The Brazilian Amazon's Double Reversal of Fortune

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Abstract

We use high-resolution satellite data to determine how Amazonian deforestation changes discretely at the Brazilian international border. We document two dramatic reversals. In 2000, Brazilian pixels were 37 percent more likely to be deforested, and between 2001 and 2005 annual Brazilian deforestation was more than three times the rate observed across the border. In 2006, just after Brazil introduced policies to reduce deforestation, these differences disappear. However, from 2014, amid a period of economic crisis and deteriorating commitment to environmental regulation, Brazilian deforestation rates jump back up to near pre-reform levels. These results demonstrate the power of the state to affect whether wilderness ecosystems are conserved or exploited.

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1 Introduction

This paper explores the degree to which national policies can exert regulatory control over conservation by examining whether there are discrete changes in deforestation at national borders. 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 precisely isolate the effect of national policies, holding constant the underlying geography.

We do so in the context of one of the most important global ecosystems: 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. The Amazon is a global public good – its immense size implies that the rate at which it is deforested will affect the pace of global warming (IPBES, 2018). Hence understanding whether conservation efforts by Amazonian nation states are effective is an issue of international importance. Indeed if these national policies have no *de facto* bite then this renders ineffective both national and international accords to slow Amazonian deforestation (Fearnside, 2012).

To study the impact of national policy in the Amazon, we use newly-updated annual 30-meter resolution Landsat 7 data which allows us to monitor deforestation in a consistent manner over time and space from 2000 to 2018 (Hansen et al., 2013). The high resolution allows us to zoom in close to the border to identify precise effects – our preferred specification uses a bandwidth of only 25km on either side of the national border. 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. This is to be expected given that historical borders were drawn with little regard to local institutions and with limited knowledge of the underlying geographies. While our focus is on results analyzing the entire 12,800km Brazilian border in the Amazon, we perform a robustness exercise restricting attention to "artificial borders" – i.e., 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).

We investigate the role of national regulation of deforestation by running spatial regression discontinuity designs, using as running variable the distance to the Brazilian national border. This paper therefore fits within a rich literature using borders to look at policy effects.[1] We document five striking facts. First, we show that up until about 2005, the level and rate of deforestation was dramatically higher on the Brazilian side of the

[1]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, the evidence in developing countries is more mixed (Michalopoulos and Papaioannou, 2014; Pinkovskiy, 2017).

border than in its neighbors. This was associated with Brazilian policies to develop the Amazon. When our data starts in 2000, Brazilian land was 37 percent more likely to be have been deforested than similar lands 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 similar across the borders with both Bolivia and Peru – the two border segments where the so-called "Arc of Deforestation" intersects the international border – indicating that the differences are due to policies in Brazil, rather in countries across the border.

Second, we show that the discontinuity in deforestation rates disappears precipitously in 2006 – just as Brazil was implementing substantially tougher national policies targeting illegal deforestation. In November 2004, Brazil launched the *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, which together 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).

Third, we document that the positive impacts of the Brazilian forest policy were relatively short-lived. Starting in 2014, deforestation rates in Brazil have started to return to near pre-2004 levels. Again, we find discontinuously higher deforestation that goes right up to the international border but not across it, which suggests that these changes were caused by Brazilian policies. This second reversal coincides with a period of economic crisis and lowered commitment to environmental regulation with many of the regulatory changes brought in by PPCDAm being undone (Ferreira et al., 2014). Most notably, the New Forest Code enacted in late 2012, and disputed in the Supreme Court until 2018, set an amnesty for "small" properties that had deforested Legal Reserve areas before 2008 – in practice, forgiving 90 percent of the rural properties in the area for engaging in crimes of illegal deforestation (Soares-Filho et al., 2014). This reversal is consistent with the hypothesis that environmental protection was weakened and reversed under political pressure (Fearnside, 2016; Azevedo et al., 2017; Freitas et al., 2018; Soterroni et al., 2018). Newly released satellite data therefore allows us to document this widespread reversal across the Brazilian Amazon, and in particular, our border analysis shows that this is a uniquely Brazilian phenomenon. This is concrete evidence that the Brazilian state is now favoring exploitation over conservation.

Fourth, 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 unprotected lands just on the opposite side of the international border, and this remains the case from 2006 onward. The Brazilian state was therefore able to enforce environmental regulations when there was the political will to do so even in these outlying areas. Instead, reductions in deforestation following the mid-2000s policy changes in Brazil were most pronounced on unclaimed and private lands outside protected areas – precisely the types of lands where the increase in enforcement by the Brazilian state was most pronounced (Appendix B.3).

Fifth, we find that the Brazilian effort to cope with illegal deforestation was effective to reduce forest loss exactly in those areas closer to economic activity, at least initially. We further document that while the effects of Brazilian deforestation policy started to weaken first in areas further from enforcement bases (in the middle tercile of distance, between 560-880km away from enforcement centers), by 2015 the impact of Brazilian deforestation policies was severely undermined even in areas closer to law enforcement. In sum, in the first reversal Brazilian effort to cope with illegal deforestation was effective in reducing forest loss exactly in those areas closer to economic and market pressure and to law enforcement bases. However, as the policy position towards environmental regulation shifted in Brazil it was precisely these areas that experienced accelerated deforestation during the second reversal.

