The Power of the State: National Borders and the Deforestation of the Amazon

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Abstract

Tropical deforestation is one of the major drivers of climate change. Much of this loss is due to illegal logging. Unlike forests in the Congo basin and South-East Asia, the world's largest tropical forest - the Amazon - has experienced a dramatic slowing in rates of deforestation over the last decade. The bulk of the Amazon is located in Brazil which has introduced a raft of policies to reduce illegal logging in recent years. We use Brazil's border with it's neighbors to identify the impact of Brazilian policies on deforestation. Because forests are a fixed resource and geography and infrastructure vary continuously over the border we can compare annual forest loss on either side of the border to tease out the impact of national forest policies from other drivers of deforestation. To do this we employ a satellite-derived data set that measures forest cover at a 30 x 30 meter resolution for the entire Amazon area across the 2000-2014 period. Our data reveals a sharp discontinuity at the border – in 2000 Amazonian pixels on the Brazilian side of the border are more likely to have been deforested and between 2001 and 2005 annual forest loss in Brazil was around four times the rate on the other side of the border. However, in 2006, just after the Brazilian government introduced a raft of policies to curtail illegal logging, these differences disappear and Brazilian rates of forest loss fall to those observed across the border. These results demonstrate the power of the state to affect whether or not natural resources are conserved or exploited even in the furthest reaches of the Amazonian jungle.

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1 Introduction

Avoiding catastrophic climate change is a central challenge for the 21st century. Preservation of tropical forests has been identified climate as critical in this respect. These forests, which cover large swathes of the tropics, capture carbon from the atmosphere and play a central role in determining the pace of climate change. Because climate change does not recognize national borders and will affect humans everywhere the preservation of tropical forests is an international policy priority, and large amounts of resources are being channeled worldwide to the small number of countries in which these forests are located.[1]

Set against this growing realization of the importance of preserving this global resource is the hard reality that tropical deforestation has actually been accelerating in recent years (Hansen *et al.*, 2013). The main reason for this is illegal deforestation. In the weakly institutionalized settings of developing countries there is often a large gap between de jure and de facto forestry policy. Policy enforcement is typically very weak and those interested in deforestation, whether to harvest timber or use the land for other purposes, often collude with local politicians and bureaucrats to circumvent official rules and regulations (Burgess *et al.*, 2012). The result is that timber is often extracted from illegal sources and overall rates of extraction are more rapid than is officially sanctioned. This equilibrium where illegal deforestation benefits the few at the cost of the many has proven to be highly resilient.

When we view the earth from space three big areas of tropical forest are visible. The first (and largest) area is the Amazon which is mainly in Brazil. The second main area is the Congo basin which is mainly in the Democratic Republic of Congo (DRC). The third main area is in South-East Asia and is mainly in Indonesia. Figure 1 plots annual rates of forest loss (i.e. the change in forest cover) for Brazil, DRC and Indonesia from 2001 to 2014. Brazil is shown to be experiencing more rapid deforestation than DRC and Indonesia in 2001, but deforestation rates begin to fall in 2005. In contrast DRC and Indonesia experience rising deforestation rates from 2001 onwards with rates roughly doubling in both countries between 2001 and 2014. The net result is that Brazil starts the period with highest rate of deforestation and ends it with the lowest rate of deforestation.

While Brazil comprises the majority of the Amazon land area, 35 percent of the Amazon is actually located in other South American countries – Bolivia, Peru, Columbia, Venezuela, Guyana, Suriname, and French Guyane. In Figure 2 we focus on deforestation in the Amazon and break it into two sections - that located in Brazil and that located neighboring countries. This reveals that the decline in deforestation in the Amazon that began in 2005 observed in Figure 1 is unique to Brazil. In contrast, deforestation rates

[1]The Norwegian Government, for example, has pledged $1 billion each to Brazil and Indonesia to conserve their forests and there are now large REDD funds also available for this purpose.

in non-Brazilian Amazon grow steadily from 2001 and have almost doubled by 2014 thus mirroring the pattern seen in DRC and Indonesia.[2] This suggests that something changed in Brazil in the mid 2000s which caused the rate of forest loss to dramatically slow down.

This paper asks whether the decline in deforestation in Brazil was due to specific forestry policies introduced by the Brazilian government, or whether it was caused by changes in the myriad other drivers of deforestation, such as roads and transportation costs(Pfaff, 1999; Barber *et al.*, 2014; Souza-Rodrigues, 2015), commodity prices or other changes in soy and beef markets (Nepstad *et al.*, 2006; Assunção *et al.*, 2015), changing geographic patterns of complementary economic activity (Hargrave & Kis-Katos, 2013), and so on. To do this we employ a novel identification strategy where we use detailed Landsat satellite data from Hansen *et al.* (2013) to measure deforestation on either side of Brazil's border with its eight neighbors which together make up the Amazon region. The borders are porous and poorly maintained, allowing free flow of people and goods (Alston *et al.*, 2012; Raza, 2013).[3] Because forest is a fixed resource, and because we can demonstrate that geography (slope, distance to water) and infrastructure (distance to roads, distance to urban center) vary smoothly across the Brazilian border,we argue that we can interpret discontinuous changes in deforestation rates around the border as capturing the influence of national forestry policies.

