National Borders and the Conservation of Nature

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Abstract

Tropical forests play a central role in slowing climate change and their conservation has become an international priority. The fact that the majority of tropical deforestation is illegal, often involves complicit states and occurs in remote places makes evaluation of national conservation policies difficult. We propose using finely grained satellite data at national borders, where one political jurisdiction ends and another begins, to evaluate how well, in aggregate, these resources are being conserved. Doing this using 30x30 meter satellite data along Brazil's 12800 km border in the Amazon reveals 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 observed across the border. From 2006 to 2014, as Brazil introduced policies to reduce deforestation, these differences at the border disappear. But they then re-appear starting in 2014, amid a period of deteriorating enforcement of environmental regulation. National borders thefore 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 timber in forests and fish in the ocean are seen as natural resources to be exploited for the benefit of a country. Benefits beyond those from 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 whose conservation is seen as critical to achieving global net zero. This has led to initiatives such as the 30 by 30 initiative to designate 30% of the world's land and ocean area as protected by 2030 (Dinerstein et al. 2019). Indeed a whole range of reports from Stern (2007) to IPCC (2022) point to ecosystem conservation as being a cost-effective means of tackling climate change. This new conservation objective is now pitted against the traditional exploitation objective. A key problem is that the benefits of exploitation accrue to the country which 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).

Forests have become the central focus in these international conservation efforts. Here the immediate value of extracting timber and of converting forest areas to more productive uses 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). 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; Matricardi 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 illustrates these different areas have experienced radically different patterns of deforestation. Brazil – which contains 65 percent of the Amazon rainforest – moves from having almost

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

the highest rate of deforestation in 2001 to having the lowest rate in 2013, and then converges back to the rates of deforestation seen Indonesia and the Democratic of Congo whose rates are rising steadily from 2001 to 2020. Even within the Amazon what is happening in Brazil looks totally different to what is happening in the non-Brazilian Amazon where we do not see the same pattern of reversals.

How do we understand these patterns? How can we assess whether national conservation policies are having any influence? All these countries have *de jure* policies to conserve these ecosystems on thier books. The problem is that illegal extraction drives a wedge between *de jure* policies and their *de facto* enforcement. Indeed it is the size of this wedge that distinguishes conservation challenges in developing countries from those in developed countries (Greenstone and Jack 2015; Hsiao 2021; Balboni et al. 2021). 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, in aggregate, national conservation efforts are working. 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 either 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 range of imperfectly enforced policies. Because political and hence 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 - demand, costs of access, availability of labor, access to finance, weather, flamability - which fall outside the purview of conservation policies. Satellite images on the other side of the border (just) outside a country's jurisdiction therefore serve as a control for (otherwise similar) satellite images which fall within a country's policy jurisdiction. This allows us to examine the aggregate, 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 both have a direct effect by changing the returns to illegal deforestation (and hence the propensity to engage in it) but also 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 is in contrast to 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 – about the size of the contiguous United States west of the Mississippi River – the Amazon plays a crucial role in the global carbon cycle and hosts an astounding amount of biological diversity. Its immense size implies that the rate at which it is deforested will affect the pace of global warming (IPBES, 2018). Within the Amazon our focus is on Brazil. Not only does it contain the bulk of the Amazon rainforest but between 2000 and 2020, 55% of global net forest area loss came from Brazil (FAO 2020) and 94% of the area deforested in the Brazilian Amazon in 2020 is deemed to have been illegal (Valdiones et al., 2021) Hence understanding whether Brazilian conservation efforts have been effective is an issue of international importance. 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 polcies in Brazil we apply a regression discontinuity design to 30x30 meter resolution Landsat 7 data set 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 up 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 Bazilian policies to open up the Amazon (Pfaff 1999; Brito et al. 2021; Probst et al. 2020). 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. These differences are mostly driven by border segments where the so-called "Arc

[2] 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).

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 2014 – when Brazilian environmental policies were relaxed. 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 seem to have led to dramatic reductions in deforestation. This reduction was, however, temporary, and starting in 2014, deforestation rates in Brazil (relative to countries just across the border) climb 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 pressure (Fearnside, 2016; Azevedo et al., 2017; Freitas et al., 2018; Soterroni et al., 2018).

Third, we show that *de jure* land-use restrictions on the Brazilian side matter, even at the border. We find that areas designated as protected areas in Brazil have always been less deforested than lands just on the opposite side of the international border. This remains the case until 2013. The Brazilian state was therefore able to enforce environmental regulations when there was the political will to do so. Given this, we find that the reductions in deforestation following the mid-2000s policy changes in Brazil were most pronounced on unclaimed and private lands outside protected areas – precisely the areas where the increase in enforcement by the Brazilian state was most pronounced. We find, however, that the second reversal is mostly driven by lower enforcement of conservation policies in all areas, even in those with stronger *de jure* land-use restrictions which underlines how fragile the pro-conservation agenda was when faced with pro-exploitation politcal 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 crack down, the fact that protected areas in Brazil were less likely to be deforested than corresponding lands just across the national border, 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 to be had 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 therefore helps us to understand why in Figure 1 the Brazilian Amazon was the only major area of tropical forest that has experienced *falling* rates of deforestation since the mid-2000s and why this downward trend has reversed in recent years (Nepstad et al. (2009); Hargrave and Kis-Katos (2013); Assunção et al. (2015)). Identifying the role of Brazilian government policies in explaining these reversals is challenging both because many other factors affect rates of deforestation and becuase a myriad of conservation policies were applied across the country. Many papers use variation within Brazil to study the role of specific policies – the creation of protected areas,[3] targeted enforcement efforts in priority municipalities,[4] and policies targeted at private rural properties (such as environmental registration and restricting access to rural credit).[5] Assunção et al. (2013) show that the satellite-based deforestation detection system (DETER) was a crucial tool for the government to fight illegal deforestation by enabling enforcement to identify and act on areas with active deforestation activity.[6]

While each of these studies focuses on identifying the effects of particular n policy it is difficult to aggregate their impact. The contribution of this paper is to identify the entire

[3]Soares-Filho et al. (2010); Nolte et al. (2013); Pfaff et al. (2014); Herrera et al. (2019).

[4]Arima et al. (2014); Assunção and Rocha (2019); Cisneros et al. (2015); Assunção et al. (2019)

[5]Alix-Garcia et al. (2018); Gibbs et al. (2015); Assunção et al. (2019).

[6]A related literature studies how regulation and infrastructure affect deforestation (e.g., Souza-Rodrigues, 2018; Asher et al., 2017) and violence in the Amazon (e.g., Chimeli and Soares, 2017).

'Brazil policy effect' – the combined effect of all of Brazilian policy 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 in this gap.

This paper fits within a rich literature using borders to study policy effects. While borders have been shown to be associated with policy outcomes in developed countries (Black, 1999; Holmes, 1998; 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 (Magruder, 2013; Chen et al., 2013; Lipscomb and Mobarak, 2016) and find evidence of significant effects. Others argue that in many developing country contexts, whilst governments can project some authority in national or regional capital cities these powers are much weaker in remote, frontier areas (Michalopoulos and Papaioannou, 2014; Pinkovskiy, 2017).[7] Our results are consistent with the nuanced evidence for developing countries. Despite substantial *de jure* policies that restrict development and promote conservation *de facto* enforcement seems to depend critically on national political will.

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 these (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 discuss the major policy changes in Brazil and in the other countries in the Amazon region, and Section 4 sets our empirical specification and data. We present our main results in Section 5. Section 6 presents the results of our counterfactual exercises. Section 7 discusses the factors influencing the dynamics of conservation and exploitation in the Brazilian Amazon. Section 8 concludes.

[7]There is as well a large literature using 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 (e.g., Gopinath et al., 2011; Aker et al., 2014).

2 Conceptual 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 and consisting of pixels i distributed over a line segment, such that $i \in [-1, 1]$; i is our index. Pixels are of equal size, but heterogeneous in their productivity $a_i > 0$. Productivity captures agronomic characteristics of that parcel of land, such as soil suitability for crops, distance to roads, access to water etc. There is a unit mass of people uniformly spread over the area. For each pixel i, an agent chooses the fraction of land to be preserved and the fraction to be deforested and used as an input for agriculture or livestock grazing, l_i. As a normalization, the value the person derives from preserving the land in each pixel is zero. Individual choose how much land and capital (a mobile factor of production) to use in production. The gross production using l_i of land and capital $k_i \geq 0$ 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 $\rho < 1$.

Land use is subject to different regulations, policies, and enforcement capacity. The model embeds this heterogeneity 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 $A(a_i, l_i, k_i)\, e^{v_i}$.

For each pixel, the individual chooses optimal input levels – 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 r and c is the cost of converting forest to productive land; implicitly, we assume an elastic global market for output, with price normalized to 1. The optimal share of land used in each pixel is

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

where $\Phi(r) = \frac{\phi}{c}\alpha^{\frac{1-\phi}{1-\rho}}\left[\alpha^{\frac{1}{1-\rho}} + (1-\alpha)^{\frac{1}{1-\rho}}\left(\frac{c}{r}\right)^{\frac{\rho}{1-\rho}}\right]^{\frac{\phi-\rho}{\rho}}$ is a function of capital prices and parameters. We see from this equation that regulation may lead to different land use choices in pixels with similar productivity levels. The weaker regulatory and enforcement levels in pixel i – that is, v_i closer to zero – the larger the share of land deforested and put to productive use.

What do we learn from looking at borders? Suppose that 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 capacity. Likewise, the cost of capital may also differ in the two countries if markets are not integrated around the border.

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

$$\delta_i \equiv \lim_{i\to 0^+} \ln l_i^* - \lim_{i\to 0^-} \ln l_i^* = \frac{\lim_{i\to 0^+} \ln a_i - \lim_{i\to 0^-} \ln a_i}{1-\phi} + \frac{\lim_{i\to 0^+} v_i - \lim_{i\to 0^-} v_i}{1-\phi} + \quad (2)$$

$$+ \frac{\ln \Phi\left(r_R\right) - \ln \Phi\left(r_L\right)}{1-\phi}. \quad (3)$$

The first term is 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 checked empirically. The second term captures the difference in land use due to the (local) difference in costs imposed by land regulationshould this not refer to land use not productivity?. The third term captures the difference in land use due to different capital costs in each country.

When comparing land use very close to the border, researchers are interested in learning about the second 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 regulatory changes at the border (the second term) and differences in land use due to different input use at the border (the third term). The regression discontinuity only identifies the local effects of regulation if this third 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 ($\alpha = 1$); and (ii) when the capital market is locally competitive and that capital is supplied elastically at constant price r on both sides of the border. If one of these conditions is satisfied, the regression discontinuity in (2) identifies the local differential effect of regulation on land use (the second term).

In the forestry case we consider here, it seems that both 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.[8] As we argue in Section 4, the local economies of the areas across the border seems to be substantially integrated, with ease 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 first-order. Thus, in our setting – land use in the fringes of the Brazil-

[8]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.

ian 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 some guidance for how to conduct counterfactuals based on estimated discontinuities. Specifically, the discontinuity in land use we will estimate below corresponds to equation (2). We can use equation (1) to help back out the net effect of an estimated change.

To do so, we need to parameterize equation (1). First, we assume 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 environmental regulation takes the form of $v_i = \delta + \nu_i$, where δ_i is a common term for all pixels in Brazil – i.e. the discontinuity effect we estimate – and ν_i are pixel-specific environmental regulation and enforcement.

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

$$\ln l_i^* = \frac{1}{1-\phi}\left[\kappa + \mu(X_i) + \delta \mathbf{1}\left\{i \in \text{Brazil}\right\} + u_i + \nu_i\right] \tag{4}$$

where κ is a constant, $\mu(X_i) = \mu_{Brazil}(X_i).\mathbf{1}\{i \in \text{Brazil}\} + \mu_{Abroad}(X_i).\mathbf{1}\{i \notin \text{Brazil}\}$, and $u_i + \nu_i$ is the structural residual. The vector X_i includes land slope, distance to water, distance to the international border, distance to roads, and distance to urban areas. The coefficient δ captures the average direct effect of Brazilian regulation on land use. The key point in equation (4) 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).

3 Environmental regulation in the Amazon

Several countries share the duty of regulating the use of the land in the Amazon. These countries often differ in their regional economic and conservation goals, as well as in the policies they employ. In this section, we describe the main conservation policies implemented by countries in the Amazon region in the last two decades. We start by providing a background on environmental regulation and land use dynamics in Brazil, the country that contains most of the Amazon forest and is responsible for most of its historical deforestation, to provide some context for the empirical results we develop below. We then describe the main conservation policies in the non-Brazilian Amazon. We present a lengthier discussion in Appendix B.1.

3.1 The Brazilian Amazon

The early days. Until the 1960s, the Brazilian Amazon's native vegetation was largely preserved. The area was inhabited by natives and a sparse non-native population. The primary economic activity was extraction of rubber. Between 1964 and 1985, the military government promoted immigration to the region with large infrastructure projects – e.g., by building roads and hydroelectric power plants – and by granting title to land put to productive use (Pfaff, 1999). This created a boom in migration and cattle ranching in the region.

The environmental footprint of the occupation of the Amazon was not a concern to the government during this period. The Ministry of Environment (MMA) and the Brazilian Environmental Agency (IBAMA) were created only during the re-democratization process in 1985 and 1989, respectively. Yet, enforcement of environmental regulation remained weak until 2004, when deforestation rates peaked in the region. On net, the the Brazilian Amazon deforested area grew from 6% to 16% between the 1980s and 2004 (MMA, 2013).

A new environmental agenda. In 2003, the newly elected President Lula appointed Marina Silva as Minister of the Environment. This signalled a switch in focus from exploitation to conservation of the Amazon. A union leader and daughter of poor, Amazonian rubber tappers Silva had already worked with Chico Mendes on protecting the Amazon from encroachment by ranchers and farmers. In November 2004, the federal government launched the *Action Plan for the Prevention and Control of Deforestation in the Legal Amazon* (PPCDAm) to crack down on deforestation in the Amazon. The action plan outlined a series of policy changes to be gradually implemented. Table A1 summarizes the main policies implemented in this period.