Combined, these results – the sharp discontinuity in deforestation levels and rates at the border, the dramatic change in deforestation at the border when then national government cracked down, the fact that protected areas in Brazil were always 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 highly 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. This policy stance was sharply reversed in the 2006-2013 period with laws to protect the Amazon rainforest being introduced and enforced. This position stalled and reversed in the post-2013 period during a period when political and economic crisis collided with a weakening of forest conservation laws.

Our results help to understand why the Brazilian Amazon was the only major area of tropical forest that has experienced *falling* rates of deforestation since the mid-2000s (Figure 1), and why this downward trend has reversed during the past few years. Brazil – which contains 65 percent of the Amazon rainforest – moves from having almost the highest rate of deforestation in 2001 to having the lowest rate in 2013, with the trend reversal occurring in the mid-2000s (see, e.g., Nepstad et al., 2009; Nolte et al., 2013; Godar et al., 2014). In strict contrast Indonesia, the Democratic Republic of Congo and the non-Brazilian Amazon (which contain the bulk of the remaining tropical forest) experience rising deforestation rates across the 2001-2018 period. Identifying the role of

Brazilian government policies in causing this decline in deforestation – and its subsequent increase – is challenging as these policies were applied throughout the country. The same challenge applies to understanding why this trend reversed from 2014 onwards.[2] By zooming in on the national border, where Brazil's policy reach ends, we can precisely identify the limits and impacts of being in Brazil and under the Brazilian policy regime.[3] The methods employed here therefore may be usefully employed by governments concerned with wilderness conservation in other contexts.

The remainder of this paper is organized as follows. Section 2 sets our empirical specification and discusses our data. We present results in Section 3. Section 4 concludes.

2 Empirical methods and data

2.1 Empirical specification

Our empirical analysis takes place at the 120-meter pixel resolution level.[4] Our running variable is distance to the border. Positive distances represent pixels in the Brazilian Amazon, while negative distances represent pixels in the Amazon outside Brazil.

Our main estimating equation is

$$Y_i = \alpha + \gamma Brazil_i + f\left(DistBorder_i\right) + \delta X_i + \varepsilon_i \tag{1}$$

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. $f\left(DistBorder_i\right) = Brazil_i * f^{Brazil}\left(DistBorder_i\right) + (1 - Brazil_i) * f^{OutsideBrazil}\left(DistBorder_i\right)$ is a polynomial of distance from the border, separately on each side of the border. 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. X_i is a vector of controls explained below. We cluster standard errors in blocks of size 25km by 25km to allow for geographical spatial error correlation.[5]

The coefficient of interest is γ, which measures the difference in the share of a pixel

[2] Several papers use variation across Brazilian municipalities for identification. Assunção et al. (2013) compare areas with more or less cloud cover to argue that satellite-based enforcement contributed to reductions in deforestation, Assunção et al. (2015) compare municipalities with greater or lower "tightness of land constraints" for farmers and Godar et al. (2014) shows that the decline in deforestation is larger in census tracts dominated by large landholders.

[3] A related literature studies how regulation and infrastructure affect deforestation (e.g., Adman, 2014; Souza-Rodrigues, 2018; Anderson et al., 2016; Asher et al., 2017) and violence in the Amazon (e.g., Chimeli and Soares, 2017).

[4] We aggregate from the 30-meter to 120-meter level to ease computational constraints.

[5] Conley (1999) standard errors would be an alternative but is computationally challenging due to the extremely large number of observations. Our OLS results show bias-corrected confidence intervals (Calonico et al., 2014).

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. We estimate equation (1) 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 within Brazil, we estimate equation (1) using a Poisson model with cluster-robust standard errors clustered at the same 25km by 25km blocks.[6] 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 across land types.[7]

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, we remove additional sources of biases and allow for causal inference. The idea that the borders are largely arbitrary is consistent with the historical evidence - they were largely set by the 1750 Treaty of Madrid (see Appendix B.3.4) when many of these areas deep in the jungle were largely unexplored and appeared as blank spaces labeled “unknown country” in maps from that time (Furtado, 2012).

To explore this assumption 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. Appendix Table A2 shows the estimates of γ which represent the discontinuous change in the level of these variables at the Brazilian border, for various subsets of the border and bandwidths. Overall, columns 1, 4, 7, and 10 show that that these factors are smoothly distributed around the Brazilian border (the remaining columns are for robustness subsamples we discuss in more detail in Section 3.1). Nonetheless, in our main specification we estimate (1) controlling for natural covariates: land, slope, and distance from water. We present results both without any controls and including additional controls for distance to infrastructure in the robustness tables.

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 25 km 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 25 km of the border, we have 1,094 clusters and 31,071,838 observations each year.

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

[7]While we present OLS results in our main specifications for ease of interpretation, Poisson results are qualitatively very similar. See Appendix Table A5, column 3, and note that that Poisson results are interpretable as percent changes in the dependent variable.

2.2 Data

Hansen et al. (2013) worked with 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 2018, at a spatial resolution of 30 meters across the whole earth. The forest cover map is constructed for 2000 because Landsat 7 was launched in the previous year, so Hansen uses it as the base cover on which he constructs annual forest loss. 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. We aggregate pixels to create a resolution of 120×120 meters to facilitate computations. 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. Summary statistics are shown in Appendix Table A1.

