is a dummy variable equal to one if pixel i is in Brazil. X_i is a vector of pixel-specific characteristics explained below, and $f(D_i)$ is a polynomial function of the distance from the border. These two terms capture pixel characteristics that influence land use, such as agronomic and economic factors represented by a_i in equation (1) in the model. Following Gelman and Imbens (2019), we use separate linear polynomials on each side of the border as our preferred specification.

Identification. The coefficient of interest is γ, which measures the difference in the share of forested pixels on the Brazilian side of the border compared to the other side in 2000 (or the deforested share in subsequent years). Our identifying assumption is that other factors influencing deforestation change smoothly across national borders. If this assumption holds, controlling for a polynomial function of distance from the border and additional pixel characteristics allows γ to serve as the empirical counterpart to the third term in equation (2). Therefore, if agronomic characteristics affecting land use evolve continuously at the border, γ identifies the local difference in forest conservation resulting from Brazilian policies relative to those of neighboring countries.

Our identifying assumption could be undermined if the precise border location were determined by local geographic or agronomic characteristics. Nevertheless, historical evidence indicates that the exact positioning of the Brazilian border in the Amazon region is largely arbitrary. Borders were primarily established through the 1750 Treaty of Madrid, a time when many of these jungle areas remained unexplored and were denoted as vast blank spaces labeled "unknown country" on contemporary maps (Furtado, 2012).[17] Additionally, our results remain robust when considering straight-line border segments, which are clearly artificial (Alesina et al., 2011) (see Section 5.3 below).

To assess these assumptions using the data, we examine potential discontinuities at the border in four factors that may influence deforestation: slope, distance to water, distance to urban areas, and distance to roads. Table 1 shows estimates of the discontinuous

[17] Appendix C.3 provides further details on the border formation.

change in the levels of these variables at the Brazilian border, considering various subsets of the border. Our findings indicate that these characteristics exhibit smooth distributions around the Brazilian border.

Table 1: Covariates Balance Check

	Land	Distance from		
	Slope	Urban Area	Water	Roads
	(1)	(2)	(3)	(4)
Panel A. *Bandwidth 27km*				
Brazil dummy (γ)	.055	.000	-.003	.000
	(.089)	(.034)	(.015)	(.019)
Panel B. *Bandwidth 27km – Excluding Mount Roraima*				
Brazil dummy (γ)	.061	-.001	-.003	-.002
	(.096)	(.036)	(.016)	(.020)
Panel C. *Bandwidth 27km – Excluding Artificial Borders*				
Brazil dummy (γ)	.054	.000	-.003	-.001
	(.081)	(.037)	(.016)	(.020)

This table shows the OLS regression estimates of the Brazilian dummy, γ, on land slope (column 1), distance from water (column 2), distance from roads (column 3) and distance from urban areas (column 4), from equation (4) with linear polynomials and triangular kernel. Panel A uses the average optimal bandwidth (Imbens and Kalyanaraman, 2012) of our dependent variables, Panel B excludes a 220km-buffer around the peak of Mount Roraima (see Figure A3a, and Panel C excludes areas around artificial borders. Units of observations are 120-meter pixels around the whole Brazilian Amazon border. Standard errors two-way clustered at overlapping 100km^2 grids in parentheses. Number of clusters and observations: 5,491 and 31,711,264 (Panel A), 5,088 and 29,298,310 (Panel B), and 4,991 and 28,508,790 (Panel C). Significance levels: *10%, **5%, ***1%.

Another potential challenge to our identifying assumption would arise if local markets were segmented at the border. In such a scenario, differential input prices could potentially impact land use investment differently on each side of the border, as illustrated by the second term in equation (2). However, evidence suggests significant integration of markets and communities at the border, including the densely populated Brazil-Bolivia segment. Notably, Brazil and Bolivia have been members of the Southern Common Market (Mercosur) since the 1990s, facilitating the movement of people and goods across the border. Moreover, the border itself is remarkably porous. The illegal movement of people across countries has been prominent, with Brazil repeatedly granting amnesties for illegal immigrants from Latin American countries. Capital also flows across border, as evidenced by Brazilians owning 32% of Bolivian soy land even as of 2000. Furthermore, soy prices in Brazil and Bolivia exhibit similar trends over time (Figure A4), suggesting that differential prices are unlikely to be the primary driver of the observed effects.[18]

[18] We discuss these matters in greater detail in Section 5.3 below and in Appendix C.4.

Estimation. In our main specifications, we estimate equation (4) using OLS. In our main specification, we include two pixel-level geographic controls: land slope and distance from water. We also present robustness results without any controls and with additional controls for distance to infrastructure.

To allow for geographical spatial error correlation, we estimate standard errors using two-way clusters at overlapping 100km^2 grids (Cameron et al., 2012), as depicted in Figure A1. Specifically, we create two 100km^2 cluster grids that partition the area, with the second cluster grid being an offset version of the first one. This approach addresses the issue of assuming independence for observations close to each other on either side of a border block, despite their spatial proximity. The second cluster grid allows for spatial correlation among these observations within the second cluster.[19]

We report results using bandwidths around the border ranging from 11km to 100km. Since we have multiple dependent variables, there is no single theory-driven optimal bandwidth. To determine the optimal bandwidth for each dependent variable, we calculate it following the methods outlined in Calonico et al. (2014) and Imbens and Kalyanaraman (2012). For comparability across equations, our preferred bandwidth is the average of the optimal bandwidths obtained using Imbens and Kalyanaraman (2012) method, which is 27km from the border. We also present results using Calonico et al. (2014) method, yielding a bandwidth of 11km from the border. In our preferred specification, which encompasses all 120m pixels within 27km of the border, we have 5,491 clusters and 31,711,264 observations per year.

Heterogeneity analysis. We assess potential variations in institutional effects across different border segments and land types in Brazil. However, performing heterogeneity analysis within a regression discontinuity design is not as straightforward as subsampling or adding interaction terms to the estimation equation (Becker et al., 2013; Carril et al., 2018). Becker et al. (2013) demonstrated that two additional assumptions are necessary to recover heterogeneous local average treatment effects in regression discontinuity. First, the covariate on which one conditions must be continuous at the threshold. Second, given the running variable, unobserved determinants of the outcome variable (i.e., the error term) should be uncorrelated with the conditioning covariate. Carril et al. (2018) proposed estimating heterogeneous effects by employing subgroups reweighted using the inverse of the propensity score to create balanced subgroups (based on observables) on both sides of the cutoff.

Estimating heterogeneous effects in a spatial setting is more complex. While geographical characteristics can be continuous at the border, other attributes such as land

[19] Conley (1999) standard errors could serve as an alternative, but computational challenges arise due to the extremely large number of observations.

type and place-based policies may not exhibit continuity. For instance, Protected Areas (PAs) are delimited by each country and terminate at the national border, potentially generating a discontinuity in protection status at the border. In this case, estimating regression discontinuity based on subgroups would likely compare pixels that are similar in observable characteristics but potentially distant from each other and therefore subject to different unobservable factors. Conditioning on PAs, for example, would compare pixels on both sides of the border, which, despite sharing the same protection status, could be hundreds of kilometers apart and exposed to distinct weather conditions. Propensity score weighting would not resolve this issue.

To address this challenge, we propose a novel approach for estimating heterogeneous effects within a spatial regression discontinuity strategy. We divide all pixels within 27km from the border into geographic subgroup blocks of 1-degree squared size. For each geographic block and protection status (i.e., PAs and non-PAs), we perform pairwise propensity score matching (without replacement) using absolute distance from the border, latitude, longitude, slope, distance to water, distance to villages or urban areas, and distance to roads as matching variables. We consider only pixels that have a common support in all covariates. We, then, estimate the regression discontinuity using the matched subsample. This ensures that, conditional on a given covariate, such as protection status, pixels on both sides of the border are balanced with respect to both observable and unobservable characteristics, as the pixels are close to each other. For computational reasons, we perform the matching using a 25 percent random sample. Our final matched sample has 3,008,278 pixels.[20]

Given the substantial variations in baseline deforestation magnitudes across land types in the Amazon, we employ a Poisson model to estimate equation (4), including matched pair fixed effects.[21] Poisson estimates allow for interpretation as percent changes in the dependent variable across land types.[22]

4.2 Data and descriptive statistics

Our primary data source consists of high-resolution maps of forest cover dynamics from Hansen et al. (2013). These maps utilize satellite imagery from Landsat 7 to detect forest cover in 2000 and track annual loss of forest cover between 2001 and 2020 worldwide, with a spatial resolution of 30 meters.[23] Importantly, because this dataset does not rely

[20]See Appendix Section B for details on the implementation of the matching exercise.

[21]Since each 120m pixel comprises sixteen 30-meter pixels, our dependent variable effectively becomes a count variable ranging from 0 to 16.

[22]We also show in Section 5.3 below that our main results are also robust to using a Poisson specification instead of OLS.

[23]The forest cover map is constructed for 2000 because Landsat 7 was launched in the previous year. Hansen and coauthors use this map as the baseline to calculate annual forest loss.

on national data inputs, it allows us to examine deforestation rates on both sides of the border using an exactly comparable metric.[24]

To identify the land use of deforested pixels, we rely on data from the MapBiomas Amazonia project.[25] This dataset combines satellite imagery from Landsat 7 with ground observations to classify land use in 2000 and track land use changes between 2001 and 2020 in the Amazon region, using a spatial resolution of 30 meters. Importantly, the MapBiomas data also consistently covers land use classifications for all countries within the Amazon region. We aggregate land use into three categories: forest, agriculture (i.e., crops and pasture), and others.

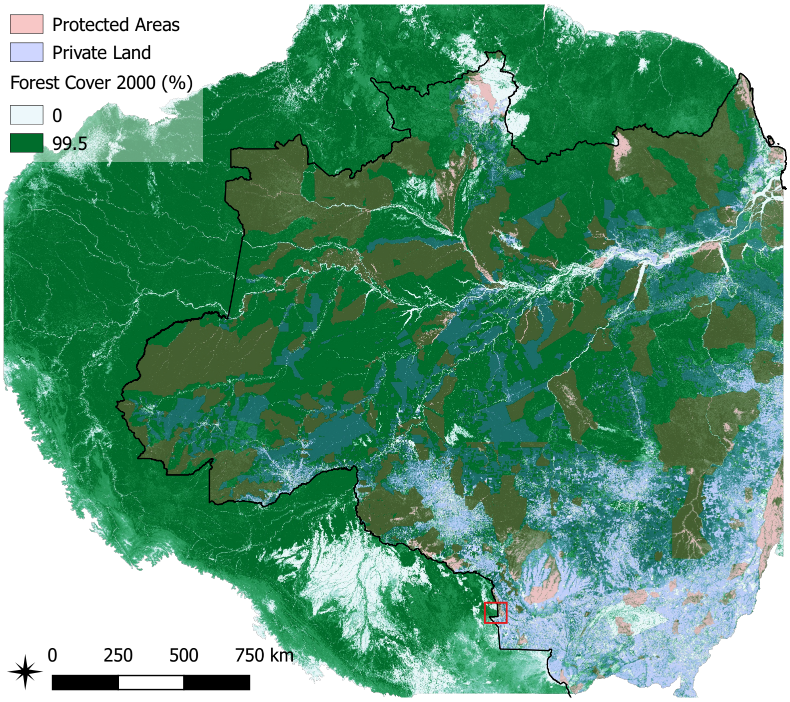
Our analysis focuses exclusively on the Amazon area as defined by RAISG (*La Red Amazónica de Información Socioambiental Georreferenciada*), which considers the biome and the legal Amazon limits specified by the various countries in the region. To address computational constraints, we aggregate pixels to a resolution of 120x120 meters. Annual forest loss is defined as the proportion of 30-meter Landsat pixels, within our 120-meter pixels, that are deforested within a given year. Forest cover in 2000 is the average tree canopy cover of the Landsat pixels. In addition to the land use data, we supplement our analysis with various other data sources. Protected areas are obtained for all countries from the World Database on Protected Areas,[26] hydrology data from 2000 is extracted from Google Earth Engine, while administrative boundaries, protected areas, elevation, slope, waterways, roads, and urban areas are obtained from OpenStreetMap's API.

Recent studies have shown that data based on satellite imagery might contain non-classical measurement errors (Alix-Garcia and Millimet, 2022; Torchiana et al., 2022). Although these papers propose various diagnostic tests and corrections to address these potential issues, implementing them is unfeasible or computationally challenging given our sample size. However, measurement error is unlikely to be a major concern in our study. First, our regression discontinuity design flexibly controls for pixel characteristics that may be correlated with measurement error. Second, Hansen et al. (2013) and MapBiomas data employ algorithms and ground observations to correct implausible classifications and transitions. For instance, cross-validation tests conducted by MapBiomas revealed less than 1.2% misclassification of forest pixels as agriculture.

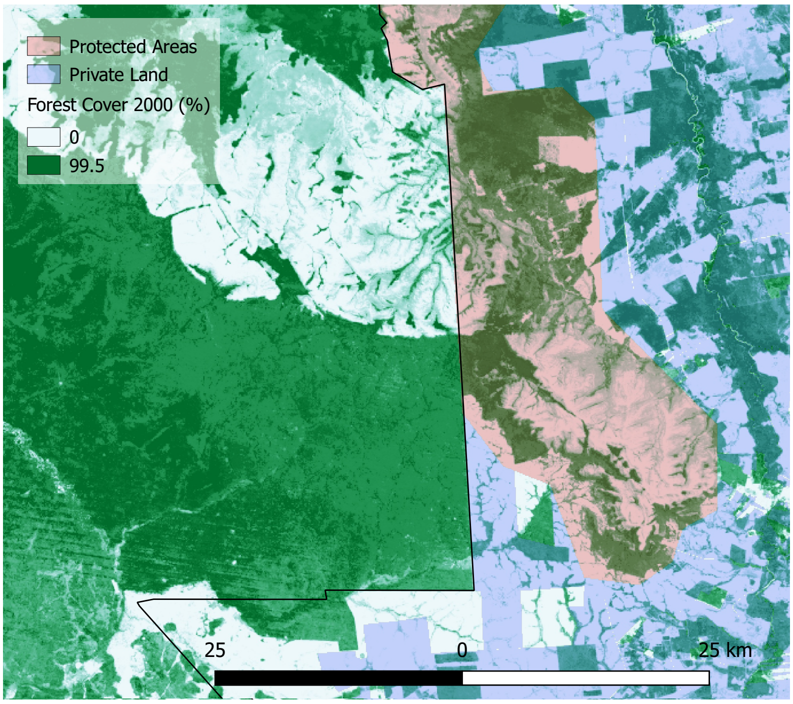
[24] An alternative data source commonly used to capture deforestation in the Brazilian Amazon is PRODES, produced by the Brazilian National Institute for Space Research (INPE). However, PRODES main focus is land use within Brazil and does not include comparable data from other countries. Hansen et al. (2013) and PRODES display similar deforestation trends during the earlier period of our analysis (Richards et al., 2017). Furthermore, Milodowski et al. (2017) utilize 5-meter optical imagery to assess the accuracy of these two sources and find that the Hansen et al. (2013) data more precisely detects forest loss in the Brazilian Amazon compared to PRODES.

[25] MapBiomas Amazonia Project - Collection 3 of annual land cover and land use maps, accessed via Google Earth Engine.

[26] UNEP-WCMC and IUCN (2022), Protected Planet: The World Database on Protected Areas (WDPA) and World Database on Other Effective Area-based Conservation Measures (WD-OECM) [On-line], July 2022, Cambridge, UK: UNEP-WCMC and IUCN. Available at: www.protectedplanet.net.