When we examine the 30 x 30 meter forest cover data within a narrow strip on either side of the border we find that, in 2000, forest cover is significantly lower on the Brazilian side of the border.[4] This may reflect both limited enforcement of forestry policy and the cumulated impact of policies to open up and develop the Brazilian Amazon. Consistent with this we find that Brazil is deforesting the Amazon forest at around four times the rate of its neighbors up to 2005. However, from 2006 onwards, deforestation rates in the Brazilian Amazon fall precipitously down to the levels observed in Brazil's neighbors. Looking at these narrow strips of pixels along the Brazilian border we see that the gap in deforestation rates between Brazil and its neighbors disappears in 2006.

This is a striking finding and we find that this coincides with a major shift in forestry policy in Brazil. As it has been documented before (Nepstad *et al.*, 2009; Assunção *et al.*, 2013b,a), starting in 2004 the federal government launched the *Action Plan for the Pre-*

[2]Though it is notable that deforestation rates in the non-Brazilian Amazon remain lower than those in DRC and Indonesia.

[3]Indeed, the borders are so porous that in 1994, Brazilian President-Elect Cardoso, on vacation near the border, accidentally wandered into Bolivia, spending over an hour before being stopped by a Bolivian solider. The solider reported that Cardoso was the first person he had ever stopped crossing the border (Cardoso & Winter, 2007).

[4]We restrict our analysis to pixels close to the border – using the Imbens & Kalyanaraman (2012) optimal bandwidth criterion, we focus on a bandwidth of only 17 km on either side of the border, though we find results even when restricting ourselves to looking at bandwidths only 5 km on either side of the border. Other than a small section of the northern border with Venezuela, which is coincident with a mountain ridge, we find that observable characteristics such as slope, distance to urban areas, water, and roads are similar on both sides of the border.

vention and Control of Deforestation in the Legal Amazon (PPCDAm). This was a holistic policy that proposed several actions focused mostly on territorial and land planning along with strengthening the specific legislation and the environmental monitoring and control. Although PPCDAm was released in 2004, its actions were implemented gradually; in particular, 2006 is exactly the year when Brazil promulgates the Law on Public Forest Management and when the Environmental Agency's Center for Environmental Monitoring (CEMAN) became fully operational (MMA, 2008).

The appointment of Marina Silva in 2003 (an environmental activist who is from the Amazon) to be Minister of the Environment led to dramatic shift in forestry policy.[5] The work of different agencies and ministries involved in environmental protection were now coordinated and satellite images were intensively used to detect illegal logging. Once detected both the army and federal police were deployed to arrest individuals and confiscate machinery. Improved monitoring and enforcement severely blunted incentives for individuals and firms to be involved in illegal logging. Though a range of factors from wood prices (which affect demand) to transportation infrastructure (which affect supply) can affect rates of deforestation, the patterns we observe around the Brazilian border are consistent with us capturing changes in the forestry policy environment in Brazil.[6]

We find that our results are robust to restricting our analysis to artificial borders as in Alesina *et al.* (2011) – i.e. those which are literally straight lines drawn on a map, as opposed to following natural features such as rivers. Also when we divide the Brazilian Amazon into protected areas and unprotected areas we find that the main reversal in deforestation rates is occurring in unprotected areas. This pattern is consistent with enforcement of forestry policy strengthening from the mid 2000s onwards. We find that access to roads in Brazil encourages deforestation but that this effect is mitigated once new policies to protect the Brazilian Amazon are introduced. This suggests that proximity to roads is necessary for intense deforestation to take place, but it is not sufficient as enhanced enforcement of forestry policy can afford protection to accessible parts of the Amazon.

To quantify the magnitude of the border effects, we estimate a logit model on the Brazilian side of the border with Bolivia (where deforestation of the Amazon was concentrated) that calculates the probability that each pixel was deforested in 2001 as a function of observable factors – such as slope, distance to water, to roads and to urban areas. This allows us to quantify the "Brazil effect" in terms of observables as we compare the propensity that each pixel on both sides of the border is deforested. We find that,

[5]Marina Silva was the colleague of Chico Mendes an environmental activist and trade union leader who was assasinated in 1988 by a cattle rancher in retaliation against his efforts to preserve the Amazon rainforest and protect the indigenous peoples that inhabit it.

[6]Timber and other commodities are a global market and so changes in prices for example should affect, for example, timber firms similarly on either side of the Brazilian border.

until 2005, the pixels that were actually deforested on the Bolivian side of the border had on average around 25 percent higher propensity to deforest than those pixels deforested on the Brazilian side. Interestingly, this pattern reverts after 2005 and, by 2009, the average propensity to deforest of deforested pixels in Brazil and Bolivia become level. Therefore, it seems that unobservable factors - such as national forestry policies - were underlying the discontinuously higher annual forest loss on the Brazilian side on the border.