For environmental regulatory purposes, we can divide land in the Brazilian Amazon into three broad classifications: areas protected for conservation reasons – e.g., national parks and indigenous land –, areas which are untitled and unclaimed, and areas under private ownership. PPCDAm imposed stricter enforcement of regulations on land use to all these types of land. The government paired technology and intelligence missions to bolster environmental monitoring and enforcement in the Amazon. In particular, the government developed a remote-sensing system (DETER) which produced 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, with local IBAMA offices receiving near real-time satellite data for enforcement. Assunção et al. 2013 and Ferreira (2021)show the remote-sensing system increased fines and contributed to reduce deforestation. Furthermore, in 2008 the government created a list of municipalities with historically high deforestation rates that would be under special scrutiny, know as priority municipalities.

PPCDAm also included land-specific policies. Since 1998, harming native vegetation in *Protected Areas* (PAs) is a felony subject to potentially harsh legal procedures and punishments – including possible jail time. This category of land thus faced the highest level of *de jure* sanction throughout the 2000-2018 period. In contrast, until 2005, deforesting untitled or *unclaimed land* outside PAs was just an infraction, punishable at most with fines. PPCDAm made deforestation of unclaimed land a felony punishable with jail time, and legislated that equipment of violators – e.g., trucks and chainsaws used to clear the land – could be seized by the authorities. Similarly until 2005*, private properties* outside PAs were required to set aside at least 80 percent of their area as native vegetation – i.e., it was illegal to deforest more than 20 percent of the private property area. Non-compliance with this threshold, however, was just an infraction. Starting in 2008, PPCDAm conditioned access to subsidized agricultural credit lines upon stricter environmental compliance (Assunção et al., 2019).

In sum, while the vast majority of deforestation in the Amazon was illegal prior to 2005, enforcement and the *de jure* legal sanctions associated with deforestation substantially increased in 2005. The considerable reduction in deforestation rates in Brazil we see in Figure 1 coincides with this new environmental agenda in the region.

Dismantling of the environmental agenda The government focus on sustaining a strong environmental agenda started to wind down in the following decade. The growing political power of the rural caucus in the Federal Congress (Rochedo et al., 2018) – supported by the lobby of the agriculture sector – increased the political pressure for deregulating some land use restrictions introduced in the previous years (e.g., Tollefson, 2016; Fearnside, 2016; Crouzeilles et al., 2017; Viola and Franchini, 2017).[9]At the same time, the government's focus for the Amazon region shifted towards promoting economic development through large investments in infrastructure and subsidies to targeted industries – such as livestock grazing. Table A2 lists the key events in this period.

The main policy change was the controversial approval in 2012 of the New Forest Code (Law 12.651/2012). Likely the most contested item of the new code was the amnesty to "small" private properties – i.e., those with less than 440 hectares in the Amazon – that before 2008 had already deforested beyond the legal limit.[10] More than the *de jure* impact of the New Forest Code, 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). In the following years, the Federal Congress made repeated efforts to undo key aspects of the regulatory

[9]Out of the 513 seats in the Federal Congress, the number of rural caucus members grew from 79 in the 2002-2006 legislature to 142 and 207 in the 2011-2014 and in the 2015-2018 legislatures, respectively.

[10]Soares-Filho et al. (2014) calculate that this would effectively forgive illegal deforestation inside private properties for 90% of Brazilian rural properties.

framework passed under the PPCDAm.[11]

This perception was reinforced by the deterioration of the government enforcement apparatus. An audit from the Office of the Comptroller General (CGU, 2016) documented that the Environmental Agency (IBAMA)'s budget was cut by 34.2% between 2013 and 2014. The report also documented a 24% reduction in the number of IBAMA's enforcement officers between 2010 and 2014. The budget suffered additional cuts over the following years such that, by 2016, it stood at only 57% of its 2013 nominal value.

In 2018, Brazil elected Jair Bolsonaro president, the single candidate openly hostile to environmental issues. With ample support from the rural caucus, the government started an unprecedented process of environmental deregulation.[12]

As Figure 1 shows, after about eight years of relatively low deforestation rates, we see this trend being reversed with increased deforestation in the second half of 2010s, following the gradual dismantling of the environmental agenda brought 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 substantially smaller than in Brazil in most of the 2000s – see Figure 1 –, no country implemented a set of policies as comprehensive as Brazil did.

Table A1 shows the timeline of environmental policies for all other countries in the region in the 2000s. In this period, we see Peru, Colombia, Suriname and Guyana developing their legal framework for forestry, and regulating economic activity in the region. Peru established the Alto Purus national park on the border with Brazil in 2004, and created the Peruvian Ministry of Environment and the Environmental Agency in 2008. Colombia passed a New General Forestry Law in 2006 – this, however, was declared unconstitutional in 2008. Bolivia and Venezuela, on the other hand, had a less active environmental agenda in the period. Bolivia's main land use policies were the 2006 Law on Community Redirection of the Agrarian Reform, focused on facilitating land titling of public lands to indigenous communities.

Table A2 lists the main event during the 2010s. We see a trend in the region of countries adopting policies within the United Nations' REDD+ umbrella. These include, e.g., the introduction of economic and ecological zoning, demarcation of protected areas and national parks, and regulating the use of payment for environmental services. Bolivia and Venezuela did not follow this trend. In 2010, Bolivia, the country closest to areas

[11] E.g., by simplifying both the land titling process of occupied public land and the environmental licensing for infrastructure projects.

[12] As the Minister of Environment summarized in a cabinet meeting in April 22 of 2020, the objective was to "(...) run the cattle trough and change all the rules and simplify norms".

with higher deforestation pressure in Brazil known as the "Arc of deforestation", enacted the Rights of Mother Earth Law which declared Mother Earth the titleholder of inherent rights of the land. This law is part of an agenda of resource nationalism, opposing market based mechanisms such as REDD+. Venezuela, despite enacting a New Forest Law in 2013, created an economic strategic zone to enable mining in the forest.[13]

In sum, the efforts employed by Brazil on the environmental front between 2004 and 2011 were not matched by the other countries in the region. While deforestation rates in Brazil fell 70% within a few years, deforestation in the non-Brazilian Amazon increased – see Figure 1. In the following decade, when Brazil was reversing its environmental agenda and deforestation resumed to increase, most countries in the region continued making progress on their environmental governance. Despite these efforts, the annual deforestation rate in the non-Brazilian Amazon also continued to increase, but at a more moderate pace than in Brazil.

4 Empirical method and data

Although the trend breaks in deforestation shown in Figure 1 coincide with major changes in the countries' environmental policies discussed in the previous subsection, we cannot draw a causal relationship between these national policies and conservation. The framework in Section 7, however, clarifies that by looking at the forest cover in plots of land close to the border between two countries, we can identify the differential effects of national policies on forest conservation. We now describe how we apply the framework to the data to estimate the differential effect of policies implemented in the Brazilian Amazon on deforestation relative to the effects of policies implemented in the non-Brazilian Amazon.

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 distance to the Brazilian international border: $DistBorder_i$. Positive distances represent pixels in the Brazilian Amazon, while negative distances represent pixels in the Amazon outside Brazil. Our main estimating equation is

$$Y_i = \alpha + \gamma Brazil_i + f\left(DistBorder_i\right) + \delta X_i + \varepsilon_i \tag{5}$$

[13] The Orinoco Mining Arc spans an area greater than 111 thousand km^2 and overlaps with protected areas and indigenous territories. This area is not near the Brazilian border.

where Y_i is the outcome of interest (forest cover in 2000 or forest loss in a given year) in pixel i. $Brazil_i$ is a dummy equal to one if pixel i is in Brazil. X_i is a vector of pixel-specific characteristics explained below and $f(DistBorder_i) = Brazil_i * f^{Brazil}(DistBorder_i) + (1 - Brazil_i) * f^{OutsideBrazil}(DistBorder_i)$ is a polynomial of distance from the border. These two terms flexibly capture pixel characteristics that influence land use, such as agronomic and economic characteristics, represented by a_i in equation (1) in the model. Following Gelman and Imbens (2019), we use separate linear polynomials f on each side of the border for our preferred specification, and use separate quadratic polynomials as robustness.

Identification. The coefficient of interest is γ, which measures the difference in the share of a pixel that is forested in 2000 (or deforested in a given year after 2000) on the Brazilian side of the border compared to the other side. Our identifying assumption is that other factors that might affect deforestation change smoothly across national borders. If this assumption is valid, by controlling for a polynomial in distance from the border and additional pixel characteristics, γ is the empirical analog of the second term in equation (2) and it identifies the local difference in the cost of land exploitation imposed by Brazilian policies relative to those of its neighbors on the share of land to be deforested and converted to other use.

Our identifying assumption would be violated if the precise location of the border was set according to local geographic or agronomic characteristics. However, historical evidence suggests that the exact location of the Brazilian border in the Amazon is largely arbitrary. Borders were largely set by the 1750 Treaty of Madrid, at the time of which many of these areas deep in the jungle were unexplored, for example appearing as large blank spaces labeled "unknown country" in contemporary maps (Furtado, 2012).[14] We also show below that our results are robust to considering straight-line border segments, which are clearly artificial (Alesina et al., 2011) (see Section 5.4 below).

To explore these assumptions in the data, we check for discontinuities at the border on 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 change in the level of these variables at the Brazilian border, for various subsets of the border. We find that these characteristics are smoothly distributed around the Brazilian border.

Another potential threat to our identifying assumption would be if local markets were segmented at the border. In this case, as the model in Section 2 shows, differential input prices could potentially impact investment in land use on both sides of the border differently. Evidence suggests, however, that markets and communities are substantially integrated at the border, including in the most densely populated border segment (Brazil-

[14] Appendix B.3 provides more details on the border formation.

Bolivia). In particular, Brazil and Bolivia have been part of the Southern Common Market (Mercosur) since the 1990s, which facilitates the movement of people and goods across the border. Moreover, the border itself is remarkably porous. The illegal movement of people from Bolivia to Brazil was also prominent, potentially encouraged by Brazil's repeated issuance of amnesty for illegal immigrants from Bolivia and other Latin American countries. And capital also flows freely: even as of 2000, Brazilians owned 32% of Bolivian soy land. We discuss this issue in more detail in Section 5.4 below, and in particular, show that soy prices in Brazil and Bolivia track very similarly over time (Figure A4), suggesting that differential prices is unlikely to be the main driver of the effects here. Appendix B.4 provides more evidence on local market integration.

Estimation. We estimate equation (5) by OLS in our main specifications. When we perform exercises to assess if there is heterogeneity in institutional effects across different segments of the border and land types in Brazil, we estimate equation (5) using a Poisson model.[15] We do this because there are substantial differences in baseline magnitudes of deforestation across the Amazon across land types, and Poisson estimates remain interpretable as percent changes in the dependent variable across land types. 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 including 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 partitioning the area, where the second cluster is an offset version of the first one (i.e., the vertex of blocks in the second cluster start at the midpoint of the blocks in the first cluster). We take this approach because, 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 the second cluster.[16]

We report results using bandwidths around the border ranging from 11km to 100km. Since we have several dependent variables, we do not have a single theory-driven optimal bandwidth. We calculate the optimal bandwidth for each dependent variable as in Calonico et al. (2014) and in Imbens and Kalyanaraman (2012). To ease comparability across equations, our preferred bandwidth is the average of the optimal bandwidths calculated across all variables using Imbens and Kalyanaraman (2012) method, which is 27km

[15]Since each 120m pixel is comprised of sixteen 30-meter pixels, our dependent variable is effectively a count variable with range $[0, 16]$.

[16]Note that Conley (1999) standard errors would be an alternative but is computationally challenging due to the extremely large number of observations.

from the border. We also present results using Calonico et al. (2014) method, which is 11 km from the border. In our preferred specification using all 120m pixels within 27km of the border, we have 5,491 clusters and 31,711,264 observations each year.

4.2 Data and descriptive statistics

Hansen et al. (2013) worked with the Google Earth Engine to detect deforestation using Landsat 7 data, resulting in a map of global forest cover in 2000 and consistent longitudinal annual forest measures. We use the latest version of this data, which has annual deforestation measures from 2001 to 2020, at a spatial resolution of 30 meters across the whole Latin America.[17] Importantly, since this dataset is worldwide and does not use any national data as inputs, we can examine deforestation rates on both sides of the border using an exactly comparable metric.[18] We aggregate pixels to create a resolution of 120×120 meters to ease computational constraints. Annual forest loss is defined as the share of 30m Landsat pixels within our 120m pixels deforested within one year. Forest cover in 2000 is the average tree cover canopy of the Landsat pixels.

Table 2 shows the summary statistics for different bandwidths around the border. While we see that the forest cover in 2000 in the whole Brazilian Amazon was similar to the fores cover in areas closest to the border (82.8% and 83.3%, respectively), annual deforestation rates were smaller in the area closer to the border than total deforestation rate. This is consistent with the 'Arc of Deforestation' being closer to the center of the country than to the areas deep in the forest. We observe a similar difference between deforestation pattern in the areas closer to the border in the non-Brazilian Amazon.

We supplement this deforestation data with a variety of other data sources. Hydrology data from 2000 was extracted from Google Earth Engine. Remaining data including administrative boundaries, protected areas, elevation, slope, waterways, roads and urban areas were extracted from OpenStreetMap's API. Table 3 presents the summary statistics of the land characteristics of pixels within 27km from the borders inside and outside Brazil.

We limit our analysis to the Amazon area as defined by RAISG (*La Red Amazónica de Información Socioambiental Georreferenciada*), taking into account the biome and the legal Amazon limits as defined by the various countries in the region.

Figure 2 shows an example of the data, displaying forest cover as of 2000. Panel (a) shows the entire Amazon, with the Brazilian international border shown in black, and Panel (b) zooms in on one particular border segment, in which the borders consists largely

[17]The forest cover map is constructed for 2000 because Landsat 7 was launched in the previous year, so Hansen and coauthors use it as the base cover on which he constructs annual forest loss.

[18]An alternative data source commonly used to capture deforestation in the Brazilian Amazon is PRODES produced by the Brazilian National Institute for Space Research. PRODES, however, does not cover land use in the other countries. Hansen et al. (2013) and PRODES depict similar deforestation trends in the earlier period of our analysis.

of straight lines. The substantially higher deforestation on the Brazilian (right-hand) side of the border is clearly visible both in the inset as well as in a number of locations along the border in panel (a).