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. On net, we have more than 277 million observations in the Amazon each year.

Figure 2 shows an example of the data, displaying forest cover as of 2000. Panel (a) shows the entire Amazon, and Panel (b) zooms in on one particular border segment, which consists largely of straight lines. The substantially higher deforestation on the Brazilian (right-hand) side of the border is visible.

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.

3 Results

3.1 Deforestation as of 2000

We begin by examining the level of forest cover in 2000, the year our data begins. Figure 3 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 exactly at the national border.

Our regression estimates using equation (1) indicate that this discontinuous change in forest cover at the border is sizable and statistically significant. Using a 25km bandwidth, forest cover in the Brazilian Amazon was around 3.9 percentage points smaller than in its neighboring countries (cluster-robust p-value equal to 0.069; see Appendix Table A3).[8] Since 89.4 percent of the land outside of Brazil was forested in 2000, this implies that deforestation prior to 2000 was 37 percent higher just inside the Brazilian border relative to on the other side.

3.2 The Double Reversal of Fortune – Annual forest loss at the border

We next plot annual deforestation rates on both sides of the border between 2001 and 2018 in Figure 4. The figures show a dramatic difference in deforestation rates in 2001-2005 that come to an abrupt halt in 2006. This is the first reversal we observe. Between 2006 and 2013, deforestation activity is spread smoothly on both sides of the Brazilian border. The change in 2006 comes from decreased deforestation in Brazil, rather than increased deforestation on the other side of the border. Deforestation rates in 2014-2018 return to close to the levels seen in the early-2000's, mostly driven by an increase in deforestation activity in Brazil.

We estimate RD models separately for each year. Figure 5a plots the RD coefficient – γ in equation (1) – from each year, along with 95 percent confidence intervals, using OLS regressions and a 25km bandwidth. We estimate annual deforestation rates of about 0.2 percentage points higher per year on the Brazilian side of the border through 2004. 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 faster than on the other side of the border.

The dramatic changes we observe at the border correspond to policy changes in Brazil.[9] First, the precipitous decline in deforestation at the border in the mid-2000s corresponds to a period of environmental policy strengthening in Brazil (Appendix B.1). This followed the appointment in 2003 of Marina Silva as Minister of Environment in the Lula government who was from the Amazon region and had a strong predilection towards conserving the rainforest. Although the comprehensive PPCDAm plan, which she helped craft, was released in 2004, its actions were implemented 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). Consonant with this, Figure 4 shows that

[8] Results vary from 2.8 percentage points to 5.6 percentage points, depending on bandwidth, which we vary from 11km to 100 km. Estimates with alternate bandwidths are shown in Appendix Table A3.

[9] Appendix B.2 provides a summary of the main policies in Brazil and neighboring countries.

in 2006 deforestation on the Brazilian side of the border collapses and the discontinuity at the border is eliminated. Taken together, these results point to an important role for Brazilian policy in determining deforestation rates at the border.[10]

Figure 4, however, also shows that the deforestation rate on the Brazilian side of the border resumes growing in 2014. This is the second reversal we observe. Increased deforestation in Brazil is associated with a lowered commitment to environmental regulation. In particular the new Government of Dilma Rousseff introduced a New Forest Code in 2012, which gave an amnesty to those who had engaged in illegal deforestation before 2008. Though contested in the courts (and finally ratified by the Supreme Court in 2018) this introduced considerable uncertainty as to whether illegal deforestation was a crime. Brazilian environmental governance was undermined over the years since 2012 by the growing political power of the agriculture producers, consecutive weak governments and scarce public resources (see Appendix B.1).[11]

Furthermore, 2014 was a particularly turbulent year for the federal government. With elections at the end of the year, the economy started giving signs of a long-lasting economic crisis, and a major corruption scandal erupted involving key politicians from the administration. The upshot of this 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). The protection environment further deteriorated when Michel Temer, the next president, signed a law that streamlined the titling of occupied public lands, which may have further encouraged land grabs in the Amazon. After three years of political and economic crisis, in 2017, we see that deforestation was about 0.17 percentage points higher at the Brazilian border (cluster-robust p-value equal to 0.015).[12]

Newly released satellite data therefore allows us to document this widespread reversal across the Brazilian Amazon, and in particular, our border analysis shows that this is a uniquely Brazilian phenomenon. We observe Brazilian deforestation rates (2014-2018) in recent years in Brazil reverting to pre-reform (2001-2005) levels thereby negating eight years of policy reforms (2006-2013) dedicated to slowing the rate of deforestation in the Brazilian Amazon (5a). Given that the Amazon accounts for 40 percent of tropical forests – and Brazil for the bulk of it – this is a troubling finding. Our analysis suggest that the

[10]An alternative explanation for the precipitous change we observe in 2006 is a differential change in output prices. 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 Appendix Figure A6, farmgate prices move almost directly in parallel in both countries through 2011, and there is no differential break in prices around 2006.

[11]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).