(a) Overview



(b) Example of area of border with Bolivia

Figure 2: Satellite Image of a Border Segment (Percentage of Forest Cover in 2000)

This figure shows the percentage of forest cover in 2000 by 120-meter pixels, using data from Hansen et al. (2013). Panel **(a)** shows the Amazon, and Panel **(b)** shows a segment of the border between Brazil and the Southern border with Bolivia (marked with a red square in the top panel). The black solid line is the Brazilian border, with Brazil on the right (eastern) side of the map. Forest cover is in shades of green (white are deforested pixels). Red shades mark Protected Areas as of 2004. Blue shades mark private non-protected land.

Table 2: Summary Statistics – Forest Loss

	Bandwidth 27km		Bandwidth 100km		Whole Amazon	
	Brazil	Abroad	Brazil	Abroad	Brazil	Abroad
	(1)	(2)	(3)	(4)	(5)	(6)
Forest cover in 2000 (%)	83.25	89.39	84.29	90.37	82.77	87.91
Forest loss 2001-2005 (%)	.382	.069	.368	.057	.509	.122
Forest loss 2006-2013 (%)	.169	.100	.178	.086	.274	.155
Forest loss 2014-2020 (%)	.277	.155	.308	.152	.454	.232

This table shows the summary statistics of forest cover and annual deforestation by period. Each column present results for a different bandwidth in *Brazil* and *Abroad* (bordering countries). Table A3 shows the summary statistics by year.

Figure 2 shows an example of the data, depicting forest cover as of 2000. Panel (a) presents the entire Amazon region, with the Brazilian international border highlighted in black. Panel (b) zooms in on a specific border segment characterized by predominantly straight lines. Notably, the figure clearly exhibits significantly higher deforestation on the Brazilian (right-hand) side of the border, visible both in the inset and at various locations along the border in panel (a).

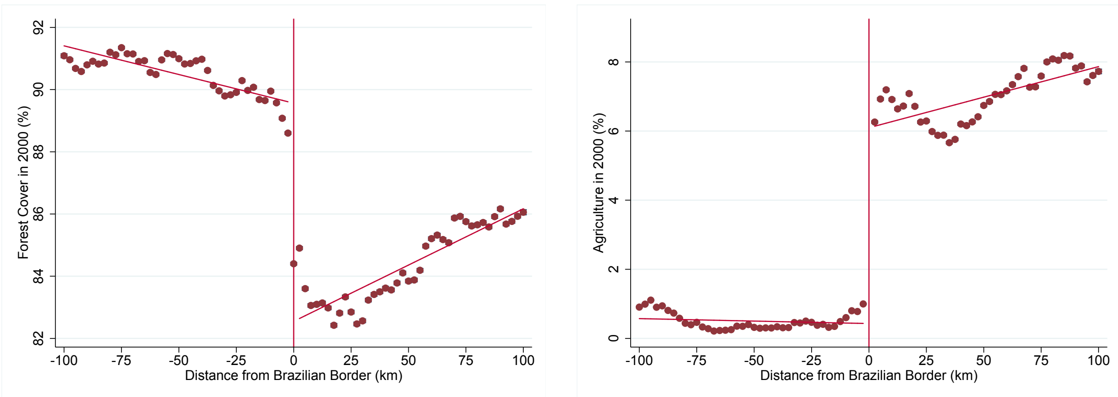
Table 2 presents summary statistics for forest cover and land use at different bandwidths surrounding the border. We see that while the forest cover in 2000 within the entire Brazilian Amazon region is similar to that in areas nearest to the border (82.8% and 83.3% respectively), the annual deforestation rates are lower in the border-proximate areas compared to the overall deforestation rate. This observation aligns with the notion that the "Arc of Deforestation" is closer to the country's interior rather than the border regions. Similar differences in deforestation patterns are also evident in the areas near the border within the non-Brazilian Amazon. Additionally, we observe a distinct disparity in the share of land utilized for agriculture between the Brazilian border areas and the other countries. Appendix Table A4 provides summary statistics for the land characteristics of pixels located within 27 kilometers from the borders, both inside and outside Brazil.

5 Results

5.1 Forest cover and land use as of 2000

We begin by examining the level of forest cover in 2000, the first year of our data. Figure 3a shows the average percentage of forest cover in 2000, calculated across eighty equal-sized distance bins from the Brazilian border, extending up to one hundred kilometers on each side. A clear visual discontinuity in deforestation becomes evident: forest cover drops sharply at the national border. Our regression estimates, using equation (4), reveal that forest cover in the Brazilian Amazon was 4 percentage points lower in 2000 compared to its neighboring countries (27km bandwidth; cluster-robust p-value equal to 0.002; see Table 3 column 1). Considering that 89.4 percent of the land outside Brazil was covered in forests in 2000, this implies that deforestation prior to 2000 was approximately 38 percent higher just within the Brazilian border relative to the other side.

This sharp difference in forest cover corresponds to a distinct discontinuity in the presence of agriculture. Figure 3b shows the percentage of agricultural land in 2000 by distances from the Brazilian border. According to our preferred specification, agricultural land in the Brazilian Amazon was 4.8 percentage points higher than in the non-Brazilian Amazon just across the border.



(a) Forest Cover in 2000

(b) Agriculture in 2000

Figure 3: Forest cover and Land Use in 2000 by Distance from Brazilian Border

This figure plots the average forest cover **(a)** and share of agriculture land (i.e., cropland and pastureland) **(b)** in 2000 by 80 equal-sized bins of distance from the Brazilian border, up to 100km away. Positive distances are on the Brazilian side, while negative distances are on the non-Brazilian side. The red line is a linear function of distance weighted by the number of observations in each bin. These figures show the abrupt drop in forest cover **(a)** and increase in agriculture **(b)** at the Brazilian border.

5.2 Annual forest loss 2001–2020

Next, we present the annual deforestation rates on both sides of the border from 2001 to 2020, as depicted in Figure 4. For clarity, we divide our study period into three intervals that correspond to different policy environments discussed in Section 3.1: Figure 4a shows annual deforestation rate between 2001 and 2005, Figure 4b covers the years 2006 to 2013, and Figure 4c the years 2014 to 2020.

In line with the lower forest cover observed in the 2000 cross-section at the border, Figure 4a shows much higher deforestation rates on the Brazilian side of the border from 2001 to 2005. Our regression discontinuity estimates indicate that during this period, the annual deforestation rates were approximately 0.2 percentage points higher on the Brazilian side of the border (27km bandwidth; cluster-robust p-value smaller than 0.001;

see Table 3 column 1). Given that the annual deforestation rate in other Amazonian countries along the border was around 0.07 percent during this period, our estimates imply that deforestation rates in Brazil were more than three times higher than on the other side of the border. Figure 4d shows that this difference stems from a disproportionately higher conversion of forest into agricultural land in Brazil.

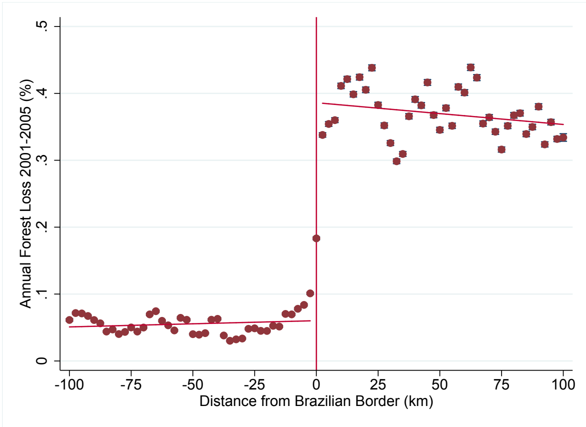
Table 3: Results Forest Loss by Period

	Maximum Distance from the Border			
	27 km	11 km	50 km	100 km
	(1)	(2)	(3)	(4)
Forest cover	-4.006***	-2.218**	-4.890***	-5.430***
in 2000 (%)	(1.304)	(.977)	(1.152)	(.965)
Annual forest loss	.221***	.159***	.269***	.281***
in 2001–2005 (%)	(.040)	(.039)	(.035)	(.029)
Annual forest loss	.023	-.011	.040**	.048***
in 2006–2013 (%)	(.021)	(.023)	(.018)	(.015)
Annual forest loss	.102***	.061**	.093***	.100***
in 2014–2020 (%)	(.030)	(.029)	(.026)	(.021)
# Observations	31,711,264	13,935,516	56,024,296	105,283,103
# Clusters	5,491	2,979	8,961	15,965

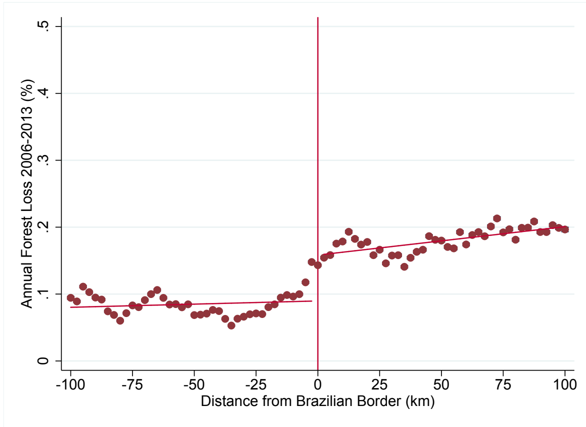
This table shows the OLS regression estimates of the Brazilian effect, γ, on the percentage of forest cover in 2000 (row 1) and annual forest loss (remaining rows), from equation (4) with linear polynomials and triangular kernel. All regressions control for the slope of the terrain and distance to water. Each column shows results for a different bandwidth, as indicated. Column 1 uses the average optimal bandwidth (Imbens and Kalyanaraman, 2012) of our dependent variables, and column 2 uses the optimal bandwidth (Calonico et al., 2014). Units of observations are 120-meter pixels around the whole Brazilian Amazon border. Standard errors two-way clustered at overlapping 100km^2 grids in parentheses. Significance levels: *10%, **5%, ***1%.

Between 2006 and 2013, as shown in Figure 4b, deforestation activity unfolds similarly on both sides of the Brazilian border. Notably, the change during this period arises from reduced deforestation in Brazil rather than increased deforestation on the other side of the border.[27] The point estimates indicate no statistically significant difference in deforestation within 27km of the border (27km bandwidth; point estimate 0.02; cluster-robust p-value equal to 0.28; see Table 3 column 1). Columns 3 and 4 suggest that deforestation was still higher on the Brazilian side, but the deforestation gap at the border was six times smaller between 2006 and 2013 compared to the previous period.

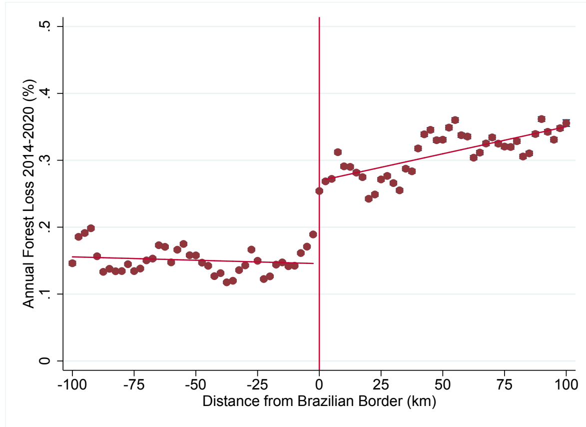
[27]The magnitude of this decrease in deforestation at the Brazilian border is comparable to estimates for the entire Brazilian Amazon. Nepstad et al. (2014) calculate a 70% decrease in deforestation between 2005 and 2013 based on PRODES data. Our data for the same period reveals a 65.3% decrease in the Brazilian Amazon and a 74.7% decrease in areas within 27km of the border (see Table A3).



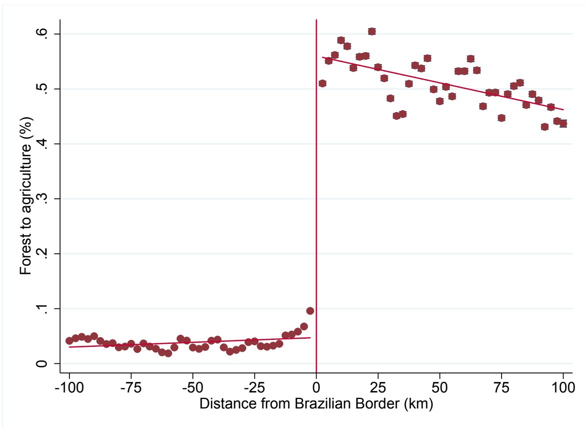
(a) Annual Forest Loss 2001–2005



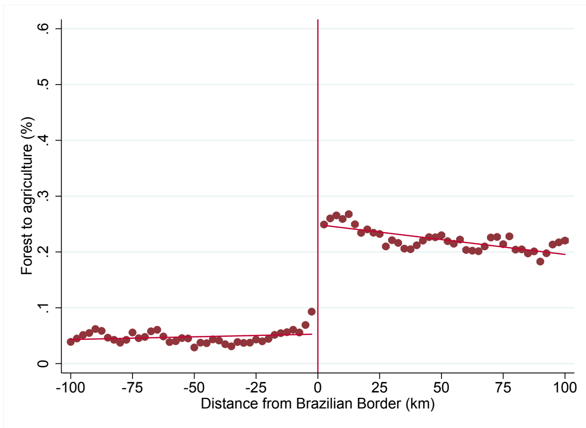
(b) Annual Forest Loss 2006–2013



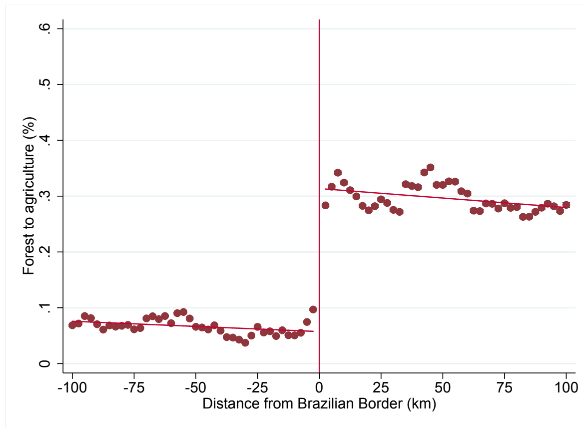
(c) Annual Forest Loss 2014–2020



(d) Forest to Agriculture 2001–2005



(e) Forest to Agriculture 2006–2013



(f) Forest to Agriculture 2014–2020

Figure 4: Land Use and Annual Forest Loss by Distance from Brazilian Border

his figure compares the average annual forest loss **(a-c)** and share of forest converted to agriculture land **(d-f)** in each period between 2001 and 2020 by 80 equal-sized bins of distance from the Brazilian border, up to 100km away. Positive distances are on the Brazilian side, while negative distances are on the non-Brazilian side. The red line is a linear function of distance weighted by the number of observations in each bin. The figure shows that the higher annual deforestation rates on the Brazilian side of the border between 2001 and 2005 **(a, d)** disappear between 2006 and 2013 **(b, e)**, but reappear between 2014 and 2020 **(c, f)**. Figures A2 shows year-by-year RD graphs.

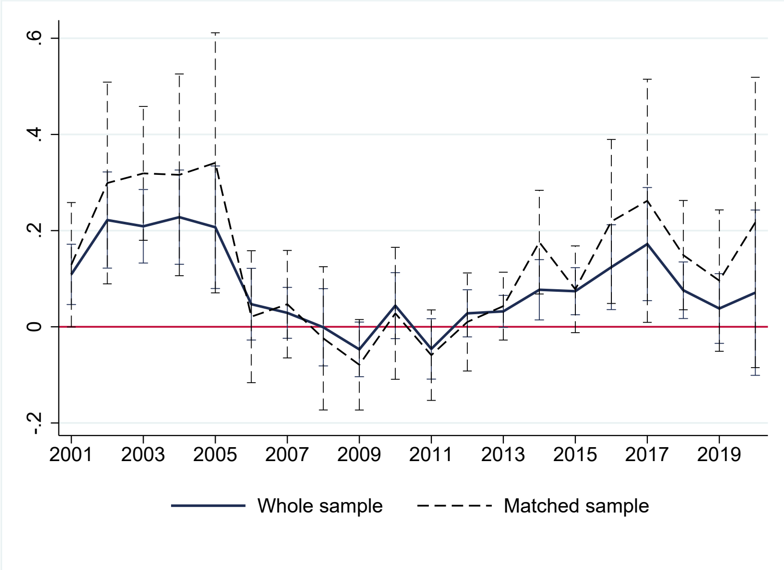
Similarly, Figure 4e shows that the gap in forest conversion to agriculture diminished by over 70 percent during this period.