5 Results

5.1 Deforestation as of 2000

We begin by examining the level of forest cover in 2000, the year our data begins. Figure 3a shows the percentage of forest cover in the year 2000 averaged by eighty equal-sized bins of distances from the Brazilian border, up to one hundred kilometers from each side of the border. The sharp discontinuity in deforestation is visually apparent: forest cover drops sharply at the national border.

Our regression estimates using equation (5) indicate that this discontinuous change in forest cover at the border is sizable and statistically significant. Using a 27km bandwidth, forest cover in the Brazilian Amazon was 4 percentage points smaller in 2000 than in its neighboring countries (cluster-robust p-value equal to 0.002; see Table 4 column 1).[19] Since 89.4 percent of the land outside of Brazil was forested in 2000, this implies that deforestation prior to 2000 was about 38 percent higher just inside the Brazilian border relative to on the other side.

5.2 Annual forest loss 2001–2020

We next plot annual deforestation rates on both sides of the border between 2001 and 2020 in the remaining panels of Figure 3. For exposition purposes, we split the horizon of our study into three periods corresponding to the different policy environments described in Section 3.1: Figure 3b shows annual deforestation rate between 2001-2005, Figure 3c between 2006-2013, and Figure 3d between 2014-2020. Consistent with observing less forest in the 2000 cross-section at the border, Figure 3d (panel b) shows similar patterns in annual deforestation rates – with much higher rates of deforestation discontinuously at the border from 2001-2005.

This then comes to an abrupt halt in 2006, as Brazil starts to implement its anti-deforestation policies. Specifically, between 2006 and 2013, deforestation activity is spread smoothly on both sides of the Brazilian border. Note that the change in 2006 comes from decreased deforestation in Brazil, rather than increased deforestation on the other side of the border.[20] We then document a second reversal: deforestation rates in 2014-2020

[19]As Table 4 shows, results vary from 2.2 percentage points to 5.4 percentage points, depending on bandwidth, which we vary from 11km to 100 km.

[20]Note as well that the size of this decrease in deforestation at the Brazilian border is on pair to estimates for the whole Brazilian Amazon. Nepstad et al. (2014) show a 70% decrease in deforestation

increase substantially. While the level of deforestation increases somewhat on both sides of the border, there is a discontinuously larger increase on the Brazilian side.

To show the patterns year-by-year, we estimate RD models separately for each year. Figure 4a plots the RD coefficient – γ in equation (5) – for each year, along with 95 percent confidence intervals, using OLS regressions and a 27km bandwidth. That is, each point shown in 4a is the RD estimate from a single year's estimation of γ in equation (5). We estimate annual deforestation rates of about 0.2 percentage points higher per year on the Brazilian side of the border through 2005. Since deforestation on the other side of the border ranged from 0.05 to 0.07 percent in other Amazonian countries, the estimates imply deforestation rates in Brazil were 3-4 times higher than on the other side of the border.

Figure A2 then shows the two patterns documented above – a precipitous decline in excess deforestation in Brazil (relative to neighboring countries) starting in 2006, and an increase in the deforestation rate on the Brazilian side of the border resumes starting in 2014. After three years of political and economic crisis, in 2017, we see that deforestation was about 0.17 percentage points higher at the Brazilian side of border (cluster-robust p-value equal to 0.004). On average, the magnitudes of the Brazil effect in the 2014-2020 period are about half the magnitudes in the 2001-2005 period.

5.3 Are these differences related to Brazilian policies?

The empirical results identify three distinct policy regimes from looking at effects at the border – a high deforestation regime until 2005, a low deforestation regime from 2006-2013, and a higher deforestation regime after. Do these three periods match changes in the Brazilian policy environment.

First reversal – pro-conservation period. The precipitous decline in deforestation at the border in the mid-2000s corresponds to a period of environmental policy strengthening in Brazil (see Section 3.1). In 2003, the newly elected president appointed Marina Silva as Minister of Environment, an environmentalist from the Amazon region and a strong advocate of conserving the rainforest. After a period of incubation, her team released the PPCDAm plan in November 2004 and started to implement its actions gradually: most notably with the Law on Public Forest Management and Center for Environmental Monitoring becoming fully operational in 2006. This allowed the satellite-based deforestation detection system (DETER) to become a key tool for targeting law enforcement activities in the Brazilian Amazon, including sending in Federal Police and troops to arrest illegal loggers and confiscate their machinery (MMA, 2008). Assunção et al. (2013) show that

between 2005 and 2013 using PRODES data. For this same period, our data shows a 65.3% decrease in the whole Brazilian Amazon and a 74.7% decrease in areas within 27km from the border (see Table A3).

the implementation of the DETER system was a crucial tool for the government to fight illegal deforestation, estimating that if DETER-enabled enforcement was halved, deforestation would have been 44% higher. Consonant with this, Figure A2 shows that in 2006 deforestation on the Brazilian side of the border collapsed, and the discontinuity at the border was eliminated.

A series of papers have documented in great detail the impacts of specific policies introduced in this period by using variation within Brazil to identify the effect of specific policies. We summarize the main papers in this literature in Table A4. Many show that targeted policies such as the creation of protected areas[21] and targeted enforcement efforts in priority municipalities[22] contributed to reducing deforestation. The same has been shown to hold for policies targeting private rural properties, such as environmental registration and restricting access to rural credit.[23] We discuss these targeted policies and investigate the heterogeneity of effects at the border in regions subject to these policies in Section 5.5.

But each of these policies targets a specific piece of the puzzle, and one cannot simply combine the existing estimates to identify the total impact of Brazilian efforts to reduce deforestation. Similarly, while others have documented the overall Brazilian time series decline in deforestation – e.g., Nepstad et al. (e.g., 2009); Hargrave and Kis-Katos (e.g., 2013); Godar et al. (e.g., 2014); Assunção et al. (e.g., 2015) – this may conflate policy-induced changes with other changes in global demand for agricultural products. Our paper, by estimating the total "Brazil" effect at the border,brings a new approach to fill this gap. By focusing on border areas and comparing the Brazilian Amazon with nearby forests in other countries not subject to Brazilian legal changes, we can identify the difference in land exploitation imposed by Brazilian policies overall relative to those of its neighbors. Our results point to an important role for Brazilian policy in reducing deforestation rates even in remote parts of the country, and in particular, we show that deforestation rates went from being 3-4 times higher in Brazil compared to neighboring areas to being almost indistinguishable from its neighbors.

Second reversal – pro-exploitation period. The second reversal we document empirically – the increase in deforestation in Brazil starting around 2014 – is associated with a weakened commitment to environmental regulation in Brazil. Specifically, Brazilian environmental governance was undermined by the growing political power of the agriculture sector, consecutive weak governments, and scarce public resources (see Appendix

[21] E.g., Soares-Filho et al. (2010); Nolte et al. (2013); Pfaff et al. (2014); Herrera et al. (2019).
[22] E.g., Arima et al. (2014); Assunção and Rocha (2019); Cisneros et al. (2015); Assunção et al. (2019)
[23] E.g., Alix-Garcia et al. (2018); Gibbs et al. (2015); Assunção et al. (2019).

B.1).[24] The New Forest Code approved in 2012 represents a milestone in this process. For example, it granted amnesty to those who had engaged in illegal deforestation before 2008. Though contested in the Supreme Court (which ratified the text in 2018), the perspective of a potential amnesty introduced considerable uncertainty as to whether illegal deforestation would be effectively prosecuted and condemned as a crime.

2014 in particular was a particularly turbulent year for the federal government. After massive civil unrest in 2013 and with elections at the end of the year, the economy began showing signs of a long-lasting economic crisis. Simultaneously, a major corruption scandal erupted involving key politicians from the administration, culminating in the impeachment of the sitting president in 2016. The upshot of these political and economic crises was that by 2016, the budget of the Brazilian Environmental Agency (IBAMA) was only 57 percent of its budget in 2013 (see Appendix B.1). The enforcement capacity of the Environmental Agency further deteriorated with the next two presidents. In this period, the government took a number of actions that in practice may have facilitated extration, such as simplifying the requirement for titling occupied unclaimed public lands in 2016, granted further amnesty to past environmental crimes, and implemented an ambitious process of environmental deregulation. We are not aware of specific papers linking the recent upward trends in deforestation in Brazil to the slow weakening of Brazilian policies. But on net, our estimates based on the discontinuites at the border suggest that this overall relaxation undid about half of the gains from the 2006-2013 period.

5.4 Robustness and Alternative Explanations.

The empirical results above are robust to a series of alternative specifications and samples. Table 4 column 1 shows the estimates of our baseline RD specifications using OLS and control for slope and distance to water, use linear polynomials, and are estimated using the entire Brazilian border. As in Figure 3b, we show results grouping years in three periods: 2001-2005, 2006-2013, and 2014-2020. The remaining columns of Table 4 show that our results are robust when we use 11, 50 and 100km bandwidths. Table 5 shows that the results are qualitatively similar if we: a) do not include the slope and distance to water controls; b) exclude a 220km buffer around the peak of Mount Roraima.[25]; c) use quadratic polynomials; d) add additional infrastructure controls (measured as distance to roads and distance to urban areas); e) use a uniform kernel; f) estimate using Poisson models. Figure 4b presents the year by year estimates using the Poisson model.

We also estimate results restricting the sample to areas around artificial borders, as in

[24]See, e.g., Tollefson (2016); Fearnside (2016); Viola and Franchini (2017); Crouzeilles et al. (2017); Rochedo et al. (2018); Freitas et al. (2018); Soterroni et al. (2018); Tollefson (2018).

[25]This is a small section of the northern border with Venezuela, which is coincident with a mountain ridge and the only part of the border where there are differences in slope at the border.

Alesina et al. (2011) – i.e., borders arbitrarily drawn by former colonizers which appear as straight lines on a map.[26] For these borders, there is no geographic feature at the border, usually not even so much as a fence. These areas correspond to 10 percent of our sample, so our standard errors are correspondingly larger. Nevertheless, we find even larger effects during the period of deforestation slowdown (Table 5 columns 6 and 7). We do not observe a statistically significant ramp up post-2014 in deforestation in this subsample.

Finally, one possible alternative explanation for the precipitous change we observe in 2006 is a differential change in output prices. Hargrave and Kis-Katos (2013) and Assunção et al. (2015) argue that commodity prices cannot account for the observed change in deforestation rates. Nonetheless, to investigate this, we obtained national domestic farmgate prices for soybeans, the main crop in these regions, for both Brazil and Bolivia (the border country closest to the Brazilian agricultural frontier), from the FAO (consistent data on cattle prices are not available). As shown in Figure A4, farmgate prices move almost in parallel in both countries through 2011, and there is no differential break in prices around 2006.

5.5 Heterogeneity in enforcement regimes within Brazil

The prior results suggest that Brazilian policy effects on deforestation reach all the way to the border. But what forms this power of the state to conserve its natural resources? That is, is this effective reach of the Brazilian state driven by *de jure* zoning regulations or by the enforcement of said regulations? To address these questions, we next probe heterogeneity in effects based on the land use classification of different areas *within* Brazil.

As we described in Section 3.1, land in the Brazilian Amazon is divided into three main zoning categories: areas that are protected for conservation and other reasons (e.g., national parks and indigenous land), areas that are under private ownership, and areas that are untitled and unclaimed. To explore whether changes in regulatory and enforcement regimes translated into differences in deforestation at the border, we re-estimate equation (5) separately for each of these three classes of land. Table 6 presents the estimated RD coefficient – i.e., γ from equation (5) – from a separate Poisson regression for each land type and period using 27km bandwidths.

First reversal – pro-conservation period. We first consider PAs created before 2004 to assess changes in enforcement regimes on deforestation. We see in Table 6 column 1 that when the national border abuts Brazilian protected areas (PAs) we observe *more* forest cover in 2000 and *less* deforestation on the Brazilian side until 2013. This is consistent

[26] Appendix B.3 discuss the formation of the border. We map the segments of artificial border in Figure A3b in the appendix.

with these areas having a stronger regulatory and enforcement protection throughout this period.[27]

In contrast, we see more deforestation on private lands on the Brazilian side of the border throughout the entire period. On this type of land, a degree of deforestation (up to 20% of the property area) is still allowed. The government implemented specific programs to incentivize landowners to comply with the land use regulations. For example, in 2008, the government conditioned access to subsidized agricultural credits on environmental compliance – Assunção et al. (2019) show that this policy contributed to reducing deforestation in private properties. The government also created a centralized rural land register (*Cadastro Ambiental Rural*/CAR) georeferencing the limits of all private properties – Alix-Garcia et al. (2018) estimates the registration program reduced forest loss in registered lands by 9% in Mato Grosso and Pará states. Consistent with these findings, Table 6 column 2 shows a dramatic fall in the differential effect of Brazilian policies on private properties that abut the national borders between 2001-2005 and 2006-2013, the time frame studied by Alix-Garcia et al. (2018) and Assunção et al. (2019).

For unclaimed lands that abut the border, we also observe *more* deforestation on the Brazilian side up until 2005. The magnitude of the discontinuity is eliminated between 2006 and 2013 when the government implemented significant regulatory changes respective deforesting these areas. For example, making deforesting these zones a felony and expropriating equipment of violators.

Second reversal – pro-exploitation period. After some years of effective policies in place, we see deforestation rates rising and the differential effect of Brazilian policies to dim in the 2014-2020 period. Differently from the first reversal, we there is no substantial regulatory changes in this period to support the environmental loss observed. While the New Forest Code was sanctioned in 2012 giving amnesty to private landowners that deforested beyond the legal limit, it has been challenged in court and turned fully effective only in 2018. This is, however, a period in which the enforcement capacity was continuously diminished. For example, the budget of the environmental agency (IBAMA) suffered massive cuts year after year, implying substantially reduced personnel and resources to monitoring and enforcement operations. Our results suggest that weaker enforcement compromised the effectiveness of the policies implemented in the previous decade everywhere.

Table 6 column 1 shows that PAs at the border becomes less effective in protecting the forest in this later period; although the point estimate for the 2014-2020 period is still negative, it is about a third of the point estimate for 2006-2013 and is not statistically

[27]This finding is in line with several studies showing that PAs have been associated with lower deforestation (Nolte et al., 2013; Pfaff et al., 2015).

different from zero (p-value equal to 0.164). This is evidence that, despite *de jure* regulatory protection, the effectiveness of PAs on preserving the forest have been diminishing for the first time.