[12]Point estimates are statistically significant in all other specifications – using different sets of controls, quadratic polynomial and excluding Mount Roraima (Tables A4), using rectangular kernel, or estimating using Poisson model (Table A5), or using 50 and 100km bandwidths (Table A3). The only exception is when using 11km bandwidth, OLS estimation and triangular kernel (when cluster-robust p-value is equal to 0.16).

recent reversal is due to political and economic crises colliding with a weakening of forest conservation laws in Brazil (Soares-Filho et al., 2014; Ferreira et al., 2014; Fearnside, 2016; Azevedo et al., 2017; Freitas et al., 2018; Soterroni et al., 2018).

These results are robust to a series of alternative specifications and samples. Our baseline RD specifications use OLS and control for slope and distance to water, use linear polynomials, and are estimated using the entire Brazilian border. Appendix Tables A4 and A5 show that the results are qualitatively similar if we: a) do not include the slope and distance to water controls; b) add additional infrastructure controls; c) estimate using Poisson models; d) use quadratic polynomials; and e) exclude a 220km buffer around the peak of Mount Roraima, 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.

We also estimate results restricting the sample to areas around artificial borders, as in Alesina et al. (2011) – i.e., borders arbitrarily drawn by former colonizers which appear as straight lines on a map (Appendix B.3.4).[13] For these borders, there is no geographic feature at the border – and indeed, usually not even so much as a fence.[14] 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, as shown in Figure A1 (see Appendix Table *A*5). We do not observe a statistically significant ramp up post-2014 in deforestation in this subsample, though we cannot reject statistically the effects of the magnitude we see in our full analysis sample.

3.3 Are these differences about Brazil?

An important question is whether the differences we observe at the border reflect differences in the policy environment within Brazil, as opposed to changes happening on the other side of the border. Examining Figure 4 suggests prima facie that they are about changes in Brazil – the deforestation rates on the non-Brazil side of the border are remarkably similar from year to year, whereas the two reversals we document are all due to changes (first decreases, then increases) on the Brazilian side of the border. The only time we see major changes outside of Brazil is 2016, when deforestation outside Brazil appears to increase – but deforestation increases even more on the Brazilian side of the border, as shown in the discontinuity estimates.

Nevertheless, to explore this issue in more detail, we further investigate heterogeneity in effects by land type within Brazil, and heterogeneity based on what country is on the

[13]We map the segments of artificial border in Figure A7b in the appendix.

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

other side of the border.

3.3.1 Heterogeneity by land classification within Brazil

We begin by examining heterogeneity in effects based on the land use classification of different areas *within* Brazil. Land in the Brazilian Amazon is divided into areas that are protected for conservation and other reasons (e.g., national parks), areas which are untitled and unclaimed and areas which are under private ownership. Since 1998, harming native vegetation in *Protected Areas* (PAs) was 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, PPCDAm made several changes that increased enforcement outside PAs.

Most notably, until 2005, deforesting untitled, or *unclaimed land*, outside PAs was just an infraction, punishable at most with fines, and individuals caught harming native vegetation or extracting resources in these lands would not even have their equipment seized. PPCDAm, which was fully implemented in 2006 when real-time satellite data became available for enforcement, made deforestation of unclaimed land a felony punishable with jail time, as in PAs, and legislated that equipment (i.e., trucks and chainsaws) of violators could be seized and confiscated.

Similarly until 2005*, private properties* outside PAs were required to set aside at least 35 percent of their area as native vegetation – i.e., it was illegal to deforest more than 65 percent of the private property area. Non-compliance with this threshold, however, was just an infraction. Starting in 2005, PPCDAm both increased the required set-aside area of private properties from 35 to 80 percent[15] and conditioned access to agricultural credit lines from public banks on environmental compliance (Assunção et al., 2013).

To explore whether differences in *de jure* enforcement regimes translated into differences in *de facto* deforestation at the border, we re-estimate equation (1) separately for each of these three classes of land. Figure 5b presents the results, where every point is an estimated RD coefficient (i.e., γ from (1)) from a separate Poisson regression using 25km bandwidths.

We see that when the national border abuts Brazilian PAs we observe *less* deforestation on the Brazilian side consistent with these areas enjoying greater *de jure* protection throughout our whole period. In strict contrast, for unclaimed lands we observe *more* deforestation on the Brazilian side up until 2005, but this discontinuity is eliminated from 2006 when PPCDAm comes into full force. For private lands, while there is a dramatic fall in the difference in deforestation rates in 2006, it is not eliminated entirely, consistent with the fact that some deforestation was still allowed in these areas. These results con-

[15]Pre-2005 infringements were not prosecuted but landowners were liable for any deforestation above the 20 percent requirement from 2005 onward.

firm that – even in these remote areas very close to the international border – differences in deforestation map to changes in land use regulations *within* Brazil.

3.3.2 Heterogeneity by bordering country

The border discontinuity our identification strategy exploits captures the net policy difference at the border. Although Figure 4 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. We did not identify any crucial land use and deforestation policy changes in neighboring countries to Brazil that could undermine our interpretation of the estimates.[16]

Nonetheless, we next investigate whether the effects we see are homogeneous across all country border segments by re-estimating equation (1) separately for the border segment with each country. Figure A3 presents the results, analogous to Figure 5b. Our estimated effects are almost identical when comparing the Brazilian border with Bolivia with the Brazilian border with Peru, the two countries where the so-called "Arc of Deforestation"– i.e., where deforestation rates are highest – intersects the international border.