We then observe a second reversal, with substantially increased deforestation rates from 2014 to 2020. Although the level of deforestation rises somewhat on both sides of the border, Figure 4c shows a significantly greater increase on the Brazilian side. Our estimates indicate that the annual deforestation rates were 0.1 percentage points higher on the Brazilian side of the border (27km bandwidth; cluster-robust p-value smaller than 0.001; see Table 3 column 1). This implies that deforestation rates in Brazil during this period were 64 percent higher than on the other side of the border, where the deforestation rate exceeded 0.15 percent. Once again, the intensified deforestation aligns with a higher conversion of forest cover into agricultural land (Figure 4f).

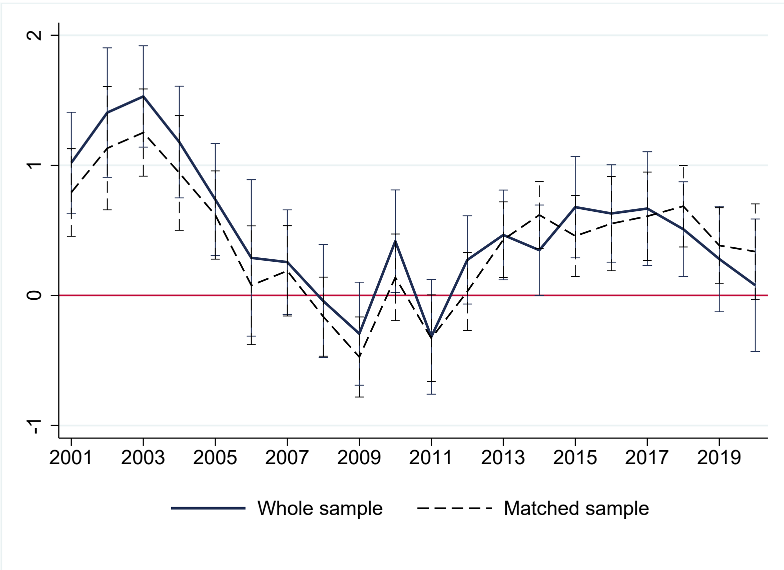
To analyze the year-by-year patterns, we estimate regression discontinuity (RD) models individually for each year. Figure 5a plots the RD coefficient – γ in equation (4) – for each year along with 95 percent confidence intervals, using OLS regressions and a 27km bandwidth. Each point in Figure 5a represents the RD estimate derived from γ in equation (4) for a specific year. We estimate annual deforestation rates to be approximately 0.2 percentage points higher per year on the Brazilian side of the border until 2005. However, this trend abruptly halts in 2006 as Brazil commences the implementation of its anti-deforestation policies. Notably, between 2006 and 2013, deforestation activity is statistically similar on both sides of the Brazilian border. Figure 5a then shows an increase in the deforestation rate on the Brazilian side of the border starting in 2014. On average, the magnitudes of the Brazil effect during the 2014-2020 period are approximately half of those observed during the 2001-2005 period.

Do these three periods match changes in the Brazilian policy environment? We identify three distinct policy regimes based on the border effects: a high deforestation regime until 2005, a low deforestation regime from 2006 to 2013, and a higher deforestation regime thereafter. As described in Section 3.1, the sharp decline in deforestation at the border in the mid-2000s aligns with a period of strengthened environmental policy in Brazil. In November 2004, the Federal government released the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm) and gradually implemented its actions. A significant milestone was the full operationalization of the satellite-based deforestation detection system (DETER) in 2006, which became a key tool for targeting law enforcement activities in the Brazilian Amazon (MMA, 2008). Consistent with this, Figure 5a shows that deforestation on the Brazilian side of the border collapsed in 2006, eliminating the discontinuity at the border.

A substantial body of literature has extensively documented the impacts of specific policies introduced during this period by leveraging variation within Brazil to identify



(a) OLS model



(b) Poisson model

Figure 5: Regression Discontinuity Coefficients by Year

This figure plots the regression discontinuity coefficients of the Brazilian effect, γ, on the annual forest loss rate by year. The coefficients are from equation (4) with 27km bandwidth, linear polynomials, triangular kernel, and controls for the slope of the terrain and distance to water. That is, each point corresponds to the discontinuity in the annual RD graph shown in Appendix Figure A2. The bandwidth is the average optimal bandwidth (Imbens and Kalyanaraman, 2012) of our dependent variables. Solid lines use the whole border area, dashed lines use the matched subsample for heterogeneity analysis. The vertical bars are 95 percent confidence intervals. Panel **(a)** uses an OLS model, and Panel **(b)** uses a Poisson model. The coefficients measure the relative increase in annual deforestation rate on the Brazilian side of the border. The units of observation are 120-meter pixels around the Brazilian Amazon border; number of observations 31,711,264. Standard errors are two-way clustered at overlapping 100km^2 grids in parentheses; number of clusters 5,491.

their effects. Assunção et al. (2023) and Ferreira (2021) demonstrate the crucial role of the DETER system in combating illegal deforestation. Many studies demonstrate that targeted policies, such as the creation of protected areas[28] and enforcement efforts in priority municipalities[29] contributed to deforestation reduction. Similar findings hold for policies targeting private rural properties, such as environmental registration (Alix-Garcia et al., 2018) and restrictions on rural credit access (Assunção et al., 2019). We summarize this literature in Table A5.

However, each of these policies addresses a specific aspect of the problem. Combining the existing estimates alone cannot determine the overall impact of Brazilian efforts to reduce deforestation. Likewise, while previous studies have documented the overall decline in deforestation in Brazil over time[30] this trend may conflate policy-induced changes with other global demand-driven factors affecting agricultural products. Our paper takes a new approach to fill this gap: estimating the total "Brazil" effect at the border. By focusing on border areas and comparing the Brazilian Amazon with nearby forests in other countries unaffected by Brazilian policy enforcement, we can identify the differential land exploitation imposed by Brazilian policies relative to its neighbors. Our results demonstrate the significant role of Brazilian policy in reducing deforestation rates even in remote parts of the country.

Similarly, the second reversal we document – the increase in deforestation in Brazil starting around 2014 – is associated with the gradual dismantling of the environmental agenda in the country. As discussed in Section 3.1, Brazilian environmental governance was undermined due to the increasing political influence of the agriculture sector, successive weak governments, and limited public resources (see also Appendix C.1).[31] The year 2014 marked a particularly turbulent period in Brazil, characterized by massive civil unrest in 2013, elections at the end of the year, major corruption scandals, and a growing economic recession, all of which weakened the environmental agenda. Consequently, by 2016, the budget of the Brazilian Environmental Agency (IBAMA) was less than half of its budget in 2013.

The enforcement capacity of the Environmental Agency continued to deteriorate as subsequent governments implemented measures that rolled back elements of the regulatory framework established under the PPCDAm. While we are not aware of specific papers linking the recent upward trends in deforestation in Brazil to the gradual weakening of Brazilian policies, our estimates based on border discontinuities indicate that this relaxation undid approximately half of the gains achieved during the 2006-2013 period.

[28]E.g., Soares-Filho et al. (2010); Nolte et al. (2013); Harding et al. (2021).
[29]E.g., Arima et al. (2014); Assunção and Rocha (2019); Cisneros et al. (2015); Assunção et al. (2022).
[30]E.g., Nepstad et al. (2009); Hargrave and Kis-Katos (2013); Assunção et al. (2015).
[31]See, e.g., Crouzeilles et al. (2017); Rochedo et al. (2018); Freitas et al. (2018); Soterroni et al. (2018).

Table 4: Robustness – Forest Loss by Period

	OLS Model							Poisson Model	
	(1)	(2)	(3)	(4)	(5)	(6)		(7)	(8)
Forest cover	-3.449***	-4.093***	-2.043*	-9.265***	-4.105***	-9.761**		-.125**	-.048***
in 2000 (%)	(1.228)	(1.085)	(1.058)	(1.734)	(1.335)	(4.257)		(.057)	(.016)
Annual forest loss	.196***	.211***	.147***	.489***	.225***	.346***		1.622***	1.109***
in 2001–2005 (%)	(.040)	(.042)	(.041)	(.060)	(.041)	(.117)		(.326)	(.187)
Annual forest loss	.012	.012	-.014	.068**	.025	-.026		-.233	.126
in 2006–2013 (%)	(.021)	(.023)	(.024)	(.033)	(.021)	(.081)		(.420)	(.151)
Annual forest loss	.091***	.102***	.060**	.209***	.105***	-.100		-.234	.435***
in 2014–2020 (%)	(.029)	(.031)	(.030)	(.043)	(.030)	(.148)		(.370)	(.134)
# Observations	31,711,264	29,298,310	31,711,264	31,711,264	31,711,264	31,711,264		31,711,264	31,711,264
# Clusters	5,491	5,088		5,491	5,491	5,491	5,491	5,491	5,491
Polinomial	Linear	Linear	Quadratic	Linear	Linear	Linear		Linear	Linear
Kernel	Triangular	Triangular	Triangular	Triangular	Uniform	Uniform		Uniform	Uniform
Excl. Mount Roraima	No	Yes	No	No	No	No		No	No
Geographic Controls	No	Yes	Yes	Yes	Yes	Yes		Yes	Yes
Infrastructure Controls	No	No	No	Yes	No	No		No	No
Artificial Border Only	No	No	No	No	No	Yes		Yes	No

This table shows the robustness estimates of the Brazilian effect, γ, on the percentage of forest cover in 2000 (row 1) and annual forest loss (remaining rows), from equation (4). Bandwidth 27km. All regressions, except column 1, control for the slope of the terrain and distance to water. Column 2 excludes a 220km-buffer around the peak of Mount Roraima. Column 3 uses quadratic polynomials of distance to the border; other columns use linear polynomials. Column 4 adds controls for the distance from roads and distance from urban areas. Columns 5 and 8 uses a subset of areas around artificial borders (i.e., straight line borders). Column 6 to 8 use an uniform kernel, remaining columns use triangular kernel. Columns 7 and 8 use a Poisson model instead of OLS. Units of observations are 120-meter pixels around the whole Brazilian Amazon border. Standard errors two-way clustered at overlapping 100km^2 grids in parentheses. Significance levels: *10%, **5%, ***1%.

5.3 Robustness and Alternative Explanations

The empirical results presented above are robust across various alternative specifications and samples. Table 3 column 1 displays the estimates of our baseline regression discontinuity (RD) specifications using ordinary least squares (OLS), controlling for slope and distance to water, utilizing linear polynomials, and estimating the entire Brazilian border sample. As in Figure 4, we group the years into three periods: 2001-2005, 2006-2013, and 2014-2020. The subsequent columns in Table 3 confirm the robustness of our findings when using 11,[32] 50 and 100km bandwidths. Additionally, Table 4 shows that the results are qualitatively similar if we: a) exclude the slope and distance to water controls; b) remove a 220km buffer around the peak of Mount Roraima[33]; c) employ quadratic polynomials; d) incorporate additional infrastructure controls (measured as distance to roads and distance to urban areas); e) utilize a uniform kernel; f) estimate using Poisson models. Year-by-year estimates using the Poisson model are depicted in Figure 5b.

We also estimate results restricting the sample to areas surrounding artificial borders, as done in Alesina et al. (2011). These artificial borders, arbitrarily drawn by former colonizers and appearing as straight lines on a map, devoid of any significant geographic features or even fences. We illustrate these border segments in Figure A3b and discuss the border formation in Appendix C.3. While these areas constitute only 10 percent of our sample, resulting in larger standard errors, we find even more pronounced effects during the period of deforestation slowdown (Table 4 columns 6 and 7). We do not observe a statistically significant increase in deforestation post-2014 in this subsample.

Considering alternative explanations, one potential factor accounting for the abrupt change observed in 2006 is a differential shift in output prices. Hargrave and Kis-Katos (2013) and Assunção et al. (2015) argue that commodity prices cannot account for the observed deforestation rate change. Nonetheless, we obtained national domestic farmgate prices for soybeans, the primary cash crop in these regions, from the FAO for both Brazil and Bolivia (the neighboring country closest to the Brazilian agricultural frontier). Figure A4 shows that farmgate prices in both countries moved in parallel until 2011, with no differential break around 2006.

Heterogeneity by bordering country Our identification strategy relies on the border discontinuity to capture the net policy difference at the border. As Appendix Figure A2 shows, most of the effects we document come from decreased, and subsequently increased, deforestation on the Brazilian side of the border, rather than changes in what is going on in the country on the other side of the border. However, our estimates could also

[32]The average Calonico et al. (2014)'s optimal bandwidth across all outcome variables.

[33]This is a small section of the northern border with Venezuela characterized by a mountain ridge and the only part of the border with variations in slope.

reflect changes in the environmental policies in other countries in the Amazon region, as discussed in 3.2. Tables A1 and A2 show that we do not identify changes in environmental regulation and enforcement in neighboring countries comparable to the changes we observe in Brazil in this period.

We investigate whether the effects we see vary across different country border segments by estimating equation (4) separately for each country. Table A7 presents the results. Our estimated effects are almost identical when comparing the Brazilian border with Bolivia, where the so-called "Arc of Deforestation" (i.e., areas in Brazil closer to the agriculture frontier and therefore under greater deforestation pressure) intersects the international border. We also observe a pattern of double reversal, although smaller in magnitude and not statistically significant, in the border segment with Peru, the second closest country border to the "Arc of Deforestation".

We find no statistically meaningful differential deforestation in the whole period for the more remote areas bordering Colombia and Venezuela. Our estimates suggest higher deforestation in Brazil along the Northern border with Guyana, Suriname and French Guiana during 2001-2005 (p-value equal to 0.054). We find that this difference gets smaller over time. However, there is very little deforestation on either side of the border in these very remote locations. For example, while the deforestation rate in Brazil in 2001 near the Bolivian border is 1.14 percent per year, it ranges between only 0.02 and 0.05 percent per year on all other country borders.

5.4 Heterogeneity in enforcement regimes

We examine heterogeneity in effects based on the land characteristics to investigate what factors contribute to the state's ability to conserve its natural resources. In particular, does this effective reach result from *de jure* zoning regulations or their enforcement? Are policies effective even in areas with higher potential for exploitation? To address these questions, we use a matched sample based on land characteristics. By conditioning on pixel-level observables, we can attribute the difference in deforestation across the border to differences in conservation policy.

Matched sample. We begin by conducting pairwise matching to obtain balanced samples on both sides of the border, controlling for observables (see Section 4.1). We use this matched sample of pixels within 27km from the border to re-estimate equation (4) separately for each category of interest in the heterogeneity analysis. Table 5 presents descriptive statistics of the matched sample. Most characteristics of the matched sample exhibit balance, except distance to the international border. In this matched sample, pixels in Brazil tend to be marginally further away from the border (mean difference about 600 meters, p-value 0.037), though distance to the border is still controlled for using the RD polynomial. Figure 5 demonstrates that the estimates obtained from the regression discontinuity models using the matched sample align remarkably well with the estimates from the entire sample when employing OLS or Poisson estimation.