In column 2, our estimates show that the differentially higher deforestation in private properties increases by 21% in this later period (between 2006-2013 and 2014-2020). The proposed amnesty for past environmental crimes, while still not sentenced, may have lowered the expectation of landowners on the likelihood of future fines, driving lower compliance to environmental law.

In unclaimed land, we find a positive point estimate for the 2014-2020 period. We calculate that the differential effect of Brazilian policies on deforestation in these areas grew from -0.156 to 0.175 percentage points in this period. Although statistically not significant, this indicates that the deforestation rate goes back to being differentially higher on unclaimed land on the Brazilian side of the border.

In sum. In the first reversal, Brazilian efforts to cope with illegal deforestation were effective in reducing forest loss exactly in those areas with weaker regulation and enforcement. However, as the centralized enforcement effort loses power, deforestation accelerated in all these areas. To further analyze the importance of enforcement, we investigate heterogeneity in effects based on transportation costs and proximity to enforcement bases from the Brazilian Environmental Agency (IBAMA) at the beginning of the period. Table 7 shows that both reversals comes from changes in deforestation in pixels closer to roads and closer to enforcement. It shows no clear pattern of differential deforestation rates in further away pixels.

This analysis thus highlights that conservation depended on the continuous enforcement of national regulations. Overall, these results confirm that – even in these areas very close to the international border – differences in deforestation map to changes in land use regulations and enforcement *within* Brazil.

5.6 Heterogeneity by bordering country

The border discontinuity that our identification strategy exploits captures the net policy difference at the border. Although Figure A2 suggests that most of the effects we document come from decreased, and subsequently increased, deforestation on the Brazilian side of the border, our estimates could be influenced by changes in the environmental policies in other countries in the Amazon region, as documented in Section 3.2. As Tables A1 and A2 show, we do not observe changes in environmental regulation and enforcement in neighboring countries with the same depth of the changes we observe in Brazil in this period.

Nonetheless, we investigate whether the effects we see are homogeneous across all country border segments by re-estimating equation (5) separately for the border segment with each country. Table 8 presents the results. Our estimated effects are almost identical when comparing the Brazilian border with Bolivia, the country 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. Although smaller in magnitude and not statistically significant, we also observe a pattern of double reversal in the border segment with Peru, the second country border closer 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. It is important to note, however, that 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.

6 Counterfactual exercises

How much deforestation would there have been had the Brazilian policies from the early 2000s or the late 2000s remained in place until 2020? In this section, we shed light on this question using the spatial regression discontinuity to perform counterfactual exercises based on a stylized model of land use. First, we calculate what the deforestation dynamics would have resembled after 2014 if Brazilian environmental governance had remained strong in that period. Second, we quantify what the deforestation dynamics would have resembled if the pro-conservation policies (PPCDAm) had not been implemented.

Estimation. We estimate the model in equation (4) for each year. This equation is similar to the main regression discontinuity equation (5) in Section 5.1. As in the previous section, we restrict the sample to pixels within 27km of the international border such that we can flexibly control by distance to the border. Let $\hat{\Theta}_t$ be the set of estimated parameters for each year t. The estimated coefficients $\hat{\delta}_t$ capture the differential average environmental regulation cost in Brazilian relative its neighboring countries. We use these estimates to build our counterfactuals.

Counterfactuals. First, we project what land use would have looked like had Brazil retained the aggressive anti-deforestation policies in place from 2006-2013 through 2020.

Specifically, we project the counterfactual land use from 2014 to 2020 by replacing the average effect of Brazilian policy in each year ($\hat{\delta}_t$) by its average effect between 2006 and 2013 ($\Delta = \sum_{t=2006}^{2013} \hat{\delta}_t/8$) when PPCDAm was fully operational and environmental governance strong. We then calculate the counterfactual deforestation in each year as

$$\widetilde{\ln l_{it}^*} = \widehat{\ln l_{it}^*} - \hat{\delta}_t + \Delta. \tag{6}$$

In words, for each year t, we compute the counterfactual land use, $\widetilde{\ln l_{it}^*}$, equals to the fitted value land use based on equation (4), $\widehat{\ln l_{it}^*}$, discounting the estimated regulatory effect on land use in that year, $\hat{\delta}_t$, and imposing the counterfactual regulation Δ.

Figure 5 presents the results. The dark solid line shows the observed deforestation at the border, and the red dashed line shows counterfactual annual forest loss in the Brazilian Amazon. Our counterfactual shows that if Brazilian environmental governance had not been weakened after 2013, deforestation rates between 2014 and 2020 would have been 30% smaller than what we observed. We see that 2016 and 2017 were years with particularly high avoidable deforestation – the distance between the solid and the dashed red line.

Second, we calculate what the deforestation dynamics would have looked like in the Brazilian Amazon at the border had PPCDAm never been implemented. Specifically, we calculate the counterfactual annual forest loss from 2006 onward under the average environmental regulation of 2001-2005 ($\Delta = \sum_{t=2001}^{2005} \hat{\delta}_t/5$). The blue dashed line in Figure 5 presents this counterfactual scenario. We see that, between 2006 and 2020, the counterfactual deforestation rate would have been 48% higher than the observed one had PPCDAm never been implemented. We see the largest difference between counterfactual and observed annual forest loss between 2006 and 2013. The counterfactual estimates are remarkably similar to what is observed towards the end of the period, in particular in 2016 and 2017. This evidence is in line with the gradual dismantling of Brazilian environmental policy in the Amazon.

As with any counterfactual analysis, this analysis comes with some caveats. The goal of this exercise is to illustrate the aggregate implications of pro-conservation or pro-exploitation policies over time. To do so, we rely on a simple semi-parametric model and granular land use data for the region. Because our regression discontinuity exercise estimates the local average differential effect of Brazilian policies on deforestation, we do not claim that this exercise captures the comprehensive effects of the Brazilian policies in the entire Amazon region. This exercise does, however, help quantify the damage caused by environmental deregulation in Brazil over the last decade, at least in the areas close to the border.

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. In particular, we document a sharp decline in deforestation associated with new environmental policies that are then slowly eroded. To help us interpreting the main drivers of policy reversals, we use an application of the model in Harstad (2020).[28]

Setup. Time t is discrete and infinite. A president P_t decides in each period the fraction of an exhaustible resource – e.g., forests – to exploit, $s_t \in [\underline{x}, \bar{x}] \subseteq [0,1]$. The limits to exploitation are given by institutional and enforcement constraints, $\underline{x}$, and by technological and market capacity, $\bar{x}$. That is, without enforcement capacity, the president has limited power to prevent exploitation. The difference $\bar{x} - \underline{x}$ represents the amount of discretion the president has to promote conservation or exploitation of natural resources. In each period, the incumbent president is set out of the office with probability $p \in (0,1)$.

Exploitation produces economic benefits $b \geq 0$ for those not in power and produces private benefits to the incumbent president $\bar{b} \geq b$. The value derived by conservation is heterogeneous across presidents and changes over time. The preferences for conservation, c_t, is i.i.d. and uniformly distributed on $[\underline{c}, \bar{c}]$. Let $\delta \in (0,1)$ be the time discount.

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 $s_t\bar{b} + (1-s_t)c_t$. In period $t+1$, only $1-s_t$ of the natural resource remains to be exploited by the next president. As this is a stationary game, we restrict attention to equilibrium in stationary strategies – Harstad (2020) also consider alternative equilibria.

The president maximizes his expected utility solving

$$\max_{s_t \in [\underline{x}, \bar{x}]} s_t\bar{b} + (1-s_t)(c_t + \delta V) \tag{7}$$

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

$$s_t(c_t) = \begin{cases} \underline{x} & \text{if } c_t > \theta(x) \\ [\underline{x}, \bar{x}] & \text{if } c_t = \theta(x) \\ \bar{x} & \text{if } c_t < \theta(x) \end{cases} \tag{8}$$

$$\text{where } \theta(x) \equiv \delta p\left(\bar{b} - b\right)x + (1-\delta)\bar{b} \tag{9}$$

[28] Please, refer to Harstad (2020) for proofs and extensions.

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, expected exploitation is

$$x = \frac{1}{1 - \delta p \left(\bar{b} - b\right) \left(\bar{x} - \underline{x}\right) / \left(\bar{c} - \underline{c}\right)} x_t(0). \tag{10}$$

Drivers of policy reversals. The model shows that the president implements stronger conservation policies, $s_t = \underline{x}$, if it derives sufficiently large benefits from preservation, $c_t > \theta(x)$. So, the election of a new president with stronger environmental concerns can explain an abrupt increase in conservation efforts. The political shifts in Brazil in the early-2000s is consistent with this conjecture.

The main equilibrium object that determines how strong these preferences need to be such that a pro-conservation policy is implemented is $\theta(x)$. Equations (9) and (10) show two main factors that, by increasing $\theta(x)$, makes more unlikely to observe pro-conservation policies in equilibrium – and more likely to observe a policy rollback if they are ever implemented.

First, the threshold for the environmental preferences that sustain a pro-conservation policy is larger the larger is the president's private benefits from exploitation, $\bar{b}$. For example, increased lobbying from the agriculture sector may increase such private benefits making more likely that the president pivots towards pro-exploitation policies – refer to Harstad (2020) for a formal discussion of lobbying in this setting. Related, Harstad and Svensson (2011) show within a dynamic model that stronger penalties imposed by the a central government make firms, here agriculture producers, more likely to engage in lobbying. Thus, short-term private economic benefits may make governments discontinue conservation policies.

Second, greater government discretion on resources exploitation, $\bar{x} - \underline{x}$, increases the threshold for a pro-conservation policy. For example, the government needs enforcement capacity to implement a lower resource exploitation when it attempts to conserve. When such discretion is low, there is small gains from implementing a pro-conservation policy and, importantly, small opportunity costs of forgone private benefits from exploitation. Over time, technological development and improved enforcement capacity increases the power of the state over resource utilization (i.e., smaller $\underline{x}$), and, consequently, the opportunity cost of the private returns from exploitation. In equilibrium, greater government discretion makes more unlikely to sustain a pro-conservation policy.

All in all, these two elements make more likely to observe the dismantling of pro-conservation policies and also increase the expected resource exploitation in long-run. We see strong evidence of both mechanisms in our setting.

8 Conclusion

Climate change pays no regard to national borders and yet the policies that constrain or exacerbate it fall within national jurisdictions. It has made conservation of natural resources a more salient issue with the spotlight focused most brightly on tropical forests. This has led to enactment of a raft of national conservation policies. These collide with low state capacity, poor enforcement, complicit states and illegal extraction. Countries, and particularly poor countries, may prefer the immediate economic gains that come from exploitation to the uncertain, future returns from conservation.

By using fine grained satellite data we are able to test whether Brazilian conservation policies had any bite at the national border. This is an interesting exercise as there has been considerable skepticism regarding the ability of the state to exercise control over global ecosystems. In effect, the ability of the state to conserve ecosystems may fall as locations become remote, which opens up opportunities for those who want to illegally extract resources. Given that rapid environmental degradation in developing countries is being driven by illegal extraction it is important to empirically assess whether or not the state has the power to conserve natural resources in these remote locations.

This is the contribution of this paper. We observe sharp discontinuities in forest loss at the border, a diminution in these as Brazil implemented policies to detect and penalize illegal logging, but then document a second reversal once Brazilian enforcement slackens. Our results therefore demonstrate the power of the state to determine whether wilderness ecosystems are conserved or exploited. Moreover, 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 (through the coordination of several government agencies). 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 has moved from congruence to dissonance as regards international efforts to arrest climate change by slowing tropical deforestation.

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 (Hansen et al., 2013). Whether or not governments act on this information is another matter and depends largely on the political willingness to do so. 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, underlie how difficult it is to maintain a pro-conservation equilibrium when there are short term economic gains to be had from exploiting natural resources. More research is needed to understand how the incentives of government's intent on promoting growth and development can be brought in line with longer-term conservation objectives.

References

Aker, J. C., M. W. Klein, S. A. O'Connell, and M. Yang (2014). Borders, Ethnicity and Trade. *Journal of Development Economics 107*, 1–16.

Alesina, A., W. Easterly, and J. Matuszeski (2011). Artificial States. *Journal of the European Economic Association 9*(2), 246–277.

Alix-Garcia, J., L. L. Rausch, J. L'Roe, H. K. Gibbs, and J. Munger (2018). Avoided Deforestation Linked to Environmental Registration of Properties in the Brazilian Amazon. *Conservation Letters 11*(3), e12414.

Allan, J. R., O. Venter, and J. E. Watson (2017). Temporally Inter-Comparable Maps of Terrestrial Wilderness and the Last of the Wild. *Scientific Data 4*, 170187.

Anderson, L. O., S. De Martino, T. Harding, K. Kuralbayeva, and A. Lima (2016). The Effects of Land Use Regulation on Deforestation: Evidence from the Brazilian Amazon. *OxCarre Working Paper No. 172*.

Andrade, L. C. d. (2016). Spillover Effects of Blacklisting Policy in the Brazilian Amazon. Working Paper.

Arima, E. Y., P. Barreto, E. Araújo, and B. Soares-Filho (2014). Public Policies Can Reduce Tropical Deforestation: Lessons and Challenges from Brazil. *Land Use Policy 41*, 465–473.

Asher, S., T. Garg, and P. Novosad (2017). The Ecological Footprint of Transportation Infrastructure.

Assunção, J., C. Gandour, and R. Rocha (2013). DETERring Deforestation in the Brazilian Amazon: Environmental Monitoring and Law Enforcement. Technical report, Climate Policy Initiative.

Assunção, J., C. Gandour, R. Rocha, and R. Rocha (2019). The Effect of Rural Credit on Deforestation: Evidence from the Brazilian Amazon: Effect of Rural Credit on Deforestation. *The Economic Journal 130*(626), 290–330.

Assunção, J., C. C. Gandour, and R. Rocha (2015). Deforestation Slowdown in the Legal Amazon: Prices or Policies? *Environment and Development Economics 20(6)*, 697–722.