We find no statistically meaningful differential deforestation in the whole period for the more remote areas bordering Colombia, Venezuela, Guyana, Suriname, and French Guiana (see Figure A3b), though the point estimates suggest higher deforestation in Brazil along the Venezuelan border and the Northern border with Guyana, Suriname and French Guiana during the early part of our sample. 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 annual deforestation rate in Brazil in 2001 near the Bolivian border is 1.14 percent, it ranges between only 0.02 and 0.05 percent on all other country borders. Thus, in the segment of the international border where deforestation is substantial, the fact that we find nearly identical effects of being in Brazil suggests that the effects are about Brazilian policy, rather than policies in the countries on the other side of the border.

3.4 Heterogeneity by distance from markets and enforcement

To the extent the effects we document are driven by the interplay between demand for deforestation and enforcement, we should expect to find heterogeneity in effects along both these dimensions. We therefore investigate heterogeneity in effects based on markets access and enforcement. First, we look at heterogeneous effects by distance to roads as a proxy for market access and transportation cost. We estimate equation (1) separately for the pixels in each tercile of the distribution of distance to roads. The solid line in

[16] Appendix B.2 provides a summary of the main policies in Brazil and neighboring countries.

Figure A4a shows the estimates for pixels within 15km to roads (the 33rd percentile), the dashed line shows pixels between 15 and 50km to roads (the 66th percentile) and the red line shows pixels further than 50km from roads. We see that all differential deforestation comes from the third of pixels closer to roads. We find no clear pattern of differential deforestation rates in pixels more than 50km away from roads.

Second, we use distance to towns or villages to capture proximity to local markets. Similar to heterogeneity by roads, Figure A4b shows larger effects in pixels closer to villages. This is consistent with changes in deforestation being more pronounced where pressures for extraction are greatest.

Last, we look at heterogeneous effects by distance to the 10 enforcement bases from the Brazilian Environmental Agency (IBAMA). Given the size of the Amazon, we see that one third of pixels around the national border are within 565km from an enforcement base, and one third of pixels are more than 880km away from an enforcement bases. Figure A5 shows the estimates for pixels within each of tercile of distance to enforcement. The results in Figure A5 suggest that the double reversal of fortune happened in areas closer to IBAMA enforcement bases. The solid line shows that PPCDAm's largest reduction in annual deforestation rate happened until 2009 in the areas closest to enforcement – within 565km. Likewise, the dark lines show that the effect of Brazilian deforestation policy started to weaken around 2013 in areas closer to enforcement, with deforestation rates being higher on the Brazilian side since then. The red dashed line shows smaller annual deforestation rates on the Brazilian side of the border in more remote pixels, further than 880km away from enforcement bases, in the whole period.

In sum, in the first reversal Brazilian effort to cope with illegal deforestation was effective in reducing forest loss exactly in those areas closer to economic and market pressure and to law enforcement bases. However, as the policy position towards environmental regulation shifted in Brazil it was precisely these areas that experienced accelerated deforestation during the second reversal. This analysis thus underlines the extent to which rates of deforestation in Brazil depended on enforcement of national policies.

4 Conclusion

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 use of federal police). 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 to international efforts to slow 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 regularly available to any government at a 30-meter 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.