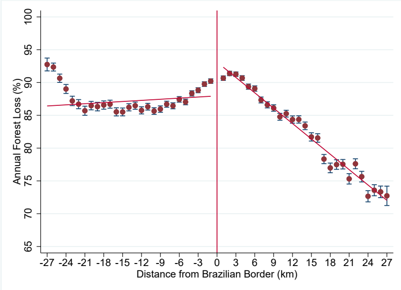
Table 5: Matching Sample Balance Test

	Before matching				After matching			
	Brazil	Abroad	Diff.	p-value	Brazil	Abroad	Diff.	p-value
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
# Observations	3,962,784	3,964,614			1,504,139	1,504,139		
Dist. to border	.116	.116	0	.967	.106	.100	.006	.037
Latitude	-3.633	-3.477	-.156	.505	-6.209	-6.171	-.037	.914
Longitude	-64.490	-64.764	.274	.169	-64.592	-64.795	.204	.411
Land slope	89.800	89.761	.039	.329	89.641	89.597	.043	.589
Dist. to water	.397	.415	-.018	.088	.305	.313	-.008	.527
Dist. to urban	.809	.837	-.028	.239	.515	.522	-.007	.781
Dist. to roads	.361	.427	-.065	.000	.224	.242	-.017	.179
Protected Areas	.483	.281	.202	.000	.232	.232	0	1

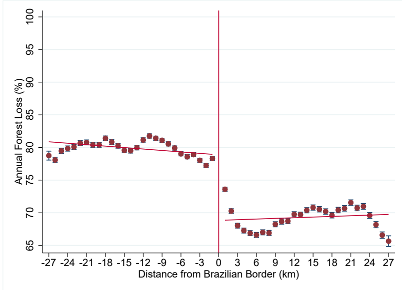
This table shows the summary statistics and mean equality tests for the matched subsample before (columns 1-4) and aftern (columns 5-8) matching. Distances measured in km, and PAs in percent (%) of pixels. p-value computed using standard errors two-way clustered at overlapping 100km^2 grids.

Heterogeneity by protection status. As discussed in Section 3.1, land in the region Amazon can be broadly categorized into two primary zoning types: protected areas (PAs) designated for conservation and other purposes (e.g., national parks and indigenous land) and unprotected areas. Figure 6 displays the average forest cover in 2000 and the average annual forest cover loss during each period categorized by protection status. The left column of the figures represents land use within protected areas (PAs), while the right column depicts land use outside PAs. A comparison between these columns reveals that while deforestation is more pronounced in unprotected areas throughout the region, the disparity is substantially greater on the Brazilian side of the border. This aligns with the notion that PAs possess stronger regulatory and enforcement protection overall.

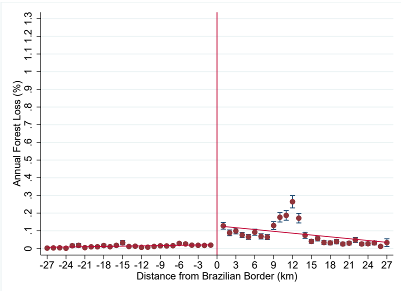
We analyze differential deforestation within PAs at the border and obtain two insights. First, while we see much less deforestation inside PAs and much less of a gap in the deforestation rate at the border when PAs adjoin the national border, we do see that PAs are less effective in Brazil. Table 6 presents the estimated RD coefficient (i.e., γ from equation (4)) obtained from a separate Poisson regression for each land type and period using the matched sample. Column 3 of the table reveals that deforestation rates inside PAs were consistently higher on the Brazilian side of the border throughout the period. Moreover, we observe a similar double reversal following the changes in policy enforcement



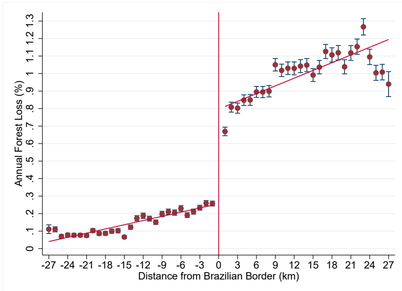
(a) PAs – Forest Cover in 2000



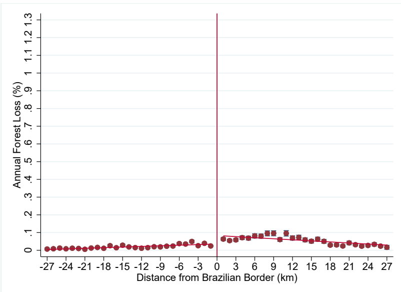
(b) Non-PAs – Forest Cover in 2000



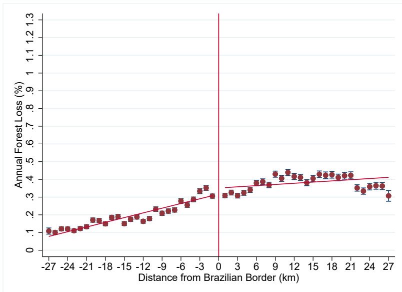
(c) PAs – Forest Loss 2001–2005



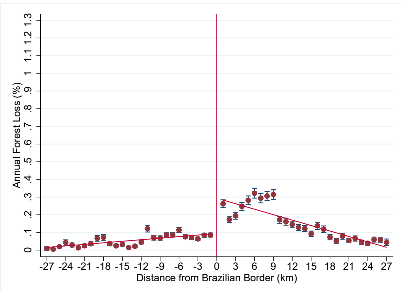
(d) Non-PAs – Forest Loss 2001–2005



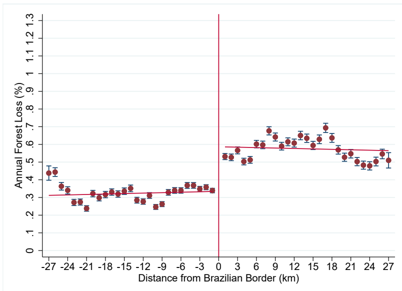
(e) PAs – Forest Loss 2006–2013



(f) Non-PAs – Forest Loss 2006–2013



(g) PAs – Forest Loss 2014–2020



(h) Non-PAs – Forest Loss 2014–2020

Figure 6: Annual Forest Loss by Protection Status – Matched Sample

This figure compares the average forest cover in 2000 **(a-b)** and the average annual forest loss in each period **(c-h)** by protection status and distance from the Brazilian border. The left column shows protected areas (PAs) and the right column shows non-PAs. Each panel plots the forest cover or loss by 1km bins of distance using the *matched sample*. Positive distances are on the Brazilian side, while negative distances are on the non-Brazilian side. The red line is a linear function of distance weighted by the number of observations in each bin.

over time in Brazil. This suggests that despite stronger *de jure* protections afforded to PAs in Brazil during this period, variation in *de facto* enforcement is still evident.

Table 6: Heterogeneous Effects by Protected Status

	Whole sample	Matched sample		
		Whole Area	Protected Areas	Non-Protected Areas
	(1)	(2)	(3)	(4)
Forest cover in 2000 (%)	-.048***	-.080***	.077***	-.137***
	(.016)	(.013)	(.026)	(.015)
Annual forest loss in 2001–2005 (%)	1.109***	.898***	1.938***	.869***
	(.187)	(.163)	(.522)	(.165)
Annual forest loss in 2006–2013 (%)	.126	-.032	.734**	-.069
	(.151)	(.116)	(.317)	(.119)
Annual forest loss in 2014–2020 (%)	.435***	.530***	1.686***	.436***
	(.134)	(.106)	(.387)	(.108)
# Observations	31,711,264	3,008,278	699,118	2,309,160
# Clusters	5,491	4,238	1,916	3,164

This table shows the Poisson regression estimates of the Brazilian effect, γ, on the percentage of forest cover in 2000 (row 1) and annual forest loss (remaining rows), from equation (4) for pixels with different protection status. All regressions use 27km bandwidth, linear polynomials, rectangular kernel, matched pair fixed effects, and control for the slope of the terrain and distance to water. Column 1 reproduces the estimates using the whole sample (as in column 8 Table 4). Columns 2-4 use matched sample. Column 2 shows results for the whole border. Columns 3 and 4 show results for pixels in protected and non-protected areas, respectively. Units of observations are 120-meter pixels. Standard errors two-way clustered at overlapping 100km^2 grids in parentheses. Significance levels: *10%, **5%, ***1%.

That said, Figure 6 shows that most of the differential deforestation at the national border occurs outside PAs. Column 4 of Table 6 demonstrates that when the national border adjoins unprotected areas, deforestation is significantly higher on the Brazilian side of the border between 2001 and 2005.[34] Our estimates reveal that the differential effect of Brazilian policies in unprotected areas diminishes in the subsequent period between 2006 and 2013. The point estimates in column 4 indicate that the deforestation gap at the border disappeared between the periods 2001-2005 and 2006-2013. This reduction of deforestation in non-PAs coincides with the implementation of a series of new de jure regulations and policies under the PPCDAm, including incentives for landowners to comply with land use regulations (e.g., Alix-Garcia et al., 2018; Assunção et al., 2019), and the classification of deforestation on unprotected unclaimed land as a felony. However, as enforcement measures weakened between 2014 and 2020, deforestation rates increased relatively more on the Brazilian side. We estimate that the differential effect of Brazilian

[34]Some degree of deforestation is legally permitted in unprotected private land in Brazil.

policies on deforestation in these areas grew over ten-fold – point estimates jumped from -0.07 to 0.44 – reaching approximately half the gap observed in earlier periods.

In sum, early Brazilian efforts to combat illegal deforestation proved effective in reducing forest loss exactly in those areas with weaker regulation and enforcement. However, as enforcement measures weakened, deforestation escalated in all areas, including those historically afforded higher protection status.

Heterogeneity by market access. We examine whether national policies had heterogeneous effects on pixels that have different potential for exploitation depending on their market access, measured by proximity to villages or urban areas and roads. We estimate RD regressions using the matched sample in non-protected areas for pixels in different terciles of distance from urban areas or roads. We focus on non-protected areas as this is where the bulk of deforestation dynamics happen.

Table 7 shows that the main difference in forest cover in 2000 is in pixels with greater market access – that is, closer to urban areas and to roads. Between 2001-2005, we see differentially higher deforestation in Brazil in all terciles of distance to urban areas, but only in pixels close to roads. Again, we find no differential deforestation rate at the border in pixels further from roads.

Table 7: Heterogeneous Effects by Market Access (Non-Protected Areas)

	Terciles of distance to villages			Terciles of distance to roads		
	1st	2nd	3th	1st	2nd	3th
	(1)	(2)	(3)	(4)	(5)	(6)
Forest cover in 2000 (%)	-.180***	-.166***	-.071***	-.268***	-.126***	-.026**
	(.026)	(.029)	(.016)	(.025)	(.024)	(.012)
Annual forest loss in 2001–2005 (%)	.664***	1.626***	1.298***	.683***	1.898***	-.444
	(.182)	(.257)	(.306)	(.176)	(.239)	(.351)
Annual forest loss in 2006–2013 (%)	-.181	.257	.235	-.154	.703***	-1.247***
	(.142)	(.216)	(.257)	(.12)	(.21)	(.3)
Annual forest loss in 2014–2020 (%)	.381***	.584***	.356	.399***	.688***	-.336
	(.108)	(.207)	(.303)	(.114)	(.183)	(.356)
# Observations	705,326	719,960	771,492	688,724	728,672	779,382
# Clusters	1,137	1,486	1,949	1,263	1,780	2,005

This table shows the Poisson regression estimates of the Brazilian effect, γ, on the percentage of forest cover in 2000 (row 1) and annual forest loss (remaining rows), from equation (4) for pixels outside protected areas with different proximity to villages or urbans areas (columns 1-3) and roads (columns 4-6). All regressions use matched sample, 27km bandwidth, linear polynomials, rectangular kernel, matched pair fixed effects, and control for the slope of the terrain and distance to water. Units of observations are 120-meter pixels. Standard errors two-way clustered at overlapping 100km^2 grids in parentheses. Significance levels: *10%, **5%, ***1%.

When Brazil implements stronger environmental policies in the years 2006-2013, we see that the gap in deforestation rate drops in all terciles of market access. In particular, we find no difference in deforestation rates at the border in pixels in the first tercile of distance to urban areas and roads. While we still see higher deforestation in pixels in the second tercile of distance to roads, the point estimates fall over 60 percent in this period – from 1.89 to 0.70. This suggests that enforcement effort was effective in reducing deforestation in places with greater market access. While the stronger Brazilian policies reduced the deforestation gap even in pixels further from markets, their effectiveness seem to diminish as we move to pixels further from roads and urban areas.

When environmental policy starts to be dismantled after 2014, we see most of the reversal in the deforestation gap happening exactly in pixels closer to markets and enforcement. We find no clear pattern of differential deforestation rates in further away pixels. This suggests that the environmental deregulation and laxed enforcement experienced in Brazil undermined conservation in areas closer to market and with greater potential for exploitation. These were exactly the areas that the environmental policies introduced in the previous decade proved most effective.

6 Counterfactual Exercises

In this section, we quantify the aggregate implications of pro-conservation or pro-exploitation policies over time. We address two important counterfactual questions. First, we examine the extent of deforestation that would have occurred had the Brazilian pro-conservation policies (PPCDAm) not been implemented. Second, we investigate the deforestation that could have been avoided if Brazilian environmental governance had remained robust until 2020. To shed light on these questions, we employ spatial regression discontinuity and conduct counterfactual exercises based on a stylized model of land use.

For each year, we estimate the model specified in equation (3) (see Section 2). This equation closely resembles the primary regression discontinuity equation (4) (see Section 4.1), but is augmented to include other characteristics – latitude, longitude, land slope, distance to water, distance to villages or urban areas, and distance to roads –, which we can use to extrapolate. Similar to the previous section, we limit our sample to pixels within 27km of the international border, allowing for flexible control of distance to the border. The estimated coefficients $\hat{\delta}_t$ capture the differential average environmental regulation cost in Brazil relative to its neighboring countries for each year t. We utilize these estimates to construct our counterfactual scenarios.

Counterfactual 1: weak environmental policy 2006-2020. We examine the deforestation dynamics that would have transpired in the Brazilian Amazon along the border if PPCDAm had never been implemented. Specifically, we project the counterfactual land use from 2006 to 2020 by replacing the average effect of Brazilian policy in each year ($\hat{\delta}_t$) during this period with its average prior to the implementation of PPCDAm ($\Delta = \sum_{t=2001}^{2005} \hat{\delta}_t/5$). We calculate the counterfactual deforestation for each year as

$$\widetilde{\ln l_{it}^*} = \widehat{\ln l_{it}^*} - \hat{\delta}_t + \Delta. \tag{5}$$

In words, for each year t, we compute the counterfactual land use, $\widetilde{\ln l_{it}^*}$, by adjusting the fitted value land use based on equation (3), $\widehat{\ln l_{it}^*}$, discounting the estimated regulatory effect on land use in that year, $\hat{\delta}_t$, and adding the counterfactual regulation, Δ.

Figure 7 presents the results, with the dark solid line representing the observed deforestation at the border and the blue dashed line depicting the counterfactual scenario. Our counterfactual analysis reveals that, had PPCDAm never been implemented, the deforestation rate in the Brazilian Amazon near the border would have been 48% higher than what was observed. The most substantial disparity between the counterfactual and observed forest loss occurs between 2006 and 2013. The counterfactual estimates closely align with the observed values towards the end of the period. This evidence aligns with the gradual dismantling of Brazilian environmental policy in the Amazon.