Assunção, J., R. McMillan, J. Murphy, and E. Souza-Rodrigues (2019). Optimal Environmental Targeting in the Amazon Rainforest. Working Paper 25636, National Bureau of Economic Research.

Assunção, J. and R. Rocha (2019). Getting Greener by Going Black: the Effect of Blacklisting Municipalities on Amazon Deforestation. *Environment and Development Economics 24*(2), 115–137.

Azevedo, A. A., R. Rajão, M. A. Costa, M. C. Stabile, M. N. Macedo, T. N. dos Reis, A. Alencar, B. S. Soares-Filho, and R. Pacheco (2017). Limits of Brazil's Forest Code as a Means to End Illegal Deforestation. *Proceedings of the National Academy of Sciences 114*(29), 7653–7658.

Balboni, C., R. Burgess, and B. A. Olken (2021). The origins and control of forest fires in the tropics. *Unpublished*.

Baragwanath, K. and E. Bayi (2020). Collective Property Rights Reduce Deforestation in the Brazilian Amazon. *Proceedings of the National Academy of Sciences 117*(34), 20495–20502.

BenYishay, A., S. Heuser, D. Runfola, and R. Trichler (2017). Indigenous Land Rights and Deforestation: Evidence from the Brazilian Amazon. *Journal of Environmental Economics and Management 86*, 29 – 47.

Black, S. E. (1999). Do Better Schools Matter? Parental Valuation of Elementary Education. *The Quarterly Journal of Economics 114*(2), 577–599.

Bonilla-Mejía, L. and I. Higuera-Mendieta (2019). Protected Areas under Weak Institutions: Evidence from Colombia. *World Development 122*, 585 – 596.

Boulton, C. A., T. M. Lenton, and N. Boers (2022). Pronounced loss of amazon rainforest resilience since the early 2000s. *Nature Climate Change 12*(3), 271–278.

Brito, B., J. Almeida, P. Gomes, and R. Salomão (2021). 10 Essential Facts About Land Tenure Regularization in the Brazilian Amazon. Technical report, Belém: Imazon.

Burgess, R., M. Hansen, B. A. Olken, P. Potapov, S. Sieber, et al. (2012). The Political Economy of Deforestation in the Tropics. *The Quarterly Journal of Economics 127*(4), 1707–1754.

Calonico, S., M. D. Cattaneo, and R. Titiunik (2014). Robust Nonparametric Confidence Intervals for Regression-Discontinuity Designs. *Econometrica 82*(6), 2295–2326.

Cameron, A. C., J. B. Gelbach, and D. L. Miller (2012). Robust Inference with Multiway Clustering. *Journal of Business & Economic Statistics*.

Cardoso, F. H. and B. Winter (2006). *The Accidental President of Brazil: a Memoir.* New York, PublicAffairs.

CGU, C. (2016). Relatório de Avaliação da Execução de Programas de Governo N. 69: Ações Relativas á Fiscalização Ambiental sob Responsabilidade do IBAMA. *Brasília: CGU*.

Chen, Y., A. Ebenstein, M. Greenstone, and H. Li (2013). Evidence on the Impact of Sustained Exposure to Air Pollution on Life Expectancy from China's Huai River policy. *Proceedings of the National Academy of Sciences 110*, 12936–12941.

Chimeli, A. B. and R. R. Soares (2017). The Use of Violence in Illegal Markets: Evidence from Mahogany Trade in the Brazilian Amazon. *American Economic Journal: Applied Economics 9*(4), 30–57.

Cisneros, E., S. L. Zhou, and J. Börner (2015). Naming and Shaming for Conservation: Evidence from the Brazilian Amazon. *PLoS ONE 10*(9), e0136402.

Cogneau, D. and A. Moradi (2014). Borders that Divide: Education and Religion in Ghana and Togo Since Colonial Times. *Journal of Economic History*, 694–729.

Conley, T. G. (1999). GMM Estimation with Cross Sectional Dependence. *Journal of Econometrics 92*(1), 1–45.

Crouzeilles, R., R. Feltran-Barbieri, M. S. Ferreira, and B. B. Strassburg (2017). Hard Times for the Brazilian Environment. *Nature Ecology & Evolution 1*(9), 1213.

Dasgupta, P. (2021). *The Economics of Biodiversity: The Dasgupta Review.* HM Treasury.

Dasgupta, P. S. and G. M. Heal (1979). *Economic theory and exhaustible resources.* Cambridge University Press.

Dell, M. (2010). The Persistent Effects of Peru's Mining Mita. *Econometrica 78*(6), 1863–1903.

Dell, M., N. Lane, and P. Querubin (2018). The Historical State, Local Collective Action, and Economic Development in Vietnam. *Econometrica 86*(6), 2083–2121.

Dell, M. and B. A. Olken (2020, 03). The Development Effects of the Extractive Colonial Economy: The Dutch Cultivation System in Java. *The Review of Economic Studies 87*(1), 164–203.

Dinerstein, E., C. Vynne, E. Sala, A. R. Joshi, S. Fernando, T. E. Lovejoy, J. Mayorga, D. Olson, G. P. Asner, J. E. Baillie, et al. (2019). A global deal for nature: guiding principles, milestones, and targets. *Science advances 5*(4), eaaw2869.

Donaldson, D. and A. Storeygard (2016). The view from above: Applications of satellite data in economics. *Journal of Economic Perspectives 30*(4), 171–98.

FAO (2020). Global forest resource assessment - key findings.

Fearnside, P. M. (2016). Brazilian Politics Threaten Environmental Policies. *Science 353*(6301), 746–748.

Ferraro, P. J., M. M. Hanauer, D. A. Miteva, G. J. Canavire-Bacarreza, S. K. Pattanayak, and K. R. E. Sims (2013). More Strictly Protected Areas are not Necessarily More Protective: Evidence from Bolivia, Costa Rica, Indonesia, and Thailand. *Environmental Research Letters 8*(2), 025011.

Ferreira, A. (2021). Satellites and fines: Using Monitoring to Target Inspections of Deforestation.

Franklin Jr, S. L. and R. S. Pindyck (2018). Tropical forests, tipping points, and the social cost of deforestation. *Ecological Economics 153*, 161–171.

Freitas, F. L., G. Sparovek, G. Berndes, U. M. Persson, O. Englund, A. Barretto, and U. Mörtberg (2018). Potential Increase of Legal Deforestation in Brazilian Amazon After Forest Act Revision. *Nature Sustainability 1*(11), 670.

Friedman, M. (1962). *Capitalism and freedom.* University of Chicago press.

Fujiwara, T., H. Laudares, and F. V. Caicedo (2017). Tordesillas, slavery and the origins of brazilian inequality.

Furtado, J. F. (2012). *Oraculos da Geografia Iluminista: Dom Luís da Cunha e Jean-Baptiste Bourguignon d'Anville na Construção da Cartografia do Brasil.* Editora UFMG.

Gelman, A. and G. Imbens (2019). Why High-Order Polynomials Should Not Be Used in Regression Discontinuity Designs. *Journal of Business & Economic Statistics 37*(3), 447–456.

Gibbs, H. K., L. Rausch, J. Munger, I. Schelly, and D. C. e. a. Morton (2015). Brazil's Soy Moratorium. *Science 347*(6220), 377–378.

Godar, J., T. A. Gardner, E. J. Tizado, and P. Pacheco (2014). Actor-Specific Contributions to the Deforestation Slowdown in the Brazilian Amazon. *Proceedings of the National Academy of Sciences 111*(43), 15591–15596.

Gopinath, G., P.-O. Gourinchas, C.-T. Hsieh, and N. Li (2011). International Prices, Costs, and Markup Differences. *American Economic Review 101*(6), 2450–2486.

Greenstone, M. and B. K. Jack (2015). Envirodevonomics: A research agenda for an emerging field. *Journal of Economic Literature 53*(1), 5–42.

Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. Turubanova, A. Tyukavina, D. Thau, S. Stehman, S. Goetz, T. Loveland, et al. (2013). High-Resolution Global Maps of 21st-Century Forest Cover Change (v1.6). *Science 342*(6160), 50–853.

Harding, T., J. Herzberg, and K. Kuralbayeva (2019). Commodity Prices and Robust Environmental Regulation: Evidence from Deforestation in Brazil. Technical report.

Hargrave, J. and K. Kis-Katos (2013). Economic Causes of Deforestation in the Brazilian Amazon: A Panel Data Analysis for the 2000s. *Environmental and Resource Economics 54*, 471–494.

Harstad, B. (2020). The Conservation Multiplier.

Harstad, B. (2022). Trade, trees and contingent trade agreements. *Working Paper*.

Harstad, B. and J. Svensson (2011). Bribes, Lobbying, and Development. *American Political Science Review 105*(1), 46–63.

Herrera, D., A. Pfaff, and J. Robalino (2019). Impacts of Protected Areas vary with the Level of Government: Comparing Avoided Deforestation across Agencies in the Brazilian Amazon. *PNAS; Proceedings of the National Academy of Sciences 116*(30), 14916–14925.

Holmes, T. J. (1998). The Effect of State Policies on the Location of Manufacturing: Evidence from State Borders. *Journal of Political Economy 106*(4), 667–705.

Hsiao, A. (2021). Coordination and commitment in international climate action: evidence from palm oil. *Unpublished, Department of Economics, MIT*.

Imbens, G. and K. Kalyanaraman (2012). Optimal Bandwidth Choice for the Regression Discontinuity Estimator. *The Review of Economic Studies 79*(3), 933–959.

IPBES (2018). *Plenary of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, 6th Session*.

IPCC (2022). *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Koch, N., E. K. H. J. zu Ermgassen, J. Wehkamp, F. J. B. Oliveira Filho, and G. Schwerhoff (2019). Agricultural Productivity and Forest Conservation: Evidence from the Brazilian Amazon. *American Journal of Agricultural Economics 101*(3), 919–940.

Krutilla, J. V. (1967). Conservation reconsidered. *American Economic Review 57*(4), 777–786.

Lipscomb, M. and A. M. Mobarak (2016). Decentralization and pollution spillovers: Evidence from the re-drawing of county borders in brazil. *The Review of Economic Studies 84*(1), 464–502.

Magruder, J. R. (2013). Can Minimum Wages Cause a Big Push? Evidence from Indonesia. *Journal of Development Economics 100*(1), 48 – 62.

Matricardi, E. A. T., D. L. Skole, O. B. Costa, M. A. Pedlowski, J. H. Samek, and E. P. Miguel (2020). Long-term forest degradation surpasses deforestation in the brazilian amazon. *Science 369*(6509), 1378–1382.

Michalopoulos, S. and E. Papaioannou (2014). National Institutions and Subnational Development in Africa. *The Quarterly Journal of Economics 129*(1), 151–213.

Miranda, J. J., L. Corral, A. Blackman, G. Asner, and E. Lima (2016). Effects of Protected Areas on Forest Cover Change and Local Communities: Evidence from the Peruvian Amazon. *World Development 78*, 288 – 307.

MMA, M. d. M. A. (2008). *Plano de Ação para Prevenção e Controle do Desmatamento na Amazônia Legal (PPCDAm). Documento de Avaliação 2004-2007.*

MMA, M. d. M. A. (2013). *Plano de Ação para Prevenção e Controle do Desmatamento na Amazônia Legal (PPCDAm) 3a Fase (2012-2015) pelo uso sustentável e conservação da Floresta.* Brasília.

Nelson, A. and K. M. Chomitz (2011). Effectiveness of Strict vs. Multiple Use Protected Areas in Reducing Tropical Forest Fires: A Global Analysis Using Matching Methods. *PLoS ONE 6*(8), e22722.

Nepstad, D., D. McGrath, C. Stickler, A. Alencar, A. Azevedo, B. Swette, T. Bezerra, M. DiGiano, J. Shimada, R. S. da Motta, et al. (2014). Slowing amazon deforestation through public policy and interventions in beef and soy supply chains. *Science 344*(6188), 1118–1123.

Nepstad, D., B. S. Soares-Filho, F. Merry, A. Lima, P. Moutinho, J. Carter, M. Bowman, A. Cattaneo, H. Rodrigues, S. Schwartzman, et al. (2009). The End of Deforestation in the Brazilian Amazon. *Science 326*(5958), 1350–1351.

Nolte, C., A. Agrawal, K. M. Silvius, and B. S. Soares-Filho (2013). Governance Regime and Location Influence Avoided Deforestation Success of Protected Areas in the Brazilian Amazon. *Proceedings of the National Academy of Sciences 110*(13), 4956–4961.

Pfaff, A., J. Robalino, D. Herrera, and C. Sandoval (2015). Protected Areas' Impacts on Brazilian Amazon Deforestation: Examining Conservation-Development Interactions to Inform Planning. *PLoS ONE 10*(7), e0129460.

Pfaff, A., J. Robalino, E. Lima, C. Sandoval, and L. D. Herrera (2014). Governance, Location and Avoided Deforestation from Protected Areas: Greater Restrictions Can Have Lower Impact, Due to Differences in Location. *World Development 55*, 7–20.

Pfaff, A. S. (1999). What Drives Deforestation in the Brazilian Amazon? Evidence from Satellite and Socioeconomic Data. *Journal of Environmental Economics and Management 37*(1), 26–43.

Pigou, A. C. (1920). *The Economics of Welfare.* Macmillian.

Pinkovskiy, M. L. (2017). Growth Discontinuities at Borders. *Journal of Economic Growth 22*(2), 145–192.

Probst, B., A. BenYishay, A. Kontoleon, and T. N. dos Reis (2020). Impacts of a large-scale titling initiative on deforestation in the brazilian amazon. *Nature Sustainability 3*(12), 1019–1026.

Rochedo, P. R., B. Soares-Filho, R. Schaeffer, E. Viola, A. Szklo, A. F. Lucena, A. Koberle, J. L. Davis, R. Rajão, and R. Rathmann (2018). The Threat of Political Bargaining to Climate Mitigation in Brazil. *Nature Climate Change 8*(8), 695.

Simonet, G., J. Subervie, D. Ezzine-de Blas, M. Cromberg, and A. E. Duchelle (2018). Effectiveness of a REDD+ Project in Reducing Deforestation in the Brazilian Amazon. *American Journal of Agricultural Economics 101*(1), 211–229.