This paper contributes to the growing literature on the management of natural resources in developing countries. A key finding in this regards is that we show that the Brazilian state had the power to influence resource extraction rates even in the remotest part of its territory thus running contrary to a large literature in development that suggests that the state has limited reach in such remote areas (Herbst, 2000). It also contributes to the literature on using political borders to capture the influence of institutions and policies. The pathbreaking paper by Holmes (1998) examines changes in manufacturing across US state borders to examine whether pro-business regulations affect manufacturing activity. Michalopoulos & Papaioannou (2014) examine whether there is a change in lights at national borders in Africa to test whether national institutions matter. The challenge with these studies is that the estimates become hard to interpret if production or consumption can be easily relocated across the border. For example, imagine that businesses have only a slight preference for locating in a pro-business state. If capital and labor are all freely mobile across the border, businesses may simply relocate to take advantage of the regulations. Comparing the amount of business activity located on the pro-business side of the border to the amount on the other side would vastly overstate the true impact of the policy on the level of manufacturing activity, as it would be largely just picking up this relocation. On the other hand, comparing household incomes across the border might understate the impact of the policy: workers could all work in the high-productivity state but live on both sides. The same challenges occur in the African context where borders are porous and workers often freely cross back and forth each day. In this respect our analysis using a factor of production - trees - which is fixed in space helps to overcome some of these difficulties.

The remainder of this paper is organized as follows: in Section 2 we provide background onthe recent trends in the Brazilian Amazon land use pattern, the *Action Plan for the Prevention and Control of Deforestation in the Legal Amazon* (PPCDAm), review the existing literature on deforestation in the Amazon and descibe and the data we employ. We outline the details of our empirical method in Section 3, and we present results in Section 4. We draw conclusions in Section 5. The appendix contains supplemental material, such as a brief timeline of PPCDAm.

2 Background and Data

In this section we describe the background of the recent trends in the Brazilian Amazon land use pattern, and the *Action Plan for the Prevention and Control of Deforestation in the Legal Amazon* (PPCDAm) implemented in mid-2000s to reduce the accelerated deforestation rates in the Brazilian Amazon. We then briefly describe the related literature and the data used in this paper.

2.1 Background

2.1.1 The Brazilian Amazon prior to 2005

Until the 1960s, the Brazilian Amazon's native vegetation was largely preserved and inhospitable, popularly known as the "Green Hell" (*Inferno Verde*). The area had a small and sparse population living at subsistence levels and the main economic activity during the region's most prosperous period was the extraction of rubber.[7] Between 1964 and 1985, the military government promoted the occupation of the region by non-indigenous people with large infrastructure constructions – e.g., by building roads and hydroelectric power plants – and colonization projects such as titling of occupied and productive land (Pfaff, 1999). As a consequence, a substantial number of migrants moved to the Amazon area creating a boom of cattle ranching in the region. Environmental consequences were not a high concern during this period. For example, the Ministry of Environment (MMA) was created only in 1985, and the Brazilian Environmental Protection Agency (IBAMA) only in 1989.

Even after the creation of IBAMA, and despite the enactment of the first Environmental Crimes Act in 1998, the low presence of the state in the Amazon region allowed cattle ranching and illegal titling in the area to expand. As a consequence, between the 1980s and 2004, the deforested area grew from 6% to 16% of total forest land in the Brazilian Legal Amazon area(MMA, 2013). This was a period where several government institutions were supposed to monitor and to enforce the environmental law, but with little coordination among them or no strong effort from the federal government to align their efforts.

2.1.2 Changes in the Brazilian legal and enforcement regime

In 2004, however, the Brazilian federal government decided to crack down on deforestation in the Amazon, and launched the *Action Plan for the Prevention and Control of Deforestation in the Legal Amazon* (PPCDAm). This was a holistic policy conceived to

[7]Many inhabitants were members of indigenous tribes who depended on the forest for thier subsistence needs.

be a "tactical-operation plan that integrates actions across government institutions" (Assunção *et al.*, 2015). Enactment of this plan followed the appointment of Marina Silva as Minister of the Environment in 2003. Her appointment to that role brought a renewed focus on tackling deforestation of the Amazon within government. She represented the interests of the local, often indigenous inhabitants of the Amazon rather those of the elite cattle ranchers and farmers who were encroaching upon the forest. The fact she enjoyed the direct support of President Lula in her endeavors, who had a massive political and popular approval, was also significant.

PPCDAm was divided into three phases. Sveral specific government actions focused on territorial and land planning, strengthening enivronmental legislation and strengtheningenvironmental monitoring and control. Overall there was a renewed focus on clearly demarcating which part of the Amazon were protected, on passing legislation to protect the Amazon and on enforcing environmental regulations which, in turn, required adequate monitoring and punishment architectures.