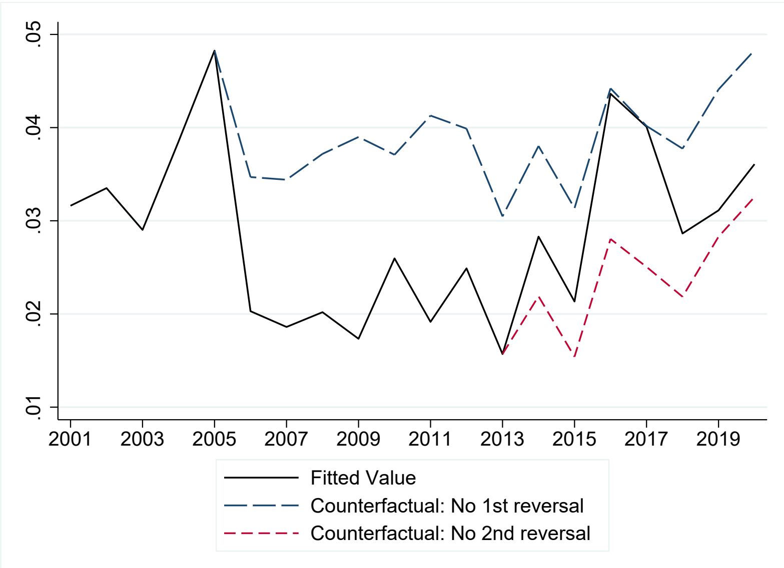


Figure 7: Counterfactual annual forest loss

This figure shows the shows the observed (dark solid line) and two counterfactual annual forest loss in pixels in Brazil within 27km from the international border. The dashed lines show the counterfactual scenarios of no first policy reversal (blue line) and no second policy reversal (red).

Counterfactual 2: strong environmental policy 2006-2020. Next, we examine the counterfactual scenario in which Brazil maintained its aggressive anti-deforestation policies from 2006-2013 through 2020. Specifically, we calculate the counterfactual annual forest loss from 2014 onward, assuming the average environmental regulation between 2006 and 2013 ($\Delta = \sum_{t=2006}^{2013} \hat{\delta}_t/8$) persisted. The red dashed line in Figure 7 represents the resulting scenario. We find that if Brazilian environmental governance had not been weakened after 2013, deforestation rates between 2014 and 2020 would have been 30% lower compared to the observed values. Notably, 2016 and 2017 stand out as years with particularly high avoidable deforestation.

As with any counterfactual analysis, certain caveats should be considered. To quantify the aggregate implications of pro-conservation or pro-exploitation policies over time, we rely on a simple semi-parametric model and detailed land use data for the region. While our regression discontinuity exercise estimates the local average differential effect of Brazilian policies on deforestation, we do not claim to capture the comprehensive effects of these policies throughout the entire Amazon region. Nonetheless, this analysis helps quantify the environmental damage resulting from the deregulation of Brazil's environmental policies over the past decade, at least in the border-proximate areas.

7 Discussion

In this section, we discuss how economic and political factors may have influenced the dynamics of conservation and exploitation in the Brazilian Amazon. We document a sharp decline in deforestation associated with the introduction of new environmental policies that are slowly eroded over time. To help us interpreting the main drivers of policy reversals, we employ an application of the model developed by Harstad (2020).[35]

Setup. We adopt a discrete and infinite time framework. A president P_t determines the fraction of an exhaustible resource (e.g., forests) to exploit, denoted as $s_t \in [\underline{x}, \bar{x}] \subseteq [0, 1]$. The limits to exploitation are set by institutional and enforcement constraints, $\underline{x}$, and by technological and market capacity, $\bar{x}$. In the absence of enforcement capacity, the president has limited power to prevent exploitation. The difference between $\bar{x}$ and $\underline{x}$ represents the extent of discretion the president has to promote conservation or exploitation. In each period, the incumbent is removed from office with probability $p \in (0, 1)$.

Exploitation yields economic benefits $b \geq 0$ for those not in power and produces private benefits $\bar{b} \geq b$ for the incumbent president. The value derived from conservation is heterogeneous across presidents and varies over time. The preferences for conservation, denoted as c_t, are independently and identically distributed (i.i.d.) and uniformly drawn from the interval $[\underline{c}, \bar{c}]$. Let $\delta \in (0, 1)$ be the time discount rate.

The timing goes as follows. In each period, the identity of P_t is revealed and the preferences for conservation c_t is drawn. The incumbent chooses s_t and receives payoff

[35] For detailed proofs and extensions, we refer readers to Harstad (2020).

$s_t\bar{b} + (1 - s_t)c_t$. In period $t+1$, only $1 - s_t$ of the natural resource remains for exploitation by the next president. As the game is stationary, we focus on equilibria in stationary strategies, although alternative equilibria are also considered by Harstad (2020).

The president maximizes their expected utility by solving:

$$\max_{s_t \in [\underline{x}, \bar{x}]} s_t\bar{b} + (1 - s_t)\left(c_t + \delta V\right) \tag{6}$$

where $V = \left(pbx + (1-p)\bar{b}x + (1-x)c_t\right) / \left(1 - \delta(1-x)\right)$ is the continuation value, and $x \equiv E_{c_\tau}\left[s_\tau(c_\tau)\right]$ for $\tau > t$ is the expected exploitation in future periods. In equilibrium, P_t chooses $s_t(c_t)$ as follows:

$$s_t(c_t) = \begin{cases} \underline{x} & \text{if } c_t > \theta(x) \\ [\underline{x}, \bar{x}] & \text{if } c_t = \theta(x) \\ \bar{x} & \text{if } c_t < \theta(x) \end{cases} \tag{7}$$

$$\text{where } \theta(x) \equiv \delta p\left(\bar{b} - b\right)x + (1-\delta)\bar{b} \tag{8}$$

In the stationary equilibrium, $x = \underline{x}\,\Pr(c_t \geq \theta(x)) + \bar{x}\,\Pr(c_t < \theta(x))$. The equilibrium is unique and interior if $\theta(\underline{x}) > \underline{c}$ and $\theta(\bar{x}) < \bar{c}$. In this case,

$$x = \frac{1}{1 - \delta p\left(\bar{b} - b\right)\left(\bar{x} - \underline{x}\right) / \left(\bar{c} - \underline{c}\right)} x_t(0). \tag{9}$$

Drivers of policy reversals. The model demonstrates that a president implements more stringent conservation policies (i.e., $s_t = \underline{x}$) when they derive sufficiently large benefits from preservation (i.e., $c_t > \theta(x)$). So, the election of a new president with stronger environmental concerns can account for a sudden increase in conservation efforts, as observed in the political shifts in Brazil during the early-2000s.

The key equilibrium object determining the level of environmental preferences required for the implementation of a pro-conservation policy is $\theta(x)$. Equations (8) and (9) identify two primary factors that increase $\theta(x)$, making pro-conservation policies less likely in equilibrium and increasing the likelihood of policy rollbacks if they are ever implemented.

First, the threshold for environmental preferences that sustain a pro-conservation policy becomes larger as the president's private benefits from exploitation, $\bar{b}$, increase. For instance, increased lobbying from the agriculture sector can augment these private benefits, prompting the president to pivot toward pro-exploitation policies. [36] Moreover, Harstad and Svensson (2011) show within a dynamic model that stronger penalties imposed by the central government make firms, including agriculture producers, more prone

[36] For a formal discussion of lobbying in this context, please refer to Harstad (2020).

to engage in lobbying. Thus, short-term private economic benefits can prompt governments to discontinue conservation policies.

Second, greater discretion by the government in resource exploitation (i.e., $\bar{x} - \underline{x}$) raises the threshold for pro-conservation policies. When the government lacks enforcement capacity, the gains from adopting pro-conservation policies are small, and importantly, the opportunity costs of foregoing private benefits from exploitation are also low. Over time, technological advancements and improved enforcement capacity enhance the government's control over resource utilization (i.e., reducing $\underline{x}$). Consequently, the opportunity cost of private returns from exploitation increases. In equilibrium, greater government discretion makes the continuation of pro-conservation policies less likely.

Taken together, these two factors make the dismantling of pro-conservation policies more likely and increase the expected level of resource exploitation in the long run. We find strong evidence supporting both mechanisms within our context.

8 Conclusion

Climate change pays no regard to national borders and yet the policies that constrain or exacerbate it fall mainly within national jurisdictions. This means that whether a country exploits or conserves its forests is now an object of international concern. As the value of exploitation accrues mainly to the host country whereas the value of conservation accrues to the whole world, national and international policy objectives may be misaligned. This is amplified by low state capacity, poor enforcement, and states complicit with illegal extraction. Countries, and particularly poor countries, may prefer the immediate economic gains from exploitation to the uncertain, future returns from conservation. This makes it difficult to ascertain whether national conservation policies are effective.

The contribution of this paper is (i) to propose a method for testing whether national policies can, on net, control conservation or exploitation of natural resources and (ii) to apply it to 30x30 meter satellite data along Brazil's 12,800 km international border across the 2000-2020 period. We document sharp discontinuities in forest loss at the border, a diminution in these as Brazil implemented policies to detect and penalize illegal deforestation, but then document a second reversal once Brazilian enforcement slackens. Our results demonstrate the power of the state to determine whether wilderness ecosystems are conserved or exploited. The pattern of diminution *within* Brazil, where post-2005 deforestation rates fall mainly in non-protected areas, but increase amid legal and political uncertainty post-2013, again points to the influence of national policies on conservation.

This finding has implications beyond Brazil. The future path of the earth's climate will, to some significant extent, be determined by whether vast wilderness ecosystems like the Amazon can be kept intact. The fact that Brazil moves from having almost the highest rate of deforestation in 2001 to having the lowest rate less than a decade later is testament to how conservation policy can be turned around. Part of this turnaround was achieved by the Brazilian state coupling better monitoring (through use of satellite data) with more stringent enforcement. The growing rise in deforestation rate experienced by Brazil from 2014 onwards, however, points to how quickly such policies can unravel when political backing for national and international conservation efforts evaporates. Indeed, Brazil moved from congruence to dissonance as regards international efforts to arrest climate change by slowing tropical deforestation. The return of Lula and Silva in 2023 may move policy in a more pro-conservation direction, but this remains to be seen.

The success of wilderness conservation, therefore, ultimately depends on the policy choices of national governments. Information on illegal logging, for example, is available to any government at a 30x30meter resolution – e.g., Hansen et al. (2013) or projects like MapBiomas. Whether governments act on this information is another matter and depends largely on their political willingness. Nevertheless, the remarkable reversal we document in Brazil suggests that it is possible to reduce the gap between *de jure* and *de facto* conservation policy, even in wilderness areas in developing countries. This is an important proof of concept for other countries considering strengthening their conservation efforts.

The transitory nature of the gains in Brazil, however, shows how hard it is to maintain a pro-conservation equilibrium when exploiting natural resources has short term economic gains. More research is needed to understand how to align the incentives of governments intent on promoting growth and development with longer-term conservation objectives.

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Appendix (for online publication only)

This appendix contains the following material:

- Section A presents appendix figures and tables.
- Section C.1 presents a timeline of relevant policy changes in the Brazilian Amazon.
- Section C.2 discusses the main policy changes in the other countries in the Amazon.
- Section C.3 presents more details on the formation of the Brazilian border.
- Section C.4 presents additional evidence on local market integration.
- Section B provides the step-by-step on the implementation of the matching analysis.

A Appendix Figures and Tables

We present the summary statistics by year in Table A3; supporting material mentioned in the paper in Figures A2 to A3 and Table 1; as well as tables summarizing the literature on environmental policies in the Amazon in Tables A5 and A6.

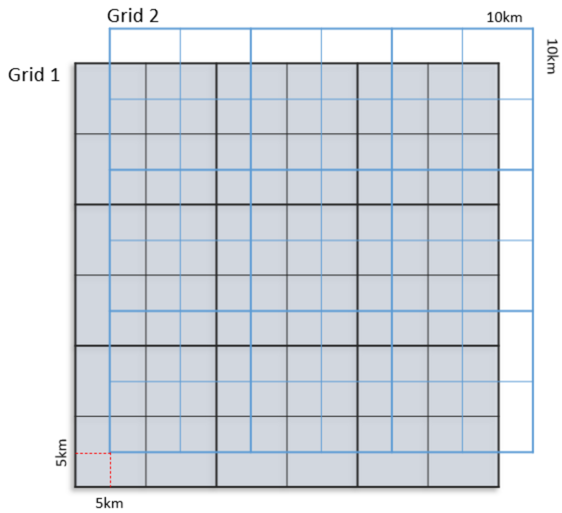


Figure A1: Example Two-Way Cluster Grids

This figure is a graphical representation of the two-way clustering (Cameron et al., 2012) we use. We create two large 100km^2 grids as shown in the figure, where “Grid 2’ (blue) is an offset version of “Grid 1” (shaded). That is, the vertex of Grid 2 starts at the midpoint of Grid 1. If we used a single clustering unit, observations close to each other on either side of a border block would be assumed to be independent despite being spatially close. The second cluster grid solves this problem as these observations are allowed to be spatially correlated in Grid 2.