Soares-Filho, B., P. Moutinho, D. Nepstad, A. Anderson, H. Rodrigues, R. Garcia, L. Dietzsch, F. Merry, M. Bowman, L. Hissa, R. Silvestrini, and C. Maretti (2010). Role of brazilian amazon protected areas in climate change mitigation. *PNAS; Proceedings of the National Academy of Sciences 107*(24), 10821–10826.

Soares-Filho, B., R. Rajão, M. Macedo, A. Carneiro, W. Costa, M. Coe, H. Rodrigues, and A. Alencar (2014). Cracking Brazil's Forest Code. *Science 344*(6182), 363–364.

Soterroni, A. C., A. Mosnier, A. X. Carvalho, G. Câmara, M. Obersteiner, P. R. Andrade, R. C. Souza, R. Brock, J. Pirker, F. Kraxner, et al. (2018). Future Environmental and Agricultural Impacts of Brazil's Forest Code. *Environmental Research Letters 13*(7), 074021.

Souza-Rodrigues, E. (2018). Deforestation in the Amazon: a Unified Framework for Estimation and Policy Analysis. *The Review of Economic Studies*.

Stern, N. (2007). *The Economics of Climate Change: The Stern Review*. HM Treasury.

Tollefson, J. (2016). Political Upheaval Threatens Brazil's Environmental Protections. *Nature News 539*(7628), 147–148.

Tollefson, J. (2018). Brazil's Lawmakers Renew Push to Weaken Environmental Rules. *Nature 557*(7706), 17.

Turner, M. A., A. Haughwout, and W. van der Klaauw (2014). Land Use Regulation and Welfare. *Econometrica 82*(4), 1341–1403.

Valdiones, A. P., P. Bernasconi, , R. Rajão, B. Manzolli, and coauthors (2021, Mar). Desmatamento Ilegal na Amazônia e no Matopiba: Falta Transparência e Acesso à Informação. *Instituto Centro de Vida, Imaflora, and WWF*.

Viola, E. and M. Franchini (2017). *Brazil and Climate Change: Beyond the Amazon*. New York, Routledge.

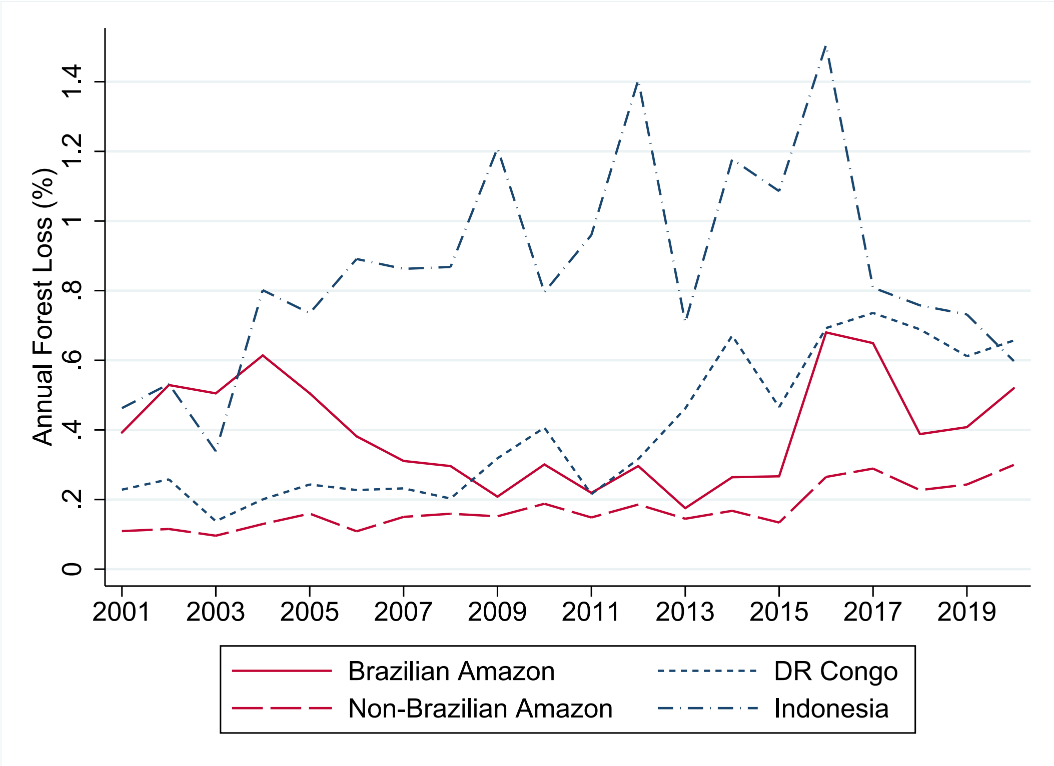
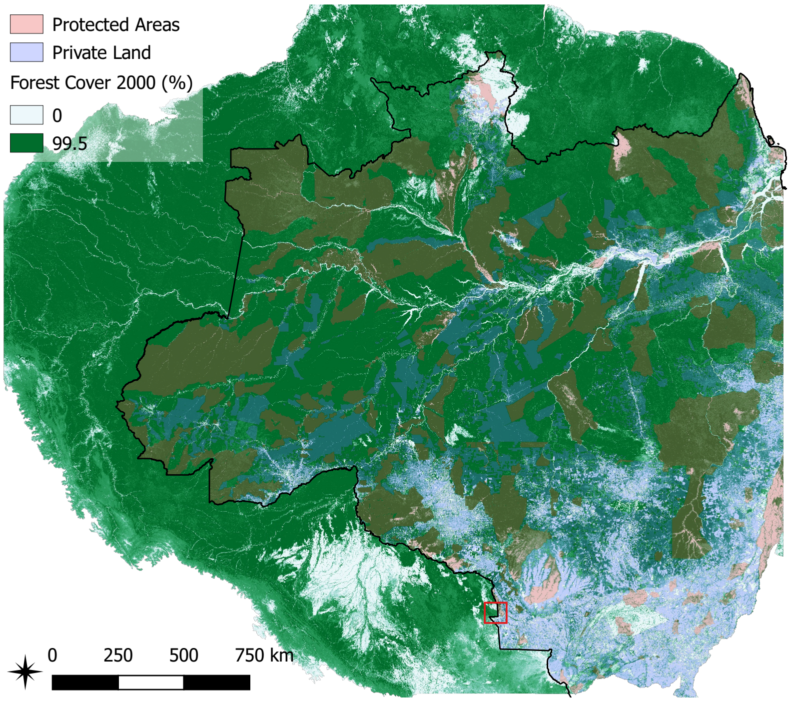
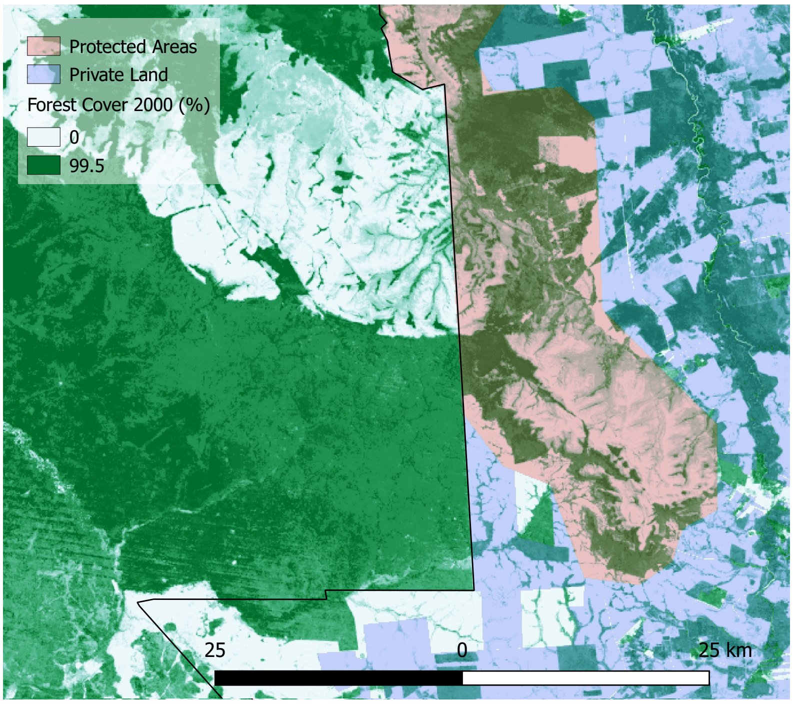


Figure 1: Forest Change in the Amazon, DR Congo and Indonesia, 2001-2020

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



(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 zoom in 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. Forest cover in shades of green (white are deforested pixels). Red shades mark Protected Areas as of 2004. Blue shades mark private non-protected land.

(a) Forest Cover in 2000

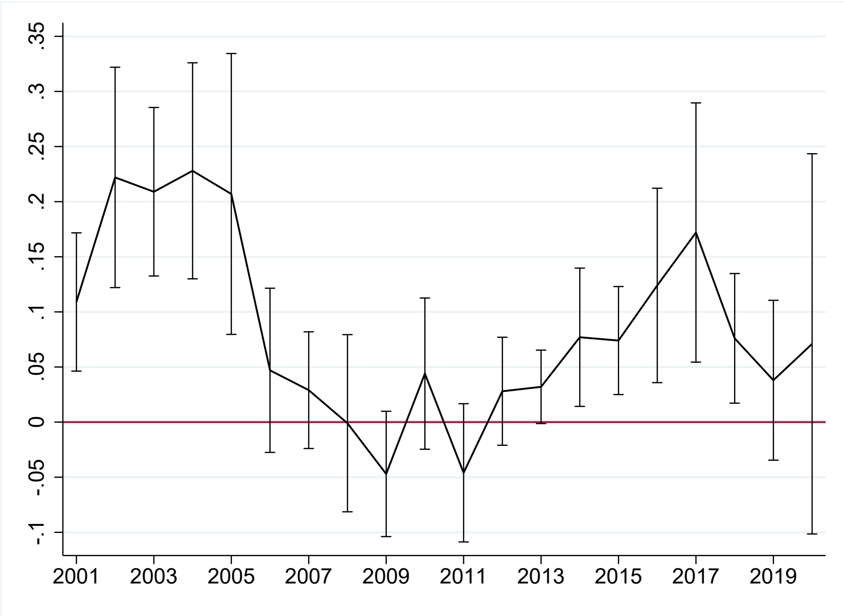
(b) Annual Forest Loss 2001–2005

(c) Annual Forest Loss 2006–2013

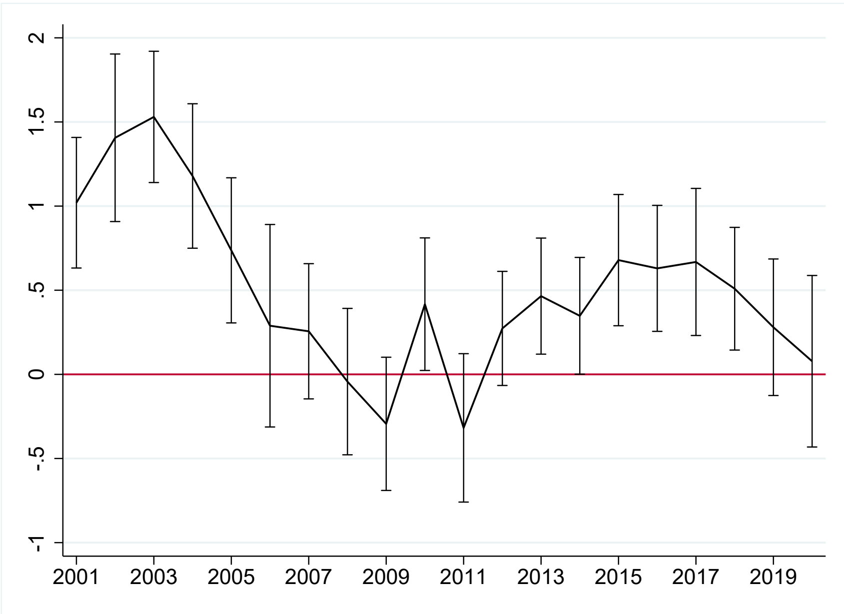
(d) Annual Forest Loss 2014–2020

Figure 3: Average Forest Cover and Annual Forest Loss by Distance from Brazilian Border

This figure shows the average forest cover in 2000 **(a)** and the average annual forest cover lost in each period between 2001 and 2020 **(b-d)** by 80 equal-sized bins of distances from the Brazilian border, up to 100 kilometers away from the Brazilian border. Positive distance represents Brazilian land, while negative distance represents non-Brazilian land. The red line shows the linear function of distance weighted by the number of observations in each bin. Panel **(a)** shows the abruptly smaller forest cover in 2000 at the Brazilian border. We can see that the discontinuous higher annual deforestation rates on the Brazilian side of the border between 2001 and 2005 – Panel **(b)** – level out between 2006 and 2013 – Panel **(c)**. Panel **(d)** shows that deforestation rates on the Brazilian side of the border returns being discontinuously higher between 2014 and 2020. Figures A2 shows annual forest loss at the border by year.



(a) OLS model



(b) Poisson model

Figure 4: Regression Discontinuity Coefficients by Year

This figure shows the regression discontinuity coefficients of the Brazilian effect, γ, on the percentage of annual forest loss by year, from equation (5) with linear running variables and 27km bandwidth — the average optimal bandwidth (Imbens and Kalyanaraman, 2012) of our dependent variables. The vertical bars represent 95 percent confidence intervals. Panel **(a)** shows the effects estimated using an OLS regression, and Panel **(b)** using a Poisson model. These estimates can be interpreted as a relative increase in annual deforestation rate on the Brazilian side of the border. All regressions control for the slope of the terrain and distance to water. Units of observations are 120-meter pixels around the whole Brazilian Amazon border; number of observations 31,711,264. Standard errors two-way clustered at overlapping 100km^2 grids; number of clusters 5,491.