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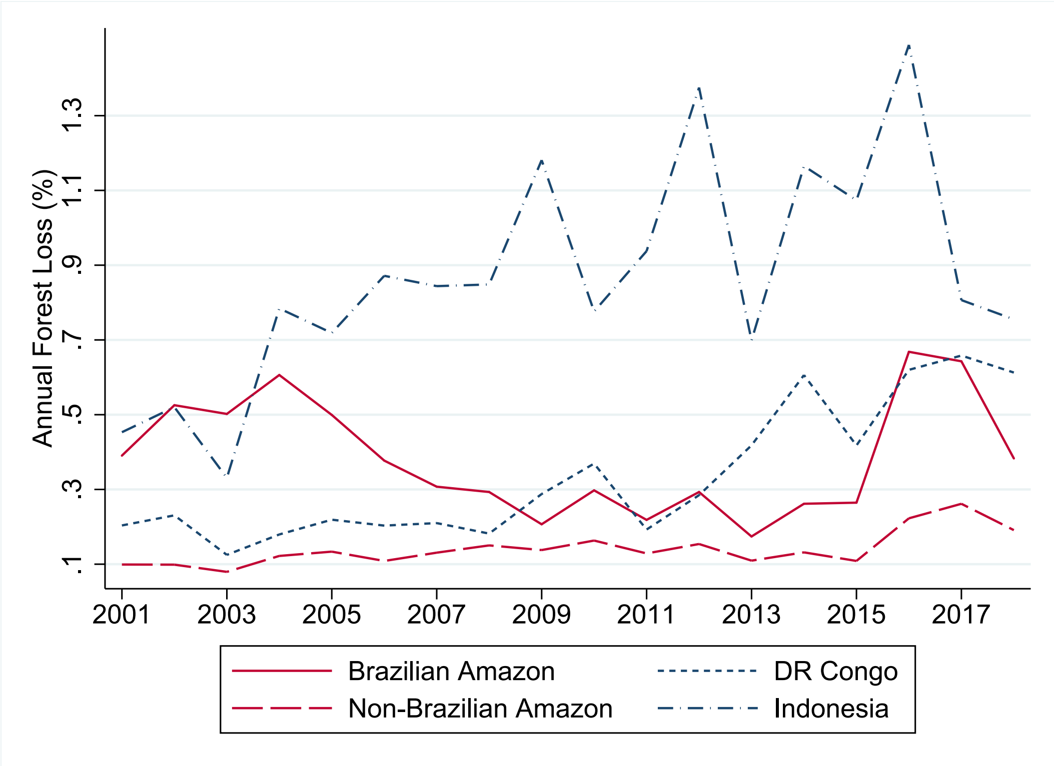
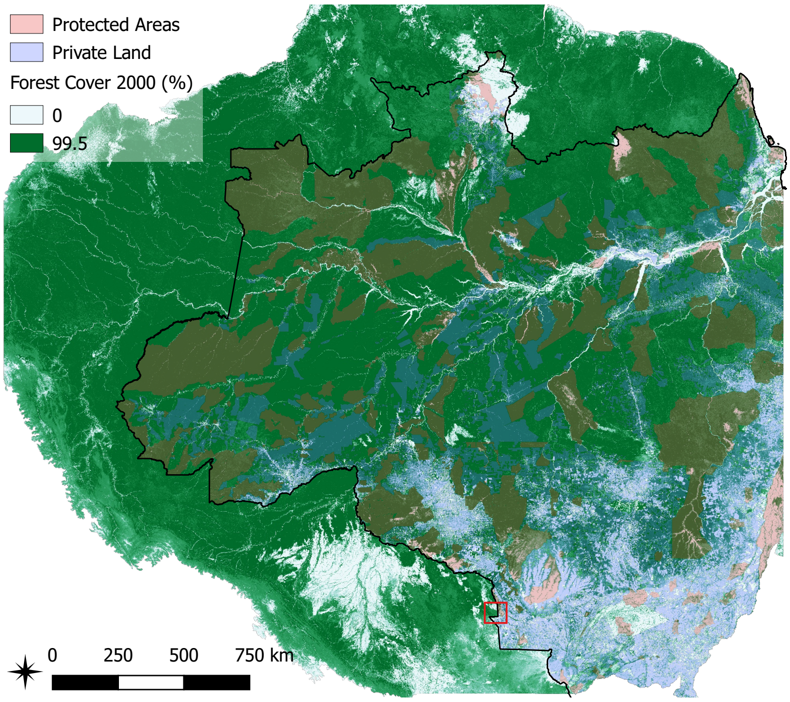
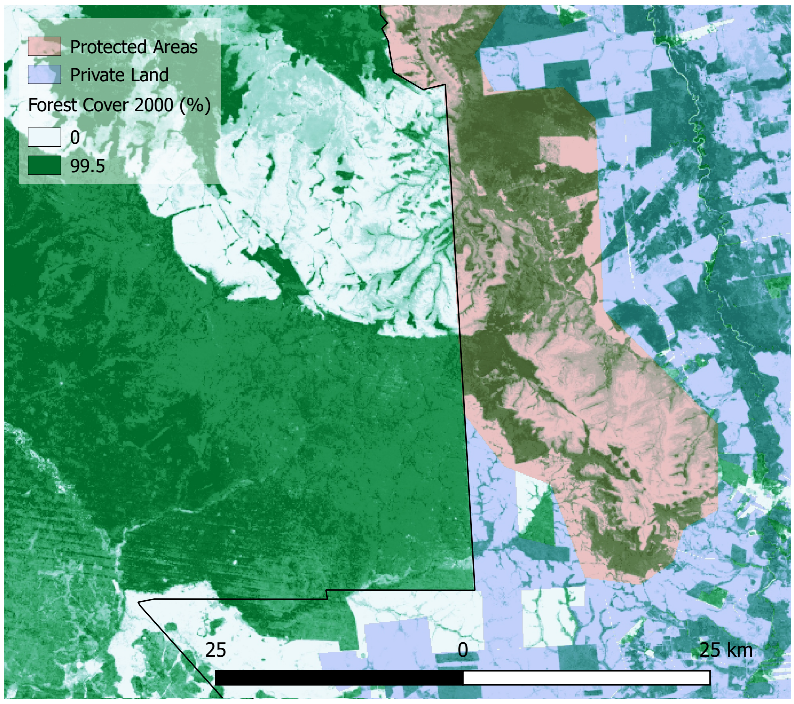


Figure 1: Forest Change in the Amazon, DR Congo and Indonesia, 2001-2018

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



(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, as calculated by the authors using data from (Hansen et al., 2013). The top panel (a) shows the Amazon, and the bottom 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.