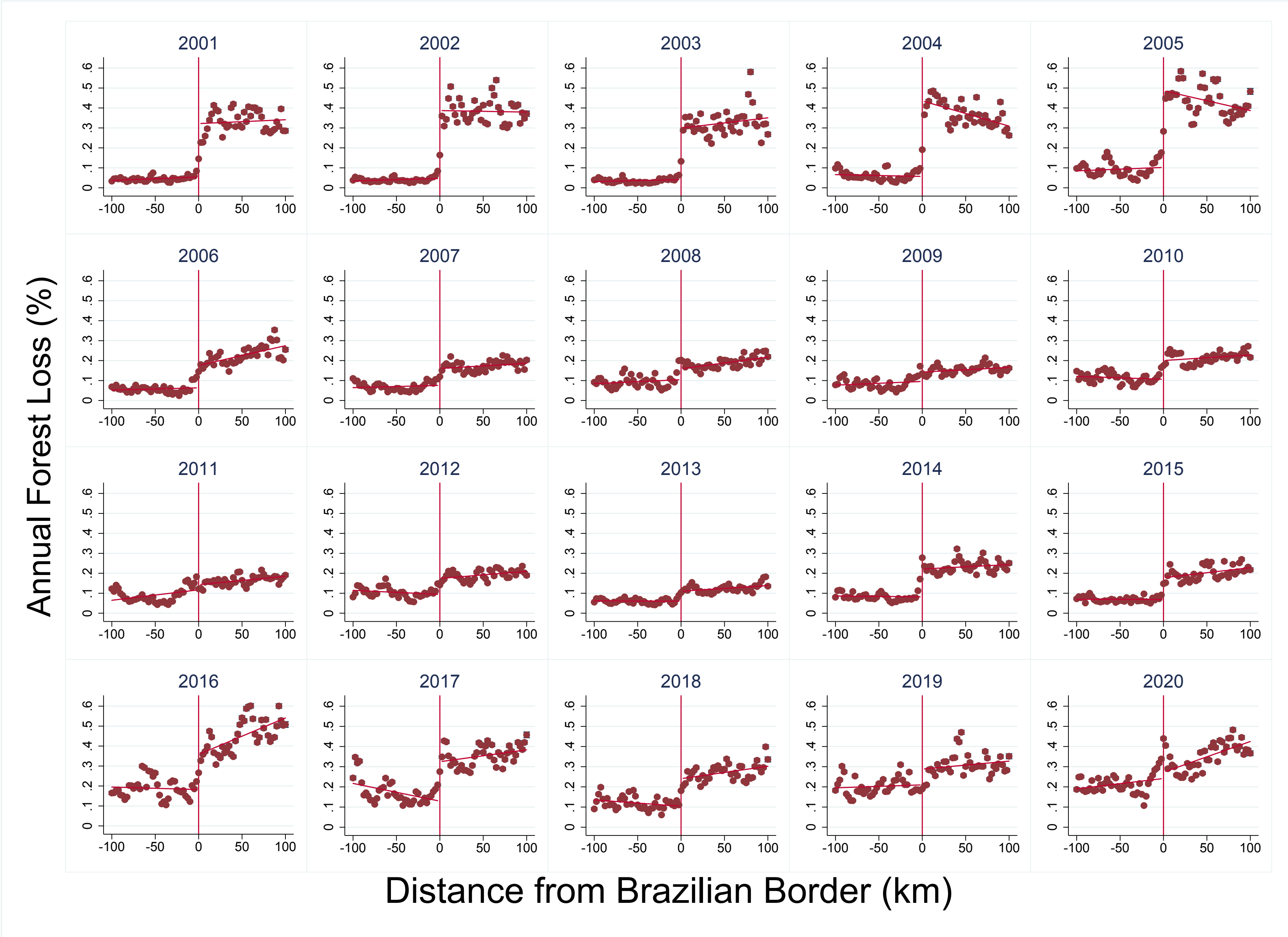
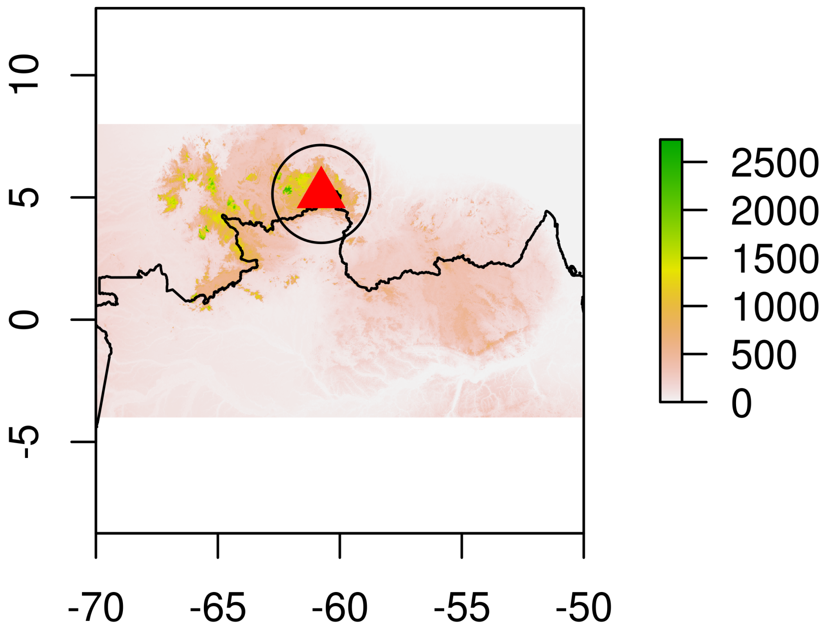
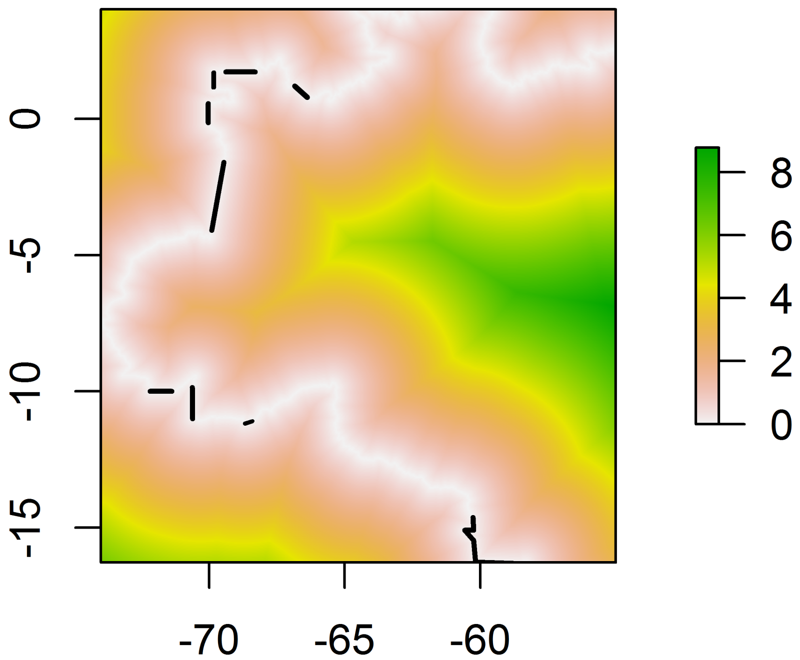


Figure A2: Annual Forest Loss at the Border by Year – 2001-2020

This figure shows the average annual forest cover lost each year between 2001 and 2020 by 80 equal-sized bins of distances from the Brazilian border, up to 100km away from the border. Positive distance represents Brazilian land, while negative distance represents non-Brazilian land. The red lines show the linear function of distance weighted by the number of observations in each bin.



(a) Map of elevation with 220km radius buffer around the peak of Mount Roraima



(b) Map of Distance From Border with Artificial Borders Highlighted

Figure A3: Maps

The map in the upper panel shows the elevation (in shades as in the scale) with a 220km radius buffer around the peak of Mount Roraima in the North segment of Brazilian border with Venezuela and Guyana. The map in the bottom panel shows the distance from border measures in latitude degrees (in shades as in the scale). The area in white is distance zero. The highlighted sections in black are the areas where the border is artificially delimited, i.e., where borders are not set by a natural landmark.

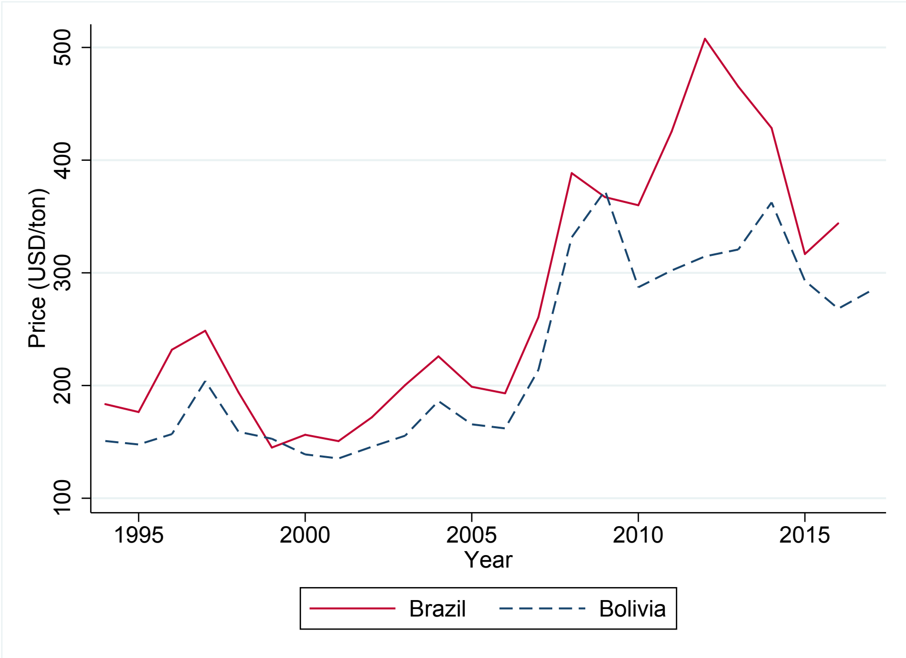


Figure A4: Farmgate Soybean Prices in Brazil and Bolivia

This figure shows average producer prices for soybeans in Brazil and neighboring Bolivia, using data from the FAO.

Table A1: Main Environmental Policies in the Amazon by Country, 2000–2009

Year	Brazil	Bolivia	Peru	Colombia	Other countries
2000	National System for Conservation Units		Forests and Wildlife Law	National Forestry Policy	VEN's Law of Biodiversity
2002	Amazon Protected Area Program		National Strategy for Biological Diversity		
2003			National Strategy on Climate Change		
2004	Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm)		National Forest Strategy for 2002-2021; Alto Purus national park created		
2005	Demarcation of Conservation Units around main roads		General Environment Act		FGU's Regional Forestry Guidelines
2006	Center for Environmental Monitoring and DETER fully operational; Public Forest Management Law; Brazilian Forest Service	Law on Community Redirection of the Agrarian Reform		New General Forestry Law, criticized for weakening timber licensing	SUR's National Forest Policy
2007	Chico Mendes Institute				GUY Forestry Commission; FGU's Parc Amazonien
2008	36 municipalities blacklisted; new law enforcement mechanisms; Norway pledges $1bi to the Amazon Fund; Central Bank conditions assess to rural credit on environmental compliance	National Holistic Forest Management Plan; incentives for Community Forest Organizations to comply with forest management plans	Creation of the Ministry of Environment, the Environmental Agency and the National Service for Government-Protected Natural Areas		GUY joins the World Bank's Forest Carbon Partnership Facility
2009	Land titles of federal public land given to smallholders squatters; 7 municipalities blacklisted		Forests and Wildlife Law; National System of Environmental Assessment and Enforcement	Colombia signs the International Pact for Legal Timber	GUY's Forests Act revised; Norway pledges to GUY up to $250 mi for carbon sequestration; SUR's National Forest Policy

Other countries include Venezuela (VEN), Guyana (GUY), Suriname (SUR), and French Guiana (FGU). See details in Appendix Section C.1.

Table A2: Main Environmental Policies in the Amazon by Country, 2010–2019

Year	**Brazil**	**Bolivia**	**Peru**	**Colombia**	**Other countries**
2010	Macro Ecological Economic Zoning	Rights of Mother Earth Law condemns market mechanisms	Action Plan for Adaptation and Mitigation Against Climate Change	Creation of the National Parks Authority; National Development Plan	
2011	7 municipalities blacklisted		National Environmental Action Plan 2011-2021; New Forests and Wildlife Law	National REDD+ Strategy	GUY National Forest Plan; Protected Areas Law; Protected Areas Commission
2012	New Forest Code grants amnesty for small properties; Environmental Rural Registry; number of IBAMA officers cut by 13.1%	Revision of the Rights of Mother Earth Law; Joint Mitigation and Adaptation Mechanism as an alternative to REDD++	Strategic Pillars of Environmental Management; National Service of Environmental Certification for Sustainable Investments	Colombian Low-Carbon Development Strategy; and National Plan for Climate Change Adaption	
2013	Constitutionality of the New Forest Code contested	Amnesty for pre 2012 illegal deforestation	Law on the mechanisms of PES	Zoning of the Amazon forest reserve	VEN's New Law of Forest; Germany to fund forest protection in GUY; SUR's R-PP approved
2014	IBAMA's budget cut by 34.2%		National greenhouse gas inventory system; National Pact for Legal Wood		
2015	Norway completes $1 billion transfer to the Amazon Fund.	Bolivia pledges at UN to regenerate 4.5mi hectares of forest	Revision of National Strategy on Climate Change	Germany, Norway and the UK pledge $300 mi to reduce deforestation	SUR's National Climate Change Policy, Strategy and Action Plan
2016	IBAMA's budget cut 13.5% from 2014		Action Plan on Gender and Climate Change	Environmental Bubbles	VEN creates Orinoco Mining Arc overlaping PAs
2017	Simplification of the land titling process of occupied public land			Forests for Peace; first national forest monitoring system; PES Act.	GUY's Green State Development Strategy
2018	Supreme Court sanctions the New Forestry Code, including amnesty item		Framework Law on Climate Change	Intergenerational Pact for Life of the Colombian Amazon; Cocoa, Forests, and Peace Initiative	FGU adopts regional forest and timber program
2019	Large number of IBAMA staff sacked; 60-days ban on use of fire in the field	Controlled burning allowed for agricultural purposes	Peru joins the Tropical Forest Alliance	Beef and dairy zero-deforestation agreement signed	

Other countries include Venezuela (VEN), Guyana (GUY), Suriname (SUR), and French Guyane (FGU). See details in Appendix Section C.1.

Table A3: Summary Statistics – Forest Loss by Year

	Bandwidth 27km		Bandwidth 100km		Whole Amazon	
	Brazil	Abroad	Brazil	Abroad	Brazil	Abroad
	(1)	(2)	(3)	(4)	(5)	(6)
Forest cover in 2000 (%)	83.25	89.39	84.29	90.37	82.77	87.91
Forest loss in 2001 (%)	.312	.057	.329	.047	.392	.109
Forest loss in 2002 (%)	.383	.051	.381	.042	.529	.115
Forest loss in 2003 (%)	.310	.049	.322	.037	.505	.096
Forest loss in 2004 (%)	.427	.069	.372	.063	.614	.130
Forest loss in 2005 (%)	.478	.118	.437	.096	.505	.160
Forest loss in 2006 (%)	.199	.069	.223	.059	.382	.109
Forest loss in 2007 (%)	.172	.090	.172	.071	.311	.150
Forest loss in 2008 (%)	.172	.103	.187	.097	.296	.159
Forest loss in 2009 (%)	.146	.109	.153	.088	.208	.152
Forest loss in 2010 (%)	.216	.118	.213	.115	.301	.188
Forest loss in 2011 (%)	.147	.136	.163	.092	.219	.149
Forest loss in 2012 (%)	.184	.105	.191	.105	.296	.186
Forest loss in 2013 (%)	.121	.067	.124	.062	.175	.145
Forest loss in 2014 (%)	.221	.097	.234	.087	.264	.168
Forest loss in 2015 (%)	.184	.076	.201	.071	.267	.134
Forest loss in 2016 (%)	.371	.177	.444	.189	.680	.265
Forest loss in 2017 (%)	.340	.162	.353	.173	.649	.289
Forest loss in 2018 (%)	.245	.113	.275	.123	.388	.227
Forest loss in 2019 (%)	.269	.212	.313	.206	.408	.243
Forest loss in 2020 (%)	.311	.247	.350	.219	.520	.300

This table shows the summary statistics of forest cover and annual deforestation in the Amazon by year. Each column present results for a different bandwidth or segment of the border in *Brazil* and *Abroad* (bordering countries).

Table A4: Summary Statistics – Land Characteristics

	Bandwidth 27km		Bandwidth 100km	
	Brazil	Abroad	Brazil	Abroad
	(1)	(2)	(3)	(4)
# Observations	14,809,321	14,841,401	52,646,804	52,636,853
Protected Areas (%)	48.3	28.1	46.3	26.6
Dist. to water (km)	44.1	46.1	41.3	38.3
Dist. to urban (km)	89.7	92.9	88.6	92.7
Dist. to roads (km)	40.1	47.4	34.6	50.8
Roads within 5km (%)	14.7	14.9	16.9	12.9
Mount Roraima's Buffer (%)	7.3	7.9	5.2	8.1

This table shows the summary statistics of the land characteristics around the border. Each column present results for a different bandwidth in *Brazil* and *Abroad* (bordering countries).

Table A5: Summary of Papers on Environmental Policies and Deforestation in the Amazon (part 1)

Article	Journal	Country	Time	Method	Policy Analyzed & Main Results
Panel A. Protected Areas					
Soares-Filho et al. (2010)	PNAS	Brazil	1997-08	Mean comparison	Expansion of PAs was responsible for 37% of the region's total reduction in deforestation between 2004 and 2006 without provoking leakage.
Ferrato et al. (2013)	EnvResLet	Multiple	Multiple	Matching	Strict protection more effective than less strict protection, but difference not significant for all countries.
Nolte et al. (2013)	PNAS	Brazil	2005-10	Matching	Strict PAs more effective than sustainable use PAs; indigenous lands effective in areas with high deforestation pressure.
Pfaff et al. (2014)	WDev	Brazil	2000-08	Matching	PAs in Acre reduced deforestation by 1-2%.
Anderson et al. (2016)	*manuscript*	Brazil	2002-13	Spatial RDD, DiD	PAs did not lead to lower deforestation in general, but were effective in Priority List municipalities.
Miranda et al. (2016)	WDev	Peru	2000-05	Matching	PAs reduced deforestation by 8% over 5 years; older PAs and mixed-use PAs more effective.
Bonilla-Mejía and Higuera-Mendieta (2019)	WDev	Colombia	2001-16	Spatial RDD	Strict-use PAs effective near human settlements.
Herrera et al. (2019)	PNAS	Brazil	2000-08	Matching	Federal PAs and indigenous lands more effective than state PAs in 'arc'; little impact of PAs outside 'arc'.
Baragwanath and Bayi (2020)	PNAS	Brazil	1982-16	Spatial RDD	Demarcation of indigenous land reduces deforestation.
Panel B. Priority List Municipalities					
Arima et al. (2014)	LandUsePol	Brazil	2009-11	Matching, DiD	Average reduction of deforestation by 82km^2 (DiD) or 25km^2 (Matching) per municipality.
Cisneros et al. (2015)	PLoS ONE	Brazil	2002-12	Matching	13-36% reduction in deforestation between 2008-12.
Assunção and Rocha (2019)	EDE	Brazil	2002-11	DiD	Policy reduced deforestation by 35%.
Assunção et al. (2022)	REStud	Brazil	2006-10	Changes-in-Changes	Policy reduced deforestation by 40%; ex-post optimal list would have created 7.5% stronger reduction.
Koch et al. (2019)	AJAE	Brazil	2004-14	DiD	Policy led to higher agricultural productivity (cattle).