The main government actions within PPCDAm were: (i) the demarcation of more than 60 million hectares of Indigenous Land and Protected Areas (*Unidades de Conservação*), which are areas under special regulation and monitoring; (ii) the enactment of laws classifying deforestation as a crime and laws increasing the required preserved area within private properties; (iii) the creation of remote-sensing system for environmental monitoring and enforcement (DETER) through coordinated actions between many government institutions[8]; and (iv) to condition the access to rural credit on farmers and producers' environmental compliance. Later, in 2008, the government implemented a new policy by *black listing* counties with high deforestation activity. These counties faced more stringent law enforcement, such as the DETER system, and landowners in these counties lost access to credit lines and access to potential markets.[9] In Appendix A, we outline the time line of the main actions related to the PPCDAm.

While even before the PPCDAm most deforestation was generally illegal in the Amazon, PPCDAm brought about several important legal changes. Land in the Amazon can be broadly classified land in three categories: *Protected Areas (PAs)*, which have strict deforestation regulation; *private properties*, which are all non-PAs private properties; and *unclaimed lands*, areas that are not PAs and are not private properties. Until 2005, private properties were required to set aside at least 35% of their area as native vegetation

[8]The Amazon remote sensing-based monitoring is mostly handled by the DETER (Real-Time System for Detection of Deforestation), a satellite-based system that captures georeferenced imagery and issues alerts signaling deforested areas. The National Institute for Space Research (INPE) produces satellite images every other week which are analyzed to identify deforestation hot spots and issue signaling alerts. Once deforestation hot spots are identified, IBAMA jointly with the Army, the Federal Police and the Federal Highway Police acts upon the areas.

[9]E.g., some beef and soybeans buyers stopped doing business with them (Adman, 2014). Two black listed counties are at the Brazilian border with Bolivia: Porto Velho and Nova Mamoré both in the state of Rondônia.

– i.e., it was illegal to deforest more than 65% of a non-PA private property. While it was illegal to deforest PAs, private properties (above the minimum requirement) and unclaimed lands, the difference was that deforesting PAs was a felony (with stricter legal procedures, and punishments that could include jail time), while deforesting unclaimed lands was just an infraction (punishable only by fines). While law enforcement was low in the Amazon, there was a clear legal difference between deforestation activities in PAs and non-PAs areas.[10]

In 2005, PPCDAm introduced two major law changes. First, PPCDAm increased the required set aside area of private properties from 35% to 80%, in practice, making illegal any further deforestation in private property since the vast majority of private properties had already deforested more than 20% of their area.[11] Second, PPCDAm made deforestation of unclaimed lands a felony and, therefore, punishable with jail time. In practice, therefore, while the vast majority of deforestation in the Amazon was illegal even prior to 2005, the de jure legal sanctions associated with deforestation in the Amazon substantially increased in 2005.

Despite all the migration and infrastructure policies supported since the military government, and despite all the recent enforcement measures promoted by the PPCDAm, the deep Amazon is still very much a frontier region. Cattle ranchers and illegal loggers are still active. "At the end of the road, on the Amazonian frontier, it feels like the Wild West, except with motor bikes and cell phones.", as wrote the Vice President and Chief Scientist of WWF, Jon Hoekstra, back in 2010.[12] In an interview to the New York Times in 2014, a top official of IBAMA, Luciano Evaristo, said about one black listed county, Novo Progresso (literal translation *New Progress*): "this is the Wild West of environmental crimes. We are waging an endless war."[13]

2.1.3 Relationship to existing literature

Since 2005, the annual deforestation rate in the Brazilian Amazon fell dramatically, reaching a 70% reduction in annual deforestation rate in 2013 relative to the ten-year average until 2005 Hansen *et al.* (2013). This decline has been well noted in the scientific community (see, e.g., Nepstad *et al.*, 2009; Nolte *et al.*, 2013; Godar *et al.*, 2014).

However, identifying the role of Brazilian government policies in causing this decline is

[10]Note that protected areas (PAs) may be privately or publicly owned, but harming vegetation inside a PA is a crime independently of its ownership.

[11]In theory, this law made every landowner with less than 80% of their property preserved be subject to prosecution and punishments. In practice, this law was never enforced. In 2012, the New Forest Code granted amnesty for past forest crimes. That is, landowners where liable for any deforestation above the 20% requirement from 2005 onwards, but not for the deforestation until 2005.