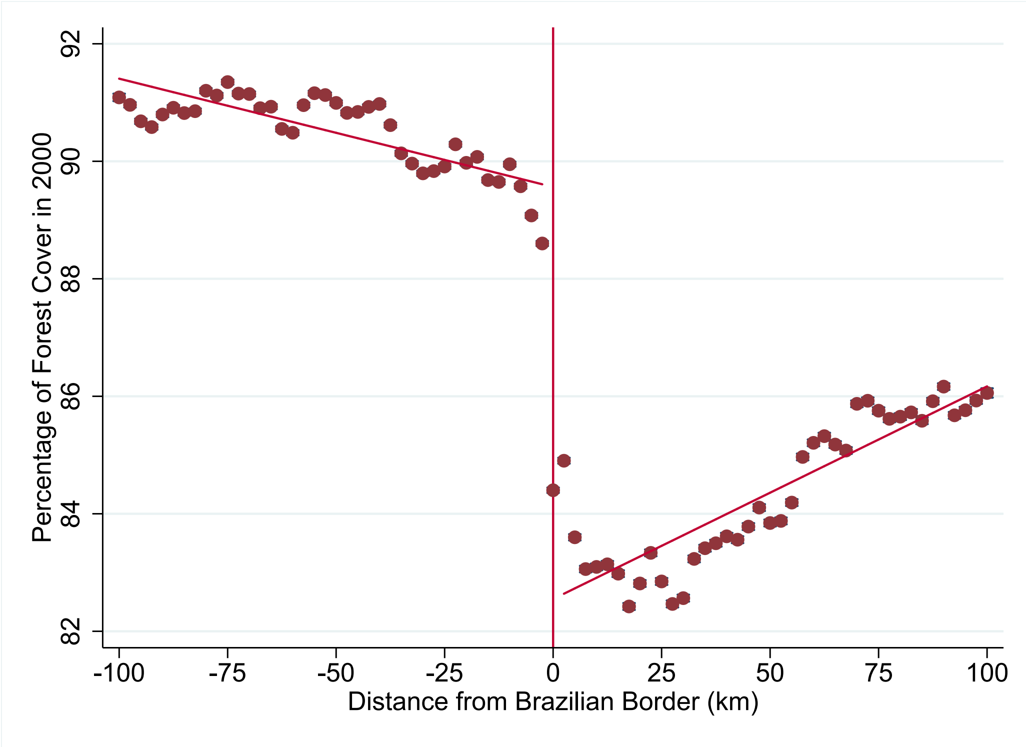


Figure 3: Average Forest Cover in 2000 by Distance from Brazilian Border

This figure shows the average forest cover in 2000 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 graph shows the abrupt reduction in forest cover at the Brazilian border. The red line shows the linear function of distance weighted by the number of observations in each bin.