Table A6: Summary of Papers on Environmental Policies and Deforestation in the Amazon (part 2)

Article	Journal	Country	Time	Method	Policy Analyzed & Main Results
Panel C. Other policies					
Hargrave and Kis-Katos (2013)	ERE	Brazil	2002-09	2SLS, Diff GMM	1% increase in fines associated with 0.2% decrease in deforestation.
Assunção et al. (2015)	EDE	Brazil	2002-09	DiD	PPCDAm policies reduced deforestation between 2005 and 2009 by 56%.
Gibbs et al. (2015)	Science	Brazil	2006-13	Descriptive	Following the 2006 Soy Moratorium, soy expansion through deforestation reduced from 30% to 1% by 2013.
BenYishay et al. (2017)	JEEM	Brazil	1982-10	DiD	Formalization of land rights of indigenous communities (under PPTAL) had no effect on deforestation.
Alix-Garcia et al. (2018)	ConsLett	Brazil	2006-13	Time-Staggered DiD	Rural Environmental Registry (CAR) in Pará and Mato Grosso; registered properties experienced 10% lower deforestation.
Probst et al. (2020)	NatSust	Brazil	2011-16	Fixed effects	Small and medium properties increased deforestation in response to land titling.
Assunção et al. (2023)	AEJAp	Brazil	2006-16	2SLS	DETER; reducing monitoring and law enforcement by half increases deforestation by 44%.
Harding et al. (2021)	JEEM	Brazil	2002-13	Triple Difference	Priority List reduced deforestation by 17%; Soy Moratorium led to shift in crops; and conservation zones lead to shift in deforestation location.
Assunção et al. (2019)	EJ	Brazil	2003-11	DiD	Requirements for rural credit concessions reduced deforestation by 60%.

Table A7: Heterogeneous Effects by Country Border

	Border segment with				
	Bolivia	Peru	Colombia	Venezuela	Guyana, Suriname, French Guyane
	(1)	(2)	(3)	(4)	(5)
Forest cover in 2000 (%)	-.272***	-.003	.002	.046*	-.011
	(.040)	(.002)	(.003)	(.024)	(.047)
Annual forest loss in 2001–2005 (%)	1.254***	.485	-.428	.363	.826*
	(.204)	(.444)	(.374)	(.418)	(.429)
Annual forest loss in 2006–2013 (%)	.202	.022	-.511	.253	.366
	(.169)	(.376)	(.352)	(.322)	(.307)
Annual forest loss in 2014–2020 (%)	.664***	.219	-.541	.009	-.191
	(.155)	(.400)	(.328)	(.339)	(.307)
# Observations	7,831,297	5,878,676	5,392,008	5,601,639	6,999,025
# Clusters	1,357	1,030	926	962	1,243

This table shows the Poisson regression estimates of the Brazilian effect, γ, on the percentage of forest cover in 2000 (row 1) and annual forest loss (remaining rows), from equation (4) for different border segments. All regressions use 27km bandwidth, linear polynomials, triangular kernel, and control for the slope of the terrain and distance to water. Units of observations are 120-meter pixels around the whole Brazilian Amazon border. Standard errors two-way clustered at overlapping 100km^2 grids in parentheses. Significance levels: *10%, **5%, ***1%.

B Details on matching analysis

This section provides the step-by-step on the implementation of the matching analysis.

1. We split the border region of pixels up to 27km from the border into 62 blocks of 1×1 latitude degrees.

2. For computational reasons, we take a 25 percent random sample within each block stratified by protection status – that is, we sample within each block-protection status.

3. For each block-protection status, we perform propensity score pairwise matching (without replacement) using as matching variables the absolute distance to the international border, latitude, longitude, land slope, distance to water, distance to urban areas, and distance to roads. We perform this matching using the command *GenMatch* in R.

4. We keep matched pairs that have common support on distance to water, urban areas, and roads by protection status on both sides of the border. We drop pairs that have a within-pair standard deviation of distance to roads greater than 0.2 standard deviations.

5. We ran the regression discontinuity exercise using equation (4) with matched pair fixed effects.

C Additional background information

C.1 Relevant policy changes in the Brazilian Amazon

C.1.1 Main historical events in the Brazilian Amazon

1494 Treaty of Tordesillas, most of the Amazon belongs to the Spanish Crown.

1637 First big Portuguese expedition to the Amazon (two thousand people).

1750 Treaty of Madrid, Portugal gains control of most of the current Brazilian Amazon.

1851-71 The precise limits of Brazilian border with Bolivia and Peru are set.

1870-00 First Rubber Cycle. Government gives incentives to migrate to the region. First big migration influx. Migrants can work as rubber tappers, but cannot own land.

1904 Brazil gains control of Acre state, on the border with Bolivia and Peru.

1909 Last borders defined in Treaty of Rio de Janeiro.

1940-45 Second Rubber Cycle (coincides with WWII). President Getulio Vargas promotes the "March to the West" and advertises the "New Eldorado".

1964-80s Military Dictatorship promotes the occupation of the area.

1976 Regularization of land titling for properties under 60 thousand hectares that were occupied illegally but in "good faith".

1978 Population in the Legal Amazon 7 million people.

1988 Local environmental leader Chico Mendes is murdered.

1989 First direct presidential election after the Military Dictatorship

1990s New large population influx with cattle ranching and soybean plantations expansion.

2000 Population in the Legal Amazon 21 million people.

C.1.2 Timeline of the main environmental policies in the Brazilian Amazon

1981 Establishment of the National Environmental Policy (Law No. 9,308).

1987 Creation of the National System for the Prevention and Control of Forest Fires (PREVFOGO) (Presidential Decree No. 97,635).

1988 Federal constitution establishes environmental rights and the responsibilities of the government regarding environmental protection.

1989 Creation of the Federal Environmental Protection Agency (IBAMA) (Law No. 7,735).

1989 Creation of the National Environmental Fund (Law No. 7,797).

1990 Establishment of an environmental licensing system (Presidential Decree No. 99,274).

1995 The mandate of President Cardoso begins.

1998 Environmental crimes act, defining penalties for environmental offenses (Law No. 9,605).

2000 Establishment of the National System for Conservation Units (SNUC) (Law No. 9,985) and of the National Forest Commission (CONAFLOR) (Presidential Decree No. 3,420).

2002 Creation of the Amazon Protected Area Program (ARPA) to expand the SNUC and guarantee financial resources to promote sustainable development (Federal Decree 4,326).

2002 Creation of Ecological and Economic Zoning, EEZ, (Federal Decree 4297).

2002 Separation of protected areas into two classes: full protection areas and sustainable use areas (weaker restrictions on use) (Decree No. 4,340).

2003 The mandate of President Lula begins, appointing Marina Silva as Minister of the Environment.

2004-2008 First phase of the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm). Provisions include the creation of the center for environmental monitoring (CEMAM) and remote-sensing system DETER.

2005 Demarcation of Conservation Units in the areas surrounding the highways BR-319 (Manaus – Porto Velho) and BR-163 (Tenente Portela – Santarém) (Law No. 11,132).

2006 Law on Public Forest Management enacted (Law No. 11,284). Included creation of the Brazilian Forest Service (SFB) and the National Forest Development Fund (FNDF).

2006 National Plan for Protected Areas (Decree No. 5,758).

2006 CEMAM fully functioning and operational centers receiving online deforestation data.

2007 Institution of the Amazon Development Superintendence (SUDAM) and redrawing of the Legal Brazilian Amazon (Complementary Law No. 124).

2007 Legal basis for the blacklisting of areas with outstanding historical deforestation rates is created (Decree No. 6,321).

2007 Creation of the Chico Mendes Institute, responsible for managing federal conservation units (Law No. 11,516).

2008 First list of 36 blacklisted municipalities is defined (MMA Ordinance 28).

2008 Reestablishment of directives to investigate and punish environmental infractions. Definition of administrative processes for environmental crimes, and introduction of new mechanisms for law enforcement (e.g., seizure of equipment used for illegal activities) (Decree No. 6,514).

2008 Creation of the Sustainable Amazon Plan (PAS) to define guidelines for sustainable development in the region.

2008 Marina Silva resigns as minister five days after releasing PAS, citing "difficulties to advance with the environmental agenda in the federal government." (extract from resignation letter).

2008-2010 "Operation Green Arc", a clampdown on illegal logging, supported by eight Federal Ministries (Agriculture, Agrarian Development, Environment, Cities, National Integration, Labor, Justice, and Health), institutes policies and actions to promote sustainable development in blacklisted municipalities.

2008 Central Bank resolution conditions the concession of rural credit in the Amazon Biome on legal and environmental compliance.

2009 Land titles of federal public land given to squatters with smallholdings (Law No. 11,952).

2009 Seven municipalities added to the list of blacklisted municipalities (MMA Ordinance 102).

2009-2011 Second phase of PPCDAm. Provisions include the creation of an inter-ministerial committee for combating environmental offenses and the Amazon Fund for coordinating international financing of deforestation and sustainability projects.

2010-2015 Second phase of Amazon Protected Area Program (ARPA), with the goal of creating 13.5 million ha of new Protected Areas.

2010 Creation of Macro Ecological Economic Zoning.

2011 The mandate of President Rousseff begins.

2011 Seven municipalities added to the list of blacklisted municipalities (MMA Ordinance 175).

2012 New Forest Code grants amnesty for small properties (440 ha or less) that had deforested the Legal Reserve area in their properties before 2008 and reduces the amount of forest cover that landowners are required to maintain. Also institutes the Environmental Rural Registry (CAR), a mandatory registration for all rural properties (Law No. 12,651).

2012 The number of IBAMA enforcement officers is reduced by 13.1% relative to 2010.

2012-2015 Third phase of PPCDAm.

2013 Prosecutor General of Brazil contests the constitutionality of 23 items of the New Forest Code, among them the amnesty for past deforestation.

2013 Massive social mobilizations all over the country.

2014 IBAMA's budget cut by 34.2% relative to the previous year. The number of IBAMA's enforcement officers falls by 24% relative to 2010.

2016 Impeachment of President Rousseff amid years of severe economic crisis.

2016-2020 Fourth phase of PPCDAm, focused on developing economic and regulatory mechanisms for promoting the forest economy without harming the forest.

2016 IBAMA loses additional 3.5% of enforcement officers and 13.5% of its budget (relative to 2014).

2017 Simplification of the requirement for land regularization and titling of occupied public land in rural and urban areas (Law No. 13,465).

2017 Those guilty of environmental crimes can secure up to a 60% discount on their fines if the remainder is invested into an IBAMA-selected project (Decree 9,179).

2018 The Supreme Court sanctions the New Forestry Code, including the amnesty item.

2019 The mandate of President Bolsonaro begins.

2019 Environmental Minister sacks a large number of IBAMA staff.

2019 Creation of conciliation centers for the investigation of environmental fines (Presidential Decree No. 9,760).

2019 Green Brazil Operation launched to control fires in the Amazon Biome.

C.2 Relevant policy changes in the non-Brazilian Amazon

C.2.1 Bolivia

1996 Forest Law regulates the use of forest resources and implements a system of forest concessions (Law No. 1,700). Also creates the Bolivian Forestry Superintendent to enforce the law.

1996 Law of National Service for Agrarian Reform (Law No. 1,715). Establishes the institutional framework for land administration, promotes land privatization and sets up a system of collective land titles. Declares that the land rights of indigenous communities have precedence over concession-holders' rights.

1997 Forest Superintendency issues 86 new forestry concessions, 27 of which overlap with indigenous territories.

2006 Law on Community Redirection of the Agrarian Reform accelerates land titling, with indigenous communities given preferential treatment (Law No. 3,545).

2008 National Holistic Forest Management Plan. Creates economic and financial incentives for Community Forest Organizations to comply with forest management plans (Supreme Decree No. 29,643).

2010 The Rights of Mother Earth Law declares Mother Earth the titleholder of inherent rights of the land, promoting resource nationalism and countering the commodification of nature (Law No. 071).

2010 The People's Agreement of Cochabamba from the World People's Conference on Climate Change and the Rights of Mother Earth (WPCCC) condemns market mechanisms such as REDD.

2010 Creation of the National Program of Forestation and Reforestation (Supreme Decree No. 0443).

2012 Revision of and creation of legal framework for Law of Rights of Mother Earth (Law No. 300).

2012 Bolivia proposes the Joint Mitigation and Adaptation Mechanism as an alternative to REDD++. Includes the principle of no mercantilism of the environmental functions of the forest.

2013 Immunity from fines granted for illegal deforestation carried out before 2012 (Law No. 337).

2013 The Forest and Land Inspection and Control Authority (ABT) issues Technical Directive 250 outlining the requirement for Forest and Land Holistic Management Plans (PGIBT).

2015 Bolivia makes a UN pledge to increase forested area by 4.5 million hectares by 2030.

2019 Agricultural frontier expanded in the Beni and Santa Cruz regions. Controlled burning is allowed for agricultural purposes (Presidential Decree No. 3,973).

C.2.2 Peru

1997 Organic Law on the Sustainable Use of Natural Resources (Law No. 26821). Aims to promote and regulate the sustainable use of natural, renewable and non-renewable resources.

1997 Law for Natural Protected Areas establishes which activities are permitted in each of the different types of national protected area (Law No. 26,834).

2000 Forests and Wildlife Law sets first regulations for sustainable use of forest and wildlife resources and establishes a system of concessions (Law No. 27,308). Identifies the National Institute of Natural Resources (INRENA) as the body responsible for managing and administering forestry and wildlife resources.

2001 National Strategy for Biological Diversity approved (Presidental Decree No. 102).

2003 National Strategy on Climate Change approved (Presidential Decree No. 086).

2004 Regulations on ecological and economic zoning (ZEE) adopted (Presidential Decree No. 087).

2004 National Forest Strategy for 2002-2021 approved, aimed at ensuring the sustainable development of forestry activity (Presidential Decree No. 031).

2004 Alto Purus national park established on the Brazilian border to reduce poaching and illegal deforestation (Supreme Decree No. 040).

2004 Creation of the National Environmental Management System (Law No. 28,245). Aims to ensure compliance with environmental objectives of public entities and strengthen cross-sectoral mechanisms of environmental management.

2005 General Environment Act establishes basic measures to protect the environment (Law No. 28,611).

2008 Creation of the Ministry of Environment (MINAM), the Environmental Assessment and Enforcement Agency (OEFA) and the National Service for Government-Protected Natural Areas (SERNANP) (Legislative Decree No. 1,013).

2009 As part of the US-Peru Trade Promotion Agreement, the government of Peru commits to reducing illegal logging and improving the governance of the forests.

2009 Forests and Wildlife Law (Law No. 29763).

2009 Creation of the National System of Environmental Assessment and Enforcement (Law No. 29,325). Aims to ensure compliance with environmental legislation by all people.

2010 Action Plan for Adaptation and Mitigation Against Climate Change proposes climate change-related polices and forest conservation and restoration projects (Ministerial Resolution No. 238).

2010 Second National Communication on Climate Change.

2010 Launch of the National Program for the Conservation of Forests to Mitigate Climate Change (Supreme Decree No. 008). Commits to conserving 54 million ha of forests, reducing the rate of net deforestation to 0 by 2020 and halting the use of slash and burn techniques.