[12]http://blog.nature.org/conservancy/2010/05/18/stopping-deforestation-on-the-amazonian-frontier/

[13]http://www.nytimes.com/2014/10/04/world/americas/brazil-rainforest-amazon-conservation-election-rousseff-silva.html?_r=0

more challenging, and there is a view that both falling commodity prices and government policy may have played a role (Assunção *et al.*, 2015). Existing evaluation approaches have generally tried to use variation within Brazil to identify the effect of government policy, but these approaches all face the challenge that Brazilian government policy changes apply throughout the country. This makes identification challenging. Assunção *et al.* (2015), for example, compare municipalities with greater or lower "tightness of land constraints," measured by the share of land that is not legally available to farmers relative to total land area, arguing that conversation policies may be more binding in areas with higher land constraints. Godar *et al.* (2014) looks within municipalities, and shows that the decline in deforestation is larger in census tracts dominated by large landholders, but this does not necessarily distinguish between government policy and changing demand for their services, or other factors. Assunção *et al.* (2013a) compare areas with more or less cloud cover to argue that satellite-based enforcement contributed to reductions in deforestation rate, though a challenge is that cloud cover may also affect the quality of the satellite data used to measure outcome variables. Assunção *et al.* (2013b) document a decline in deforestation post-2008 that is larger in the "Amazon Biome" area, and suggest that this differential decline is due to a 2008 change that made access to rural credit lines conditional on farmers' environmental compliance. Again, the challenge is that there may have been other changes in this subset of the Amazon other than credit.

The degree to which a coordinated government policy can reduce deforestation matters, as it should inform the approach taken to reduce tropical deforestation in other parts of the world. This paper brings a new approach to this question by focusing in on border areas and comparing the Brazilian Amazon with nearby forest other countries not subject to Brazilian legal changes.

2.2 Data

We have collected remote sensing data for the Amazon area from various sources. Our main data source is Hansen *et al.* (2013), which contains forest cover in 2000 and annual forest loss from 2001 to 2013 at a 30 x 30 meter resolution. Importantly, 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. Hydrology data from 2000 was extracted from Google Earth Engine (image MOD44W_005_2000_02_24) and remaining georeferenced data with administrative boundaries, protected areas, elevation, slope, roads and urban areas were extracted from OpenStreetMap's API [14]. We standardized the resolution of all data to 120 meters by 120 meters at the equator – i.e. 0.001077978 latitude degrees. We have in total more than 277 million observations. Table

[14]https://www.openstreetmap.org

1 present summary statistics of all variables used.

3 Empirical Method

We investigate any discontinuous change in forest cover in 2000 and in the rate of forest loss between 2001 and 2014 at the national border between Brazil and surrounding countries to identify the effect of different national institutions deep in the jungle. Table A1 in the appendix presents the share of the Amazon Forest in each country, as well as summary statistics on their respective contribution on forest change.

We estimate spatial regression discontinuity designs using as running variable the distance to the Brazilian national border. A pixel with distance equal to zero is a pixel on the Brazilian border, positive distances represent pixels in Brazilian territory, and negative distances represent pixels 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 sized 120 meters by 120 meters. $Brazil_i$ is a dummy equal to one if pixel i is in Brazilian territory. $f\left(DistBorder_i\right) = Brazil_i * f^{Brazil}\left(DistBorder_i\right) + (1 - Brazil_i) * f^{OutsideBrazil}\left(DistBorder_i\right)$ is a polynomial of distance from the border allowing for different shapes on both sides of the border. Following Gelman & Imbens (2014), we favor linear polynomials f as our preferred specification and use quadratic polynomials as robustness. We alsofully interact the polynomial to allow it to be different on each side of the border. X_i is a vector of controls explained in more detail below. We cluster the errors in blocks of size 50km by 50km to allow for some geographical error correlation.[15]

The coefficient of interest is γ, which measures the difference in the probability a pixel is still 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.

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. We look directly at four factors that may influence deforestation: land slope, distance to water, distance to urban areas, and distance to roads. Table 2 shows the estimates of γ which represent the discontinuous change in the level of these covariates at the Brazilian border for three different segments of the border and four

[15] An alternative would be to use Conley (1999) standard errors. However, this is computationally challenging given the extremely large number of observations.

different 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 4.1 below). Nonetheless, in our main specification we estimate (1) controlling for natural covariates: land slope and distance from water. We present results without any controls and including controls for distance from urban areas and distance to roads in the robustness tables.

We use bandwidths of maximum distance from the border ranging from 5 km to 100 km. Since we have different dependent variables, we do not have one theory-driven optimal bandwidth. We calculate the optimal bandwidth for each dependent variable as Imbens & Kalyanaraman (2012). The optimal bandwidth of forest cover in 2000 is 5 km from the border, but the optimal bandwidth for annual deforestation depends on which year we calculate it for. To ease comparability across equations, our preferred bandwidth is the average of the optimal bandwidths calculated across all variables, which is 17 km from the border, though we report results using a variety of alternative bandwidths. In our preferred specification using all pixels within 17 km of the border, we have 301 clusters and 20,537,712 observations.

4 Results

In this section we estimate any discontinuous change in forest cover and forest loss in the Amazon around the Brazilian border. We start by examining the deforestation pattern across Brazilian borders both graphically and by presenting the estimates of the spatial discontinuity regression described in the previous section. We also investigate heterogeneous results across different country borders, deforestation pattern in Protected Areas (PAs) and non-PAs, Black Listed counties, and in forest areas near to roads. This helps us to understand the contribution of different components of the Action Plan to the the observed deforestation slowdown. Last, we estimate the probability that each plot of land (pixel) in the Brazilian state with higher deforestation activity, Mato Grosso, would be deforested in 2001 given its geographic and infrastructure characteristics. We use these estimates to discuss the average cost of deforestation of pixels that were actually deforested over the years in Brazil and in Bolivia.