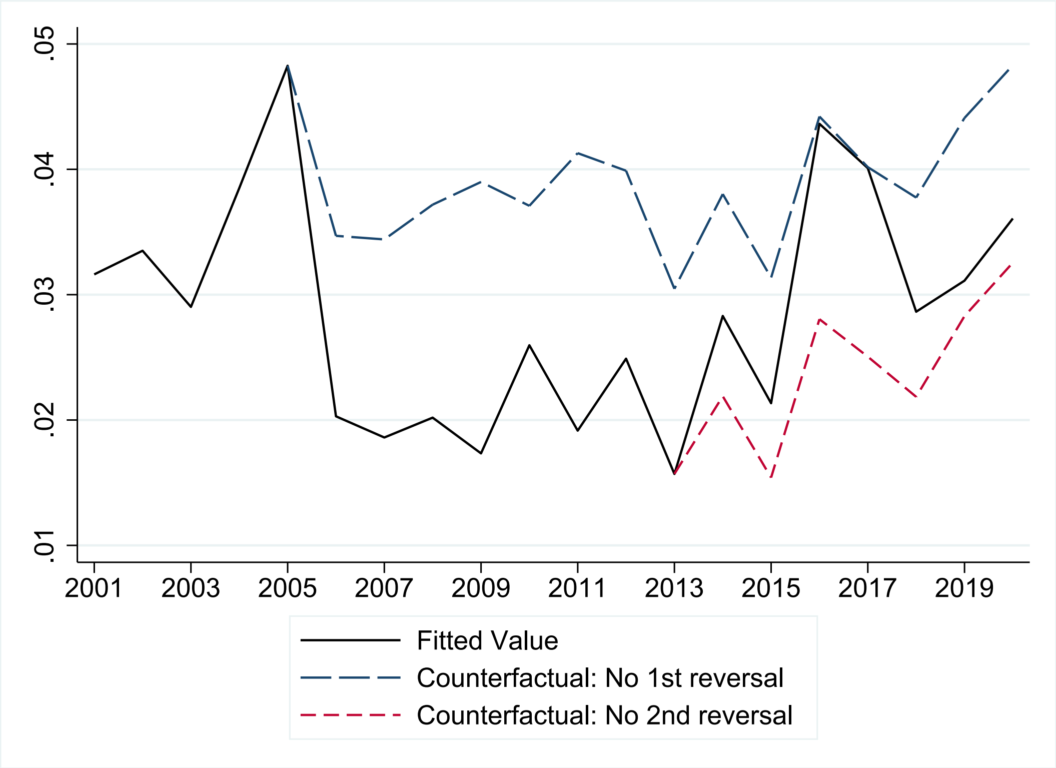


Figure 5: Counterfactual annual forest loss

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

Table 1: Covariates Balance Check – Linear Polynomials

	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 Artificiam Borders*				
Brazil dummy (γ)	.054	.000	-.003	-.001
	(.081)	(.037)	(.016)	(.020)

This table presents the 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 (5) with *linear polynomials* and triagular kernel. Panel A refers to the optimal bandwidth of (Imbens and Kalyanaraman, 2012), Panel B excluded 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%.

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 or segment of the border in *Brazil* and *Abroad* (bordering countries). The average optimal bandwidth (Imbens and Kalyanaraman, 2012) is 27km. Table A3 shows the summary statistics by year.

Table 3: 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	.7	46.3	.2
Private Non-PAs (%)	14.7	-	18.6	-
Unclaimed Non-PAs (%)	36.9	-	35.1	-
Area in Black Listed Counties (%)	3.0	-	1.5	-
Dist. to enforcement (km)	704	742	648.4	788
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 or segment of the border in *Brazil* and *Abroad* (bordering countries). Units of observations are 120-meter pixels around the whole Brazilian Amazon border.

Table 4: Results Forest Loss by Year

	Brazil dummy (γ) Maximum Distance from Border			
	27 km	11 km	50 km	100 km
	(1)	(2)	(3)	(4)
Forest cover in 2000 (%)	-4.006***	-2.218**	-4.890***	-5.430***
	(1.304)	(.977)	(1.152)	(.965)
Annual forest loss in 2001–2005 (%)	.221***	.159***	.269***	.281***
	(.040)	(.039)	(.035)	(.029)
Annual forest loss in 2006–2013 (%)	.023	-.011	.040**	.048***
	(.021)	(.023)	(.018)	(.015)
Annual forest loss in 2014–2020 (%)	.102***	.061**	.093***	.100***
	(.030)	(.029)	(.026)	(.021)

This table presents the 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 (5) 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 refers to the average optimal bandwidth (Imbens and Kalyanaraman, 2012) of our dependent variables, and column 2 refers to the optimal bandwidth (Calonico et al., 2014). Units of observations are 120-meter pixels around the whole Brazilian Amazon border; number of clusters and observations: 31,711,264 (column 1), 13,935,516 (column 2), 56,024,296 (column 3), and 105,283,103 (column 4). Standard errors two-way clustered at overlapping 100km^2 grids in parentheses; number of clusters: 5,491 (column 1), 2,979 (column 2), 8,961 (column 3), and 15,965 (column 4). Significance levels: *10%, **5%, ***1%.

Table 5: Robustness – Forest Loss by Period

Dep. Variable:	Brazil dummy (γ)							
	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)
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 presents the 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 (5). Bandwidth 25km, bias-correction bandwidth 53km, and triangular kernel as in column 1 Table 4. All regressions, except column 1, control for the slope of the terrain and distance to water. Column 2 uses a subset of the border excluding 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 further 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 use an uniform kernel, remaining columns use triangular kernel. Columns 7 and 8 use a Poisson model instead of OLS. Unit of observation: 120-meter pixels. Standard errors two-way clustered at overlapping 100km^2 grids in parentheses. Number of clusters and of observations: 5,088 and 29,298,310 (column 2), 5,491 and 31,711,264 (columns 5 and 8), and 5,491 and 31,711,264 (remaining columns). Significance levels: *10%, **5%, ***1%.

Table 6: Heterogeneous Effect by Land Type (Poisson model)

Dep. Variable:	Brazil dummy (γ)		
	Protected Areas	Private and Non-Protected Areas	Unclaimed and Non-Protected Areas
	(1)	(2)	(3)
Forest cover	.050***	-.382***	-.077***
in 2000 (%)	(.015)	(.048)	(.024)
Annual forest loss	-.821**	2.755***	.698***
in 2001–2005 (%)	(.337)	(.186)	(.203)
Annual forest loss	-.877***	1.309***	-.156
in 2006–2013 (%)	(.206)	(.178)	(.170)
Annual forest loss	-.294	1.584***	.175
in 2014–2020 (%)	(.211)	(.168)	(.154)

This table presents the Poisson regression estimates of the Brazilian effect, γ, on the percentage of forest cover in 2000 (row 1) and annual forest loss by period (remaining rows), from equation (5) with linear polynomials and rectangular kernel. All regressions control for the slope of the terrain and distance to water. Maximum Distance from Border 27 km. Each column refers to different land types within Brazil. Unit of observation: 120-meter pixels. Standard errors two-way clustered at overlapping 100km^2 grids in parentheses. Number of clusters and of observations: 4,542 and 23,522,027 (column 1), 3,891 and 18,200,157 (column 2), 4,566 and 21,716,062 (column 3). Significance levels: *10%, **5%, ***1%.

Table 7: Heterogeneous Effect by to Roads and Enforcement (Poisson model)

Dep. Variable:	Brazil dummy (γ)			
Heterogeneity by:	Distance to Roads		Distance from Enforcement	
	Below Median	Above Median	Below Median	Above Median
	(1)	(2)	(3)	(4)
Forest cover in 2000 (%)	-.117***	.003	-.112***	.010
	(.031)	(.008)	(.025)	(.016)
Annual forest loss in 2001–2005 (%)	1.184***	-.069	1.229***	-.238
	(.196)	(.304)	(.210)	(.262)
Annual forest loss in 2006–2013 (%)	.184	-.341	.212	-.387*
	(.161)	(.298)	(.171)	(.227)
Annual forest loss in 2014–2020 (%)	.497***	.049	.629***	-.479**
	(.142)	(.300)	(.157)	(.204)

This table presents the Poisson regression estimates of the Brazilian effect, γ, on the percentage of forest cover in 2000 (row 1) and annual forest loss by period (remaining rows), from equation (5) with linear polynomials and rectangular kernel. All regressions control for the slope of the terrain and distance to water; bandwidth 27km. Each column refers to results across subsamples of pixels closer or more distant from roads (columns 1 and 2; median distance 30km) and IBAMA's enforcement bases (columns 3 and 4; median distance 760km). Unit of observation: 120-meter pixels. Standard errors two-way clustered at overlapping 100km^2 grids in parentheses. Number of clusters and of observations: 3,010 and 15,855,848 (column 1), 3,054 and 15,855,416 (column 2), 2,790 and 15,855,632 (column 3), and 2,770 and 15,855,632 (column 4). Significance levels: *10%, **5%, ***1%.

Table 8: Heterogeneous Effect by Country Border (Poisson model)

Dep. Variable:	Brazil dummy (γ) by Border Segment				
	Border 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)

This table presents 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 (5) with linear polynomials and rectangular kernel. All regressions control for the slope of the terrain and distance to water; bandwidth 25km. Each column refers to results across different country border segments. Unit of observation: 120-meter pixels. Standard errors two-way clustered at overlapping 100km^2 grids in parentheses. Number of clusters and of observations: 1,357 and 7,831,297 (column 1), 1,030 and 5,878,676 (column 2), 926 and 5,392,008 (column 3), 962 and 5,601,639 (column 4), and 1,243 and 6,999,025 (column 5). Significance levels: *10%, **5%, ***1%.

Appendix (for online publication only)

This appendix contains the following material:

- Section A presents appendix figures and tables.
- Section B.1 presents a timeline with the relevant policy changes in the Brazilian Amazon.
- Section B.2 discusses the main policy changes in the other countries in the Amazon.
- Section B.3 presents greater details on the formation of the Brazilian border.
- Section B.4 presents additional evidence on local market integration.

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 A4 and A5.

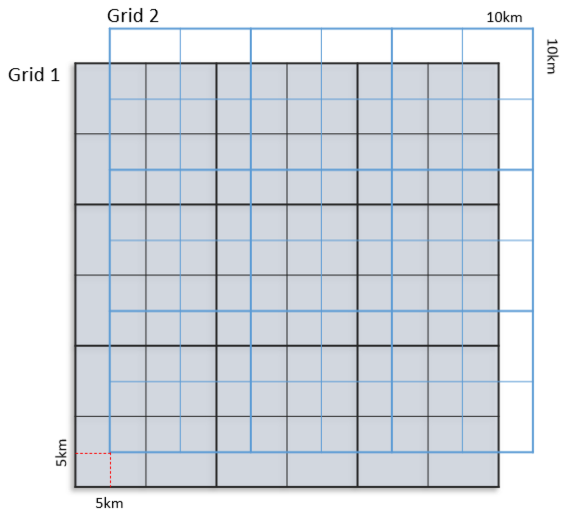


Figure A1: Example Two-Way Cluster Grids

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.