2011 The National Environmental Action Plan 2011-2021 (PLANAA) is published. Long-term environmental planning instrument that specifies targets and provides indicators for tracking progress.

2011 New Forests and Wildlife Law (Law No. 29,763, replacing Law No. 27,308). Creates bodies to improve management of forests and wildlife (National Forest and Wildlife Service (SERFOR), National Forest and Wildlife Management System (SINAFOR)). Requires information about forest management plants to be made available to the public. Came into force in 2015.

2012 Adoption of the Strategic Pillars of Environmental Management. Proposes actions to strengthen and improve the environmental and social approach to development.

2012 Creation of the National Service of Environmental Certification for Sustainable Investments (SENACE), which reviews environmental impact assessments for the country's main investment projects (Law No. 29,968).

2012 National Environmental Action Agenda 2013-2014. Expresses and renews Peru's commitment to sustainable development.

2013 Law on the mechanisms of payment for ecosystem services (PES) (Law No. 30,215). Promotes, regulates and supervises voluntary PES for the conservation, restoration, and sustainable use of ecosystems.

2014 Creation of INFOCARBONO, the national greenhouse gas inventory system (Supreme Decree No. 013).

2014 National Environmental Action Agenda 2015-2016.

2014 The National Pact for Legal Wood is signed by several government agencies, indigenous federations, private companies and nonprofit organizations.

2015 Revision of the 2003's National Strategy on Climate Change.

2016 Approval of the Action Plan on Gender and Climate Change (Executive Decree No. 012).

2018 Approval of the Framework Law on Climate Change (Law No. 30,754).

2019 Peru joins the Tropical Forest Alliance, a system of public-private partnerships that promotes action towards deforestation-free supply chains.

2019 Peru signs an agreement to end palm oil-driven deforestation by 2021.

C.2.3 Colombia

1959 Introduction of environmental planning and establishment of the Zonas de Reserva Forestal (ZRF), with forest clearance prohibited within these (Law No. 2).

1974 Natural Resource Code defines different uses for forest areas (Decree No. 2,811).

1977 Establishment of the national scheme of protected areas (Decree No. 622)

1993 Afro-Colombian communities get the right to the sustainable use of natural resources without a license (Law No. 70).

1994 Creation of the Forest Incentive Certificate (CIF), which promotes forests by covering part of the establishment and maintenance costs (Law No. 139).

1996 Forestry Decree establishes the obligation of regional authorities to grant licenses for use of forest resources.

1997 National Policy for Cleaner Production.

2000 Definition of the current National Forestry Policy (CONPES 3,824 of 1996, and PNDF of 2000), with emphasis on zoning forest areas by permitted use, and sustainable use as a method of conservation.

2006 New General Forestry Law enacted but then declared unconstitutional in 2008. Environmental organizations criticize the new law for weakening timber licensing and transportation requirements.

2009 Colombia signs the International Pact for Legal Timber.

2010 Creation of the National Parks Authority (Decree No. 2,372).

2010-2014 National Development Plan, including goals of avoiding 200,000 hectares of deforestation and restoring 90,000 hectares of forest.

2011 National REDD+ Strategy are part of President Santos Government's National Development Plan and enacted into law (Law No. 1,450).

2012 Launch of the Colombian Low-Carbon Development Strategy (ECDBC), aimed at promoting efficient low-carbon growth. National Plan for Climate Change Adaption.

2013 Zoning of the Amazon forest reserve, including conservation/sustainable production land cover classes based on bio-physical conditions of land cover.

2015 Germany, Norway and the UK agree to contribute around $300 million to reduce deforestation in Colombia.

2016 Introduction of Environmental Bubbles, establishing a first-response mechanism for dealing with deforestation and other environmental events.

2016 Introduction of a national carbon tax.

2017 Integral Strategy for Controlling Deforestation and Managing Forests (EICDBG). Establishment of a carbon offset program allowing emitters to avoid paying carbon tax only by offsetting emissions. Forests for Peace program with the aim of restoring ecosystems in areas of conflict (Prem, Saavreda, Vargas, 2020). Establishment of Colombia's first national forest monitoring system (SMByC). Payments for Ecosystem Services Act.

2018 Definition of the guidelines for the management of climate change (Law No. 1,931). Intergenerational Pact for Life of the Colombian Amazon (PIVAC), a Supreme Court sentence giving citizen rights to the Amazon biome and legally requiring the government to intervene by controlling deforestation. Launch of Greenbelt initiative to increase protected area connectivity by restoring forests along the border.

2019 Colombia signs beef and dairy zero-deforestation agreement to eliminate deforestation from supply chains. Launch of Operation Artemis, clampdown on illegal deforestation.

C.2.4 Venezuela

1996 Decree 1,257 establishes regulations for developing environmental impact assessments for forest exploitation activities.

1999 Constitution establishes basic environmental rights, and that state shall develop a zoning policy in accordance with sustainable development. The Ministry of Production and Commerce is given the mandate to define policies, planning, and regulate forestry activities (Decree 369). The Ministry of Environment is responsible for managing and controlling forest resources.

2000 Law of Biodiversity (Law No. 5,468): those using forest products must do so in a sustainable manner that does not harm biological diversity.

2013 New Law of Forests (Law No. 40,222): establishes the precepts that govern access and management of natural resources.

2016 Creation of the Arco Minero de Orinoco National Strategic Zone to increase extraction of mineral resources (Presidental Decree No. 2248). Total area of 111,843.70 km^2 located at the north of the Amazon, overlapping with protected areas and indigenous territories.

C.2.5 Guyana

1994 National Environmental Action Plan recognizes the need for sustainable development and environmental protection and establishes conservation-related objectives.

1996 Environmental Protection Bill. Provisions include the establishment of the Environmental Protection Agency (Law No. 11 of 1996).

1996 Iwokrama International Centre for Rainforest Conservation Act, providing 360,000 hectares of forest for sustainable management and use.

1997 National Forest Policy Statement (NFPS) describes need for increased forest monitoring.

1997 World Bank agrees to $6 million in funding for creating an environmental protection system in Guyana's rainforest.

1998 Forests Act regulates the cutting and removal of forest produce.

2007 Creation of the Guyana Forestry Commission to develop forest policy, enforcement, and certification of forest products (Law No. 20 of 2007).

2008 Guyana joins the World Bank's Forest Carbon Partnership Facility (FCPF).

2009 Low Carbon Development Strategy (LCDS) outlines an action plan to enable the transition of the country to a low-carbon economy.

2009 Norway agrees to compensate Guyana up to $250 million for carbon sequestration efforts over 2009-2014.

2009 Revised Forests Act repeals its 1998 predecessor, creating Protected Areas and setting a framework for land use regulation (Law No. 6 of 2009).

2011 Creation of the Guyanese National Forest Plan to implement the Forests Act 2009 and the National Forest Policy.

2011 Protected Areas Law enacted, also establishing the Protected Areas Commission, the Protected Areas Trust and a Trust Fund. Minister empowered to declare Protected Areas.

2013 Germany agrees to provide funding to support tropical forest protection in Guyana.

2017 Kanashen Village declared the country's first Amerindian Protected area.

2017 Approval of the framework document for the Guyana Green State Development Strategy, building on the LCDS from 2009.

C.2.6 Suriname

1987 Constitution declares all untitled land the property of the state. As a result, lands inhabited by indigenous and maroon communities become legally untitled.

1991 Forest Management Act sets requirements for the sustainable production and export of timber and non-timber products and considers interests of forest-dwellers.

1998 Establishment of the Foundation for Forest Management and Production Control (SBB) to oversee all forest management.

2006 National Forest Policy approved under the Forest Management Act, regulating both economic activity and land use.

2009 Interim strategic action plan to strengthen sustainable forest management, putting the National Forest Policy into action.

2009-10 Suriname's readiness preparation proposal (R-PP) (required to access readiness funds) is rejected by the World Bank following expression of concerns by forested communities regarding lack of consultation.

2013 Suriname's readiness preparation proposal (R-PP) is approved by the World Bank following relevant consultations.

2013 National Institute for Environment and Development in Suriname (NIMOS) for managing REDD+ project.

2015 Launch of National Climate Change Policy, Strategy and Action Plan outlining government strategy on climate change mitigation and adaptation until 2021.

C.2.7 French Guiana

2005 Adoption of regional forestry guidelines (Orientations Régionales Forestières Guyane).

2007 Creation of the "Parc Amazonien de Guyane" on the border with Brazil.

2008 Decree delimiting the land for afforestation.

2018 Regional Forestry and Wood Comission (CRFB) adopts regional forest and timber program (PRFB).

2019 Decree that offers the possibility to protect natural habitats.

C.3 The formation of the Brazilian border

Since we focus on the Brazilian border, it is useful to understand briefly the history of how the border was drawn. The broad limits of the Brazilian territory were defined in the colonial period when the Portuguese and the Spanish Crowns had very limited knowledge about the precise geography of the center of the South American continent. As such, they usually do not correspond to major differences in economic opportunity – and as we will see, include many arbitrary straight-line segments.

The Treaty of Madrid defined the general lines of the Portuguese – Brazilian – border with the Spanish colonies in 1750. When drawing the Treaty of Madrid map, Portugal and Spain agreed on two general guidelines: (i) who had first established local presence should keep the area (*uti possidetis*); (ii) rivers should be used as border divisions as much as possible to ease demarcation. The main objective of Portugal during the negotiations was to hold control of the (known) mining regions located between the center of the continent and the Atlantic coast, pushing the border west to keep potential invaders away. The main objective of the Spanish crown was to maintain navigable access to the sea. As such, the Treaty of Madrid set the limits of the colonies in that region by the Paraguay and Guaporé

Rivers, which are located more than 200km and more than 500km, respectively, from the Portuguese westernmost important settlement, Cuiabá.

At that time, in the middle of the 18th century, the areas in the center of the South American continent – and which form the borders we study today – were still largely unknown. This was particularly true for the Amazon area and the northern segment of the Brazilian border. Indeed, the magnitude of this "unknown" land can be seen by the vast blank spaces in the base map used in the Treaty of Madrid: *Carte de l'Amérique Méridionale*.[37] In fact, the precise location of rivers' springs and mouths – and what was between them – was not exact. The straight-line segments we can see in the Brazilian border are a consequence of this lack of information. These are due to rivers that followed a different path than the predicted one or that ended before reaching other geographic feature – and in such cases, the Treaty of Madrid (and the subsequent 1867 Treaty of Ayacucho) specified that a straight line should be used instead.[38]

The current limits of the Brazilian frontier were set in the first decade of the 20th century. In 1904, Brazil bought from Bolivia the region comprising the current state of Acre. This was a diplomatic solution between both countries to end a series of revolutions of Brazilian rubber tappers that aimed to create an independent state.[39] The final limits of the state of Acre were agreed between Brazil and Peru in 1909. Even at that time, more than one hundred and fifty years after the Treaty of Madrid, the geography of the area was largely unknown, as the straight line border segments suggest.[40]

C.4 Integration at the Brazil-Bolivia border

Our identification strategy assumes that policy and institutions are the only factor that impacts deforestation choices discontinuously at the border. If local markets are segmented at the border or if Brazilians and non-Brazilian communities were markedly dif-

[37] "[The] *Carte de l'Amérique Méridionale shows, with great detail and many new local circumstances, the empty state of our knowledge with large completely naked spaces"* (D'Anville, 1779).

[38] Article VI of the Treaty of Madrid says "... and, from there, seek the straight line by higher ground to the main head of the nearest river, which flows into the Paraguay River for its Eastern bank, which *might* be what they call Corrientes." The Treaty of Ayacucho (1867) that defined the precise border between Brazil and Bolivia, more than 100 years later, writes: "This river to the West follow the border by a parallel, taken from the left bank in South latitude 10º 20' until you find the Javary River. *If* Javary River has its sources North from this East-West line, follow the border, from the same latitude, for a line to get the main source of said Javary.".

[39] The conflict happened in the area around the old border in the portage city of Porto Acre, more than 80 kilometers from the current border.

[40] Paragraph 9 of Article I of the Treaty of Rio de Janeiro 1909 says "If the meridian of the source of Chambuyaco River does not cross the Acre River, that is, if the source of Acre River is to the East of that meridian, the border, from the point of intersection of that meridian with the 11º parallel, will continue for more marked land accidents, or by a straight line, until you find the source of the Acre River, and then down the course of the same Acre River, to the point where the Peru-Boliva border begins, on the right bank of Alto Acre."

ferent, differential changes in the drivers of deforestation could potentially impact farmers on both sides differently. Evidence suggests that markets and communities are substantially integrated at the Brazilian-Bolivian border. We focus on this border segment as it is more densely populated and has a larger discontinuity in deforestation rates. We first describe formal integration (land ownership laws and trade regulation) and then discuss some indicators of informal integration.

In the 1990s, Bolivia began an ambitious investment-promotion program for land cultivation. By marketing lands at discounted prices and welcoming foreign investors, Bolivia attracted a large amount of foreign capital to its agriculture sector (McKay and Colque, 2016). By 2000, foreigners owned 73.1% of the Bolivian soy lands – Brazilians owned 31.9% of the land (Urioste, 2012). The soy production, however, was concentrated near the center of the country and far from the borders. In fact, Bolivian law forbade foreign land ownership in a 50 km strip from the border (de Jong and Ruiz, 2012) – exceptions to this law were introduced in 2004 for two important trading points in the region, Cobija and Guayeramirim in Bolivia (Aseff et al., 1997). Regarding formal trade integration, in 1996, Bolivia joined the Southern Common Market (Mercosur), of which Brazil was already a member. The agreement aimed to abolish tariffs between Bolivia and the Mercosur countries on a 10-year horizon and to eliminate non-tariff barriers. Mercosur, however, never abolished all trade barriers in the region.

While formal institutions enabled a substantial degree of integration between Brazilian and Bolivian neighboring communities, in practice, existing formal barriers were a little hindrance to cross-border integration. This was driven by lax enforcement and difficulties of monitoring (de Jong et al., 2014). For example, despite the prohibition of foreign land-ownership in the 50 km of the border, a significant number of Brazilian nationals resided in the borderlands of the Bolivian department of Pando for decades undisturbed by law enforcement (de Jong and Ruiz, 2012). Illegal movement from Bolivia to Brazil was also prominent, potentially encouraged by Brazil's repeated issuance of amnesty for illegal immigrants. Residents surveyed in the Amazonian cross-border region among Peru, Brazil, and Bolivia expressed that "since the beginning, there were no barriers" to the flow of people among communities and urban areas (Wong Villanueva et al., 2020). Some households traded actively with Brazilian markets, with a large portion of local trade being contraband (Aseff et al., 1997). For example, on the Brazilian border city of Corumbá, many Bolivian merchants traveled to Brazil to work and sell their produce; a survey with stallholders in local fairs on the Brazilian side found more than 50% of merchants were Bolivian (Aguiar, 2016). The similarity between the composition of agriculture practices on both sides near the border is another evidence of local integration (Perz et al., 2012).

The ease of cross-border access raises the question of whether Brazilian environmental policies have spillovers in the neighboring countries. If such spillovers were significant at the border, our estimates for the impact of Brazilian policy in Brazil would be downward biased as they would capture a potential increase in deforestation on the non-Brazilian side. We find limited evidence of such spillover. Figure A2 shows very little changes in deforestation outside the Brazilian border until 2016. One reason for the lack of movement before 2016 may be that the expansion zone of soy production in Bolivia– where investments were most prominent – happened far from the border (McKay and Colque, 2016). We cannot rule out, however, that the sharp increase in deforestation outside the Brazilian border after 2016 may be partly due to delayed spillovers from Brazilian policies. For example, Brazilian investments into cattle-ranching increased around 2012 in Bolivian municipalities next to the border, and these producers began to develop the local infrastructure to support trade with Brazil (Urioste, 2012). These municipalities later became hot spots of deforestation (de la Vega-Leinert and Huber, 2019).

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