4.1 Main Results

Figure 4 shows the percentage of forest cover in 2000 averaged by eighty equal-sized bins of distances from the Brazilian border, up to one hundred kilometers from each side of the border. Positive distances represent plots of land (pixels) in the Brazilian Amazon, while negative distances represent pixels in the Amazon outside Brazil. We can see that the level of forest cover on the Brazilian side of the border is smaller than the forest cover abroad independently of the distance from the border. Furthermore, we can see that forest cover drops sharply exactly at the national border.

Our regression estimates indicate that this discontinuous change in forest cover at the border is sizable and statistically significant. Table 3 presents the estimates of the Brazilian institutions effect, γ, from equation (1) on the percentage of forest cover in 2000 (column 1), controlling for two geographic characteristics – the slope of the terrain and the distance to water. Different panels present estimates using different bandwidths, as indicated. Panel A presents results using our preferred bandwidth: 17 km from each side of the border. We find that, in 2000, the forest cover in the Brazilian Amazon was around 3.3 percentage points smaller than in its neighboring countries due to the Brazilian institutions. Since 89% of the land outside of Brazil was covered in 2000, this implies that deforestation prior to 2000 was 30 percent higher just inside the Brazilian border than just on the other side. Extrapolating this local point estimate to the whole Brazilian Amazon, this result would mean that by 2000 an area equivalent to the whole Ecuadorian and French Guianan Amazon together had been deforested in Brazil due to Brazil specific policies relative to those pursued by Brazil's neighbors in the Amazon region.

Our point estimates increase with the bandwidth used, but remain sizable even when consider a very narrow 5 km bandwidth. Panel B presents the estimates for the optimal bandwidth (Imbens & Kalyanaraman, 2012) for forest cover in 2000. In this specification, considering pixels within just 5 km from the border, we still find that Brazilian policies led to 1.2 percentage point less forest cover in 2000. Panels C and D present results using larger bandwidths; considering a 100 km bandwidth, we find that Brazilian institutions led to 5.7 percentage points less forest cover in 2000.

We next plot annual deforestation rates on both sides of the border, in figures 5 and 6, annually between 2001 and 2014. The figures show the percentage of forest cover lost in each year against the distance from the Brazilian border, up to one hundred kilometers from each side of the border. Until 2005, annual forest loss was three to eight times larger on the Brazilian side of the border than on the other side. Annual deforestation rate near the border ranged from 0.3 to 0.4 percent in Brazil, while it ranged from 0.05 to 0.1 percent in the other Amazonian countries. These results point to large differences in national policies which affect deforestation.

Figures 5 and 6 also show us that this dramatic difference in deforestation rates comes to an abrupt halt in 2006. Between 2006 and 2012, deforestation activity is smoothly spread on both sides of the Brazilian border. Although the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (PPCDAm) was released in 2004, its actions were implemented gradually and we see in Figure 5 that 2006 is turning point as regards slowing deforestation at Brazil's borders which often represent the more remote parts of the Amazon.

In particular, 2006 is exactly the year when Brazil promulgates the Law on Public Forest Management, when IBAMA's Center for Environmental Monitoring (CEMAN) became fully operational and when the local operational basis from IBAMA started receiving online deforestation data (MMA, 2008). In 2013 and 2014, deforestation on the Brazilian side starts to increase, but if we attend to the scale of the graphs we see that the deforestation activity around the border in 2014 is similar to 2006's one, and still substantially smaller than pre-Action Plan levels. This apparent trend reversal may be credited to large infrastructure projects being built in the Amazon area, or the New Forestry Code approved in 2012 which gave greater flexibility to agricultural land use and decentralized in part its own implementation to the States (Ferreira *et al.*, 2014).

The estimates of our spatial discontinuity regression (1) corroborate the graphical evidence. Table 3, columns 2-15, present the estimates of the Brazilian institutions effect, γ, by annual forest loss from 2001 and 2014. Using a 17 km bandwidth, we see in Panel A that in each year until 2005 (columns 2 to 6) the probability that a forested pixel was deforested on the Brazilian side of the border was around four times the rate on the other side of the border – see Table 1 for the summary statistics. In 2004, for example, the probability that a given forest plot was deforested near the border outside Brazil was around 0.083 percent whilst the deforeation rate on the Brazil side of the border was 0.422 percent. This difference is statistically significant at 1 percent. Point estimates are increasing with the bandwidth but remain substantial in magnitude and statistically significant even using just those pixels within 5 km of the border.