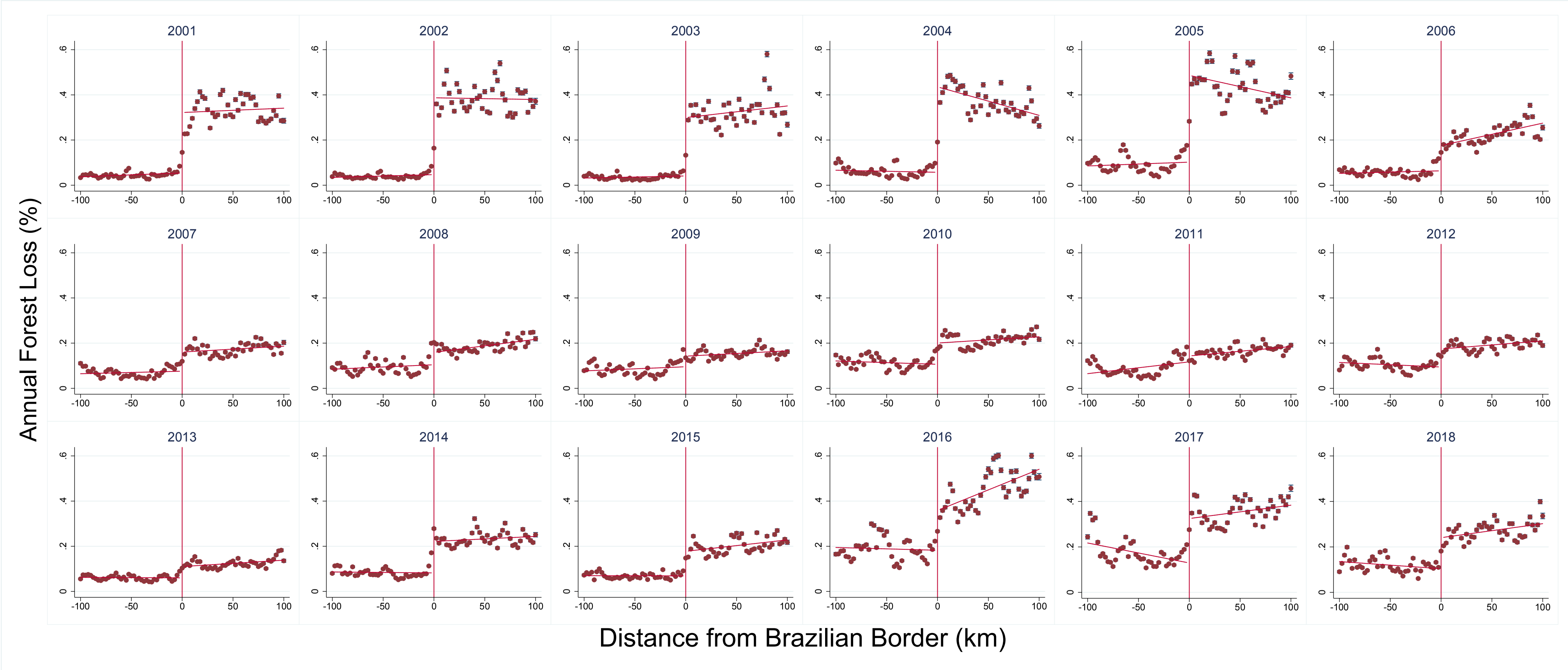
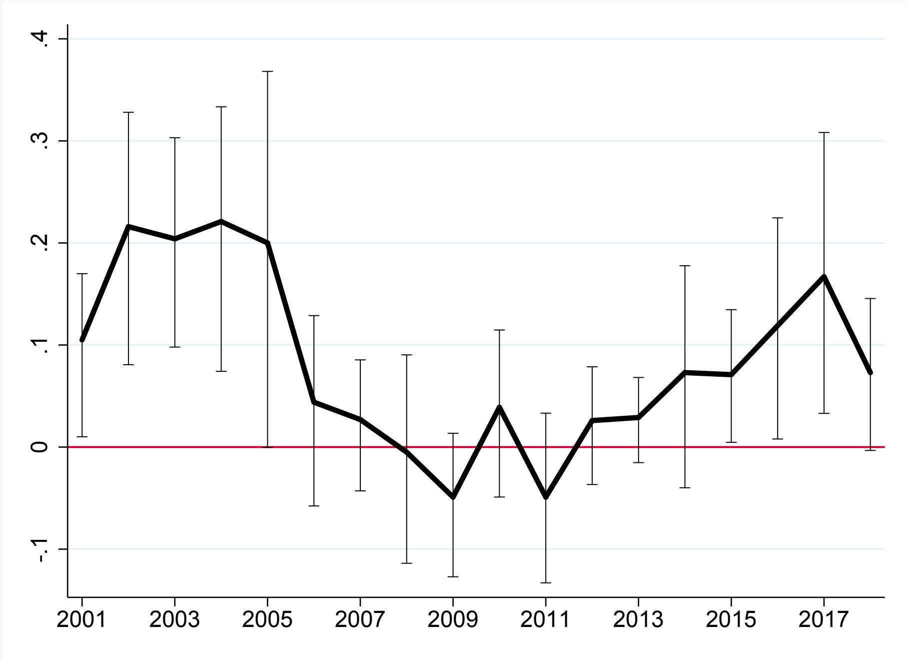
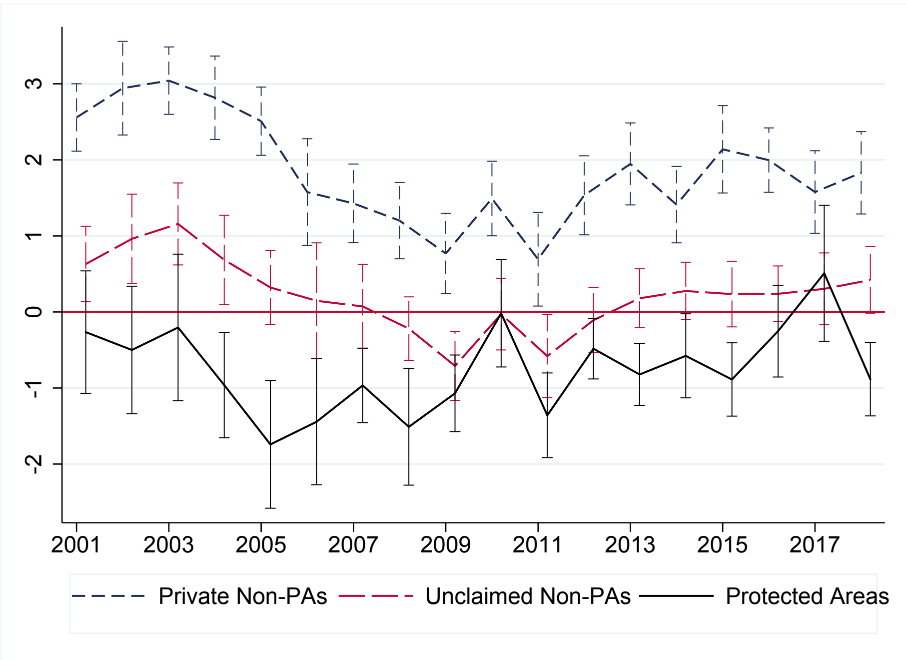


Figure 4: Average Annual Forest Loss at the Border by Year – 2001-2018

This figure shows the average annual forest cover lost each year between 2001 and 2018 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. It shows that the discontinuous higher annual deforestation rates on the Brazilian side of the border level out between 2006 and 2013. The red lines show the linear function of distance weighted by the number of observations in each bin.



(a) Overall Effects (OLS model)



(b) Heterogeneous Effects by Land Type (Poisson model)

Figure 5: 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 (1) with linear running variables and 25 km bandwidth. The top panel (a) shows the overall effects estimated using the whole Brazilian border trough OLS regressions (presented in column 1 Table A3 in Appendix). The vertical bars represent 95 percent confidence intervals. The bottom panel (b) shows the heterogeneous effects by land type estimated using a Poisson model (presented in Table A6 in Appendix). These estimates can be interpreted as a relative increase in annual deforestation rate on the Brazilian side of the border.