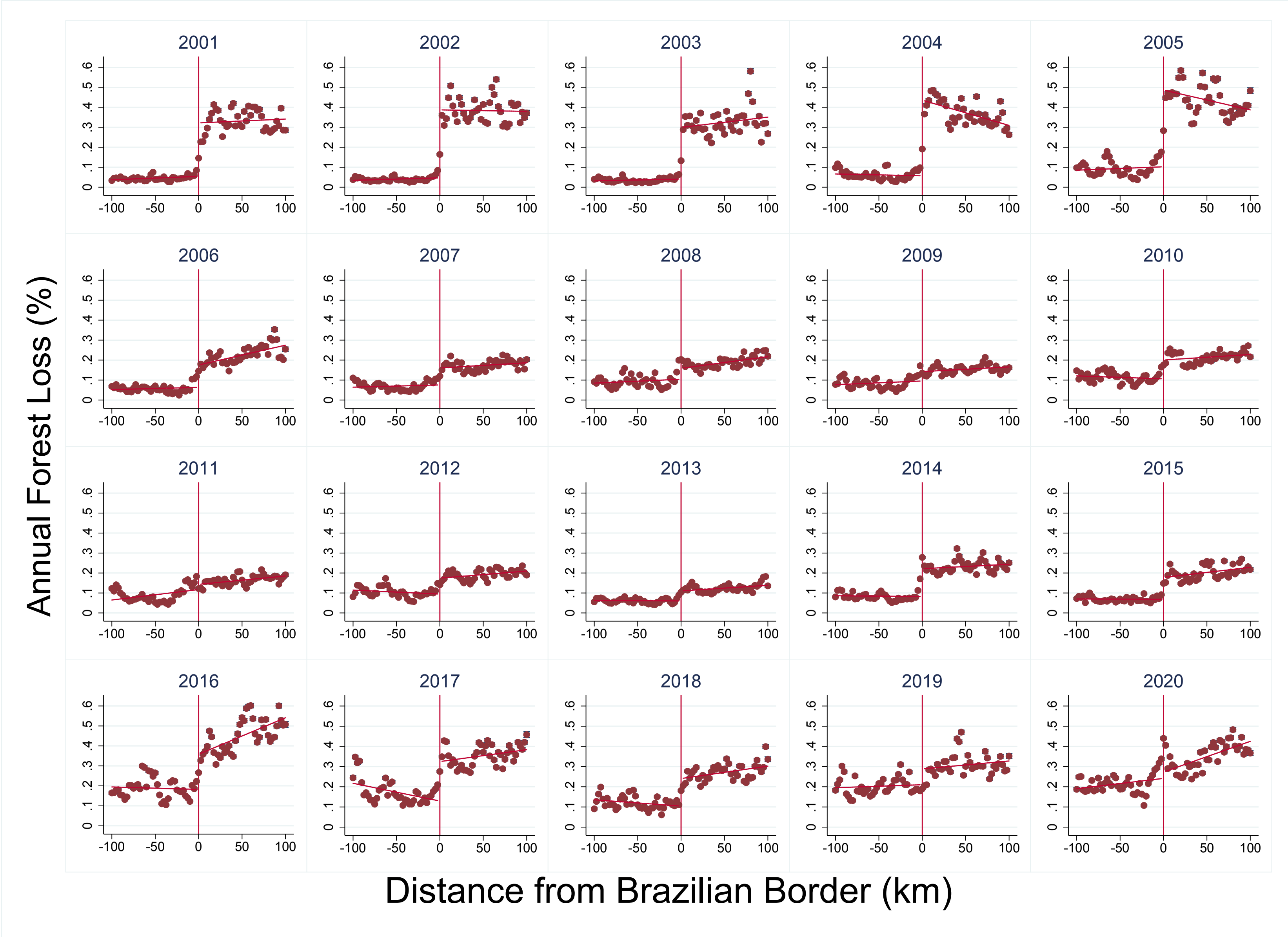
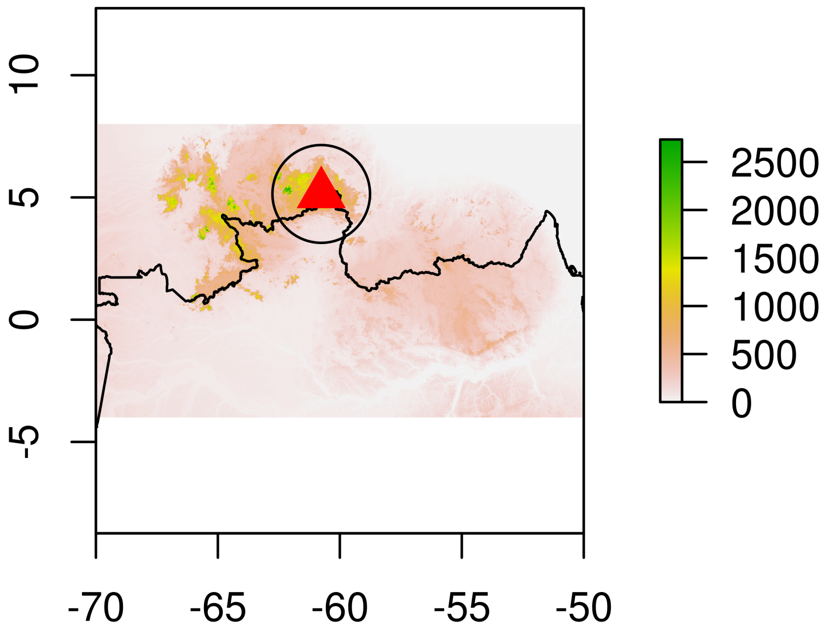
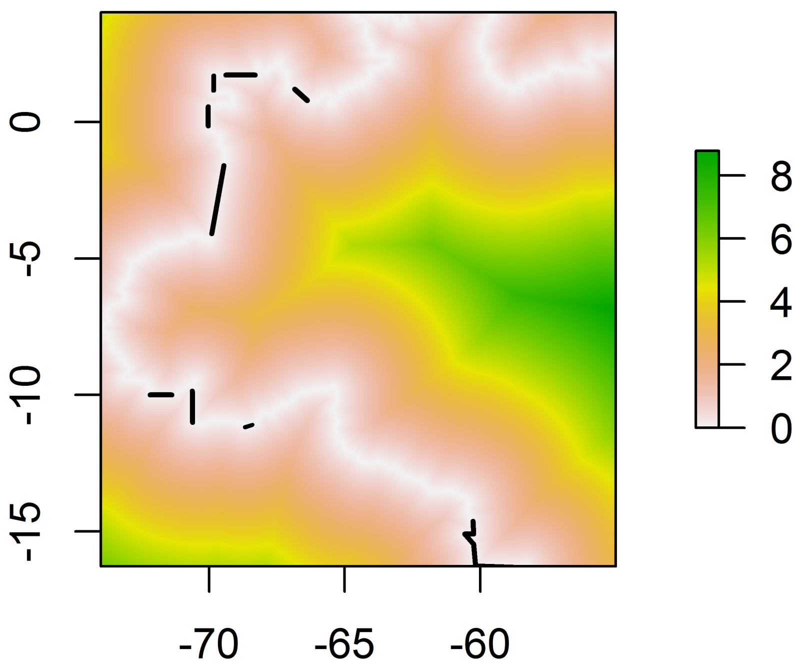


Figure A2: Annual Forest Loss at the Border by Year – 2001-2020

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 100 kilometers 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.

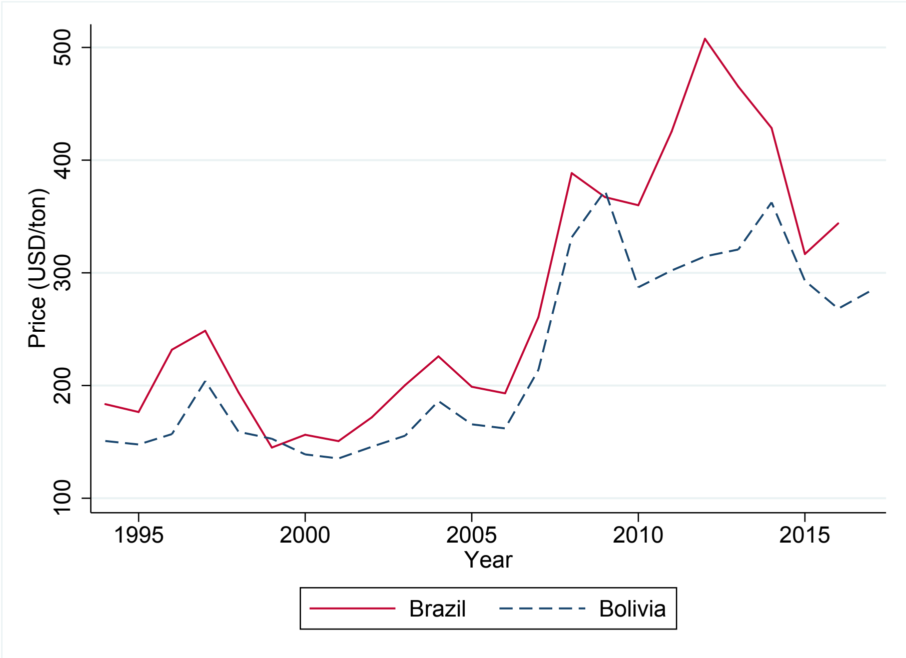


Figure A4: Farmgate Soybean Prices in Brazil and Bolivia

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 B.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 B.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 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.
Nelson and Chomitz (2011)	PLoS ONE	Multiple	2000-08	Matching	PAs effective in Latin America, with indigenous land more effective than multi-use or strict.
Ferraro 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%.
Pfaff et al. (2015)	PLoS ONE	Brazil	2000-08	Matching	PAs reduced deforestation by around 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.
Andrade (2016)	*manuscript*	Brazil	2005-12	Spatial DiD	Priority List had spillovers on neighbors and reduced deforestation for neighbours by 15-36%.
Assunção and Rocha (2019)	EDE	Brazil	2002-11	DiD	Policy reduced deforestation by 35%.
Assunção et al. (2019)	*manuscript*	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 A5: 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.
Simonet et al. (2018)	AJAE	Brazil	2010-14	Matching DiD	REDD++ Project Sustainable Settlements in the Amazon (PAS) conserved around 4 hectares of forest for each participating farm.
Assunção et al. (2013)	*manuscript*	Brazil	2006-16	2SLS	DETER; reducing monitoring and law enforcement by half increases deforestation by 44%.
Harding et al. (2019)	*manuscript*	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%.

B Additional background information

B.1 Relevant policy changes in the Brazilian Amazon

B.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 gave incentives to migrate to the region. First big migration influx. Migrants could work as rubber tappers, but could not own land.

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

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 promoted 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.

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.

B.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 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, setting out and 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 the management of 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 the 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) with the aim to define guidelines for sustainable development in the region.

2008 Marina Silva resigns as minister five days after the PAS was released, given the "difficulties that she had been facing to advance with the environmental agenda in the federal government." (extract from the 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) instituted policies and actions to promote sustainable development in black listed municipalities.

2008 Central Bank resolution conditioning the concession of rural credit in the Amazon Biome upon 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 black listed municipalities (MMA Ordinance 102).

2009-2011 Second phase of PPCDAm. Provisions include the creation of an interministerial 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 black listed 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 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 lose 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 able to 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 sanctioned 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.

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

B.2.1 Bolivia

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

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

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

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

2008 National Holistic Forest Management Plan. Created 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).

B.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 establishing which activities are permitted in each of the different types of national protected area (Law No. 26,834).

2000 Forests and Wildlife Law set 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 the management and administration of 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 with the intention of reducing 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 establishing 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). Aimed Commitment 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 which 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 designed to improve management of forests and wildlife (National Forest and Wildlife Service (SERFOR), National Forest and Wildlife Management System (SINAFOR)). Requirement for 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 a set of actions aimed at strengthening and improving 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. Expression and renewal of 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 which promotes action towards deforestation-free supply chains.

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

B.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 defining different uses for forest areas (Decree No. 2,811).

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

1993 Afro-Colombian communities are given the right to the sustainable use of natural resources without the need of 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 criticized 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 were 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 contribute around $300 million to reduce deforestation in Colombia.

2016 Introduction of Environmental Bubbles, establishing a first-response mechanism form 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 Cocoa, Forests, and Peace initiative to eliminate deforestation from supply chains. 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.

B.2.4 Venezuela

1996 Decree 1,257 establishes the 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 the management and control of 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.

B.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) describing need for increased forest monitoring.

1997 World Bank agreed to $6 million in funding for the creation of 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 established the Protected Areas Commission, the Protected Areas Trust and a Trust Fund. Minister empowered to declare Protected Areas.

2013 Germany agree 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 form 2009.

B.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 setting requirements for the sustainable production and export of timber and non-timber products and considering 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 in the scope of 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 in order 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.

B.2.7 French Guiana

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

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

2008 Decree delimiting the land for afforestation.

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

2019 Decree that offers the possibility to protect natural habitats.

B.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 easy demarcation. The main objective of Portugal during the negotiations was to hold the 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 would be defined 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 the 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*.[29] 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.[30]

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.[31] The final limits of the state of Acre were agreed between Brazil and Peru in 1909. Even in that period,

[29] "[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).

[30] Article VI of the Treaty of Madrid says "... and, from there, seek the straight line by higher ground to the main head of the more nearby 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.".

[31] 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.

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.[32]

B.4 Integration at the Brazil-Bolivia border

Our identification strategy assumes that the only factor that impacts deforestation choices discontinuously at the border is policy and institutions. If local markets are segmented at the border or if Brazilians and non-Brazilian communities were markedly different, differential changes in the drivers of deforestation could potentially impact farmers on the two sides differently. Evidence suggests that markets and communities are substantially integrated at the Brazilian-Bolivian border. We focus the discussion on this border segment as it is the one more densely populated and the one where the discontinuity in deforestation rates is the largest. We first describe the 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, 73.1% of the Bolivian soy lands were owned by foreigners – 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 forbids 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 the formal trade integration, in 1996, Bolivia joined the Southern Common Market (Mercosur), of which Brazil was already a member. The agreement aimed at abolishing tariffs between Bolivia and the Mercosur countries on a 10-year horizon and at eliminating non-tariff barriers. Mercosur, however, never came to abolish all trade barriers in the region.

While formal institutions already enable a substantial degree of integration between Brazilian and Bolivian neighboring communities, in practice, existing formal barriers are a little hindrance to cross-border integration. This is 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

[32]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."

by law enforcement (de Jong and Ruiz, 2012). Illegal movement from Bolivia to Brazil is 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 are mentioned to trade 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, a large number of Bolivian merchants traveling to Brazil to work and sell their produce; a survey with stallholders in local fairs in the Brazilian side found more than 50% of merchants were Bolivian (Aguiar, 2016). The similarity between the composition of agriculture practices at the two 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 we should expect spillovers from Brazilian environmental policies 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 in the non-Brazilian side of the 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 intended to support trade with Brazil (Urioste, 2012). These municipalities later became hot spots of deforestation (de la Vega-Leinert and Huber, 2019).

References

Aguiar, C. M. (2016). (In) hospitable Border Zones: Situating Bolivian Migrants' Presence at Brazilian Crossroads. In *Constructing and Imagining Labour Migration*, 57–82. Routledge.

Aseff, J., J. Espejo, and J. A. Morales (1997). The Importance of Border Trade: the Case of Bolivia. In *Western Hemisphere Trade Integration*, 136–157. Springer.

D'Anville, J.-B. B. (1779). Mémoire Sur un Accroissement Considérable de Connoissances

Locales en ce qui Intéresse l'Amérique Méridionale. n. 539, 11p. In: Furtado (2012). Oraculos da Geografia Iluminista: Dom Luís da Cunha e Jean-Baptiste Bourguignon d'Anville na Construção da Cartografia do Brasil. Editora UFMG, 2012.

de Jong, W., W. Cano, M. Zenteno, and M. Soriano (2014). The Legally Allowable Versus the Informally Practicable in Bolivia's Domestic Timber Market. *Forest Policy and Economics* 48:46–54.

de Jong, W. and S. A. Ruiz (2012). Strangers Among Trees: Territorialisation and Forest Policies in the Northern Bolivian Amazon. *Forest Policy and Economics*, 16:65–70.

de la Vega-Leinert, A. C. and C. Huber (2019). The Down Side of Cross-Border Integration: The Case of Deforestation in the Brazilian Mato Grosso and Bolivian Santa Cruz Lowlands. *Environment: Science and Policy for Sustainable Development*, 61(2):31–44.

McKay, B. and G. Colque (2016). Bolivia's Soy Complex: the Development of 'Productive Exclusion'. *The Journal of Peasant Studies*, 43(2):583–610.

Perz, S. G., L. Cabrera, L. A. Carvalho, J. Castillo, R. Chacacanta, R. E. Cossio, Y. F. Solano, J. Hoelle, L. M. Perales, I. Puerta, D. R. Céspedes, I. R. Camacho, and A. a. C. Silva (2012). Regional Integration and Local Change: Road Paving, Community Connectivity, and Social-Ecological Resilience in a Tri-national Frontier, Southwestern Amazonia. *Regional Environmental Change*, 12(1):35–53.

Urioste, M. (2012). Concentration and "Foreignisation" of Land in Bolivia. *Canadian Journal of Development Studies/Revue canadienne d'études du développement*, 33(4):439–457.

Wong Villanueva, J. L., T. Kidokoro, and F. Seta (2020). Cross-Border Integration, Cooperation and Governance: A Systems Approach for Evaluating "Good" Governance in Cross-Border Regions. *Journal of Borderlands Studies*, 1:24–34.