We threfore are finding that the national policies and institutions do matter at the border, both for level of deforestation in 2000 and for subsequent deforestation rates until 2005. However, we see that coincidentally with the Action Plan (PPCDAm), from 2006 onwards, this new raft of Brazilian policies eliminate the differential in deforestation rates between Brazil and her neighbours. Table 3 (columns 7-15) shows that our estimates of the effect of Brazilian institutions at the border, γ, become smaller and not statistically significant. For some years, the point estimates considering larger bandwidths – Panels C and D – are statistically significant, but these are at least a third of the point estimates for 2004.

These results are robust to a series of alternatives specifications and samples, as shown in Table 4. We use a 17 km bandwidth in all regressions in this table. Panel A presents results when we do not controls for the slope of the terrain and distance to water and use only linear polynomials of distance to the border as controls. Panel B excludes 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. Panel C uses quadratic polynomials of distance to the border as control. Panel D adds too infrastructure controls: the distance to roads and the distance from urban areas. In all these specifications, the estimated results are very close to the ones presented in Table 3 Panel A.

In Table 4 Panel E, we estimate the effect of Brazilian institutions restricting the sample to areas around artificial borders as in Alesina *et al.* (2011) – i.e. those which are literally straight lines drawn on a map, as opposed to following natural features such as rivers.[16] For these borders, there is no geographic feature at the border – and indeed, usually not even so much as a fence. Nevertheless, we find even larger effects: a 10 percentage point difference in deforestation at artificial borders in 2000, and around 0.5 percentage point difference in annual forest loss in 2003 and 2004.

4.2 Heterogeneity

Our results point that Brazilian institutions matter overall, we now document evidence of heterogeneity in institutions across different segments of the border and different land types within Brazil. We first investigate heterogeneous results across different country borders, as shown in Tables 5 and 6. We examine the Brazilian borders with Bolivia, Peru, Columbia, Venezuela, Guyana, Suriname, and French Guyana.[17] We can see that in all fourteen years for which we have data available, Brazilian national policies have no effect on deforestation pattern near the Brazilian border with all these countries, except one: Bolivia. We can see that almost the main differences in deforestation rates are found around the border with Bolivia. The estimates presented in Table 5 Panel A suggest that, until 2005, Brazilian national policies affected deforestation rate around the border with Bolivia four times more than the national average.

The fact that the results we find are concentrated around the border with Bolivia could have two reasons: Bolivian policies could be particularly good to cope with deforestation, or local policies within Brazil could be particularly problematic in that region. Evidence suggest that it is the latter. First, as shown in Table A1 and Figure A1 in the appendix, the Bolivian Amazon had the smallest share of Amazon forest cover in 2000 and second highest deforestation rates in the following fourteen years, just behind Brazil. That is, compared with all other countries in the Amazon area, Bolivia does not seem to be particularly effective in deterring deforestation. Second, the area within Brazil near the border with Bolivia is at the forefront of deforestation, this is an area pressed in between the national frontier and the large-scale agricultural frontier.

We also document evidence of heterogeneity in policies within the Brazilian side. For example, in 2008 when the government *black listed* counties due to high deforestation activities, the only two counties that are at the Brazilian border share a border with Bolivia – these are Nova Mamoré and Porto Velho. Table 7 Panels A and B present

[16]We map the segments of artificial border in Figure A3 in the appendix.

[17]Table A1 in the appendix show the area of Amazon in each country, as well as key summary statistics.

our results when we split the sample in border segments on black listed counties and counties not black listed. We see that Brazilian institutional effect on forest cover in 2000 is around one order of magnitude higher in black listed counties than in counties not black listed; local policies in black listed counties led to 22 percentage points less forest cover in 2000, as compared to only 2.7 percentage points in all other counties at the border. That is, in terms of deforestation these are areas with particularly bad local policies within Brazil. This analysis shows that the areas singled out for the black list are not having higher deforestation because of higher local demand factors; it really appears to be worse governance, since the effects on deforestation are largely limited to the Brazilian side of the border.

Table 7 Panel A and B – columns 2 to 6 – also show that, until 2005, Brazilian policies led to higher deforestation rate on average in both black listed and non-black listed counties, however the effects were one order of magnitude higher for black listed counties. We can see in Panel B – columns 7 to 15 – that the differential rate in annual forest loss in Brazil relative other countries disappear from 2006 onwards in non-black listed counties, as discussed before. We do not find that the large impacts on deforestation of local policies in black listed counties disappeared. Brazilian local policies in these areas continued leading to higher annual deforestation until 2013, however, its effect shrank more than 65 percent relative to 2004. As shown in Panel A, while in the year that the Action Plan (PPCDAm) was launched, in 2004, local policies in black listed areas led to 2.4 percentage points higher annual forest loss, the largest point estimate for after 2006 is a 0.8 percentage point higher deforestation rate.[18]

We have further evidence that Brazilian laws and its enforcement, as well the changes brought by the Action Plan (PPCDAm), and not particularly good Bolivian policies, were responsible for the differential policies effects estimated at the border. As we describe in section 2.1, although most deforestation is illegal in Brazil, certain areas have special legal protections and other areas gained additional legal protection with the PPCDAm. Until 2005, destroying or harming native vegetation in *Protected Areas* was a crime subject to harsher legal procedures and punishments – including possible jail time – than deforesting vegetation in non-protected areas. We see in Table 7 Panels C and D that when the national border abuts these protected areas there is *less* deforestation on the Brazilian side in all period studied; but, when the national border does not abut a protected area there is *more* deforestation on the Brazilian side, at least until 2005.

In 2005, PPCDAm changed the regulation and punishment of deforesting non-protected areas: it increased the minimum set aside area of private properties from 35% to 80% of rural properties, and turned deforestation of unclaimed lands into a felony, thereby,

[18]Adman (2014) investigates the mechanisms within black listed counties that acted to reduce deforestation and find that political pressure on local politicians played a meaningful role.

increasing its potential punishment. Since the potential punishments for deforesting protected areas stayed unchanged, we would expect that these legal changes would affect local policies only in non-protected areas. Evidence corroborate this intuition. We find no meaningful change on the Brazilian policies in these protected areas in the whole period studied – see Table 7 Panel C. However, we estimate in Panel D of this same table that local policies in non-protected areas led to annual deforestation rates around 0.5 percentage points higher on the Brazilian side of the border until 2005, but these effects dropped sharply in 2006 onwards to around 0.1 percentage points, often imprecisely estimated. This shows that the national policies effect is not being driven by the fact that the differences in deforestation are because deforestation is uniformly more profitable in Brazil, but rather by different enforcement regimes on the Brazilian side of the border.

Clearly, access to infrastructure, such as roads, matters for deforestation as well (Pfaff, 1999). In fact, if we restrict our attention to pixels on either side of the border that are within 5 km of a road, we find that all differential effect of national policies at the baseline comes from these pixels close to roads. By contrast when we examine pixels more than 5 km away from a road on either side of the border we find largely no difference on baseline forest level and annual deforestation rate. Table 7 Panels E and F present these estimates. This suggests that proximity to roads – or infrastructure – is necessary for intense deforestation to take place, but it is not sufficient. National and local policies are important to deforestation on top of the existence of basic infrastructure, and can be shaped to help coping with deforestation.

4.3 Quantifying the magnitude of the border effect

Proximity to roads are important for deforestation, but other characteristics of the forest may also affect the propensity that each plot of forest will be deforested. For example, proximity to urban areas, proximity to rivers and the slope of the terrain also influence the cost of deforesting a given plot of land or may affect the expected productivity of that plot. Pixels' geographic characteristics provide us some information about the profitability of deforesting eachplot of land. To quantify the magnitude of the border effects, we estimate a logit model on the Brazilian side of the border with Bolivia that calculates the probability that each pixel is deforested in 2001 as a function of observable factors.[19] We use these estimates (see Appendix Table A2) to predict the propensity that each pixel in Bolivia is deforested based on their characteristics.

This allows us to quantify the Brazil effect in terms of observables as we compare the propensity of being deforested of pixels that were actually deforested in Brazil and in

[19]We use the level and the squared values of slope, distance to water, distance to roads and distance to urban areas as pixels characteristics. We restrict our estimation to a 17 km bandwidth around the Brazil-Bolivia border.

Bolivia. Figure 5 present the predicted probability that each pixel would be deforested for all pixels actually deforested each year in Brazil (solid red line) and in Bolivia (blue dashed line). We see that, until 2005, pixels deforested on the Brazilian side of the border had on average a smaller propensity to be deforested based on their observable factors than the pixels that we deforested on the Bolivian side of the border. In other words, in a period when a much larger area was being deforested on the Brazilian side of the border, pixels deforested in Bolivia tended to be around 25 percent more profitable than those deforested in Brazil if we considered only their geographic characteristics. It must be that unobservable factors, such as local policies, where underlying the higher deforestation rate on the Brazilian side. Interestingly, this pattern was reverted after 2005 exactly when the border effect estimated in Table 5 Panel A become statistically equal to zero; the average propensity to deforest of deforested pixels in Brazil and Bolivia become level by the end of the period studied.

5 Conclusion

We estimate spatial regression discontinuity designs at the national border between Brazil and surrounding countries to identify the effect of national institutions deep in the hinterland. Our results show that national institutions and policies are important at the border: both baseline forest cover and annual deforestation rate change abruptly at the border – we find higher deforestation activity on the Brazilian side of the border. Furthermore, we find evidence of heterogeneous institutions within Brazil – the bulk of deforestation happened in forest areas subject to weaker and more lenient laws – non-*Protected Areas.*

We also document that weak institutions can be strengthen in a short period of time. Following the Brazilian government released a action plan for prevention and control of deforestation in the Amazon (PPCDAm) – which enacted a harsher legal framework against deforestation in non-protected areas – we estimate that negative effect of Brazilian institutions at the border virtually disappear from 2006 onwards. We find that the bulk of this change happened in areas near roads, where access was substantial, and within non-protected areas, exactly the areas that were subject to the legal changes. The results demonstrate the power of concerted state enforcement even in the deep hinterlands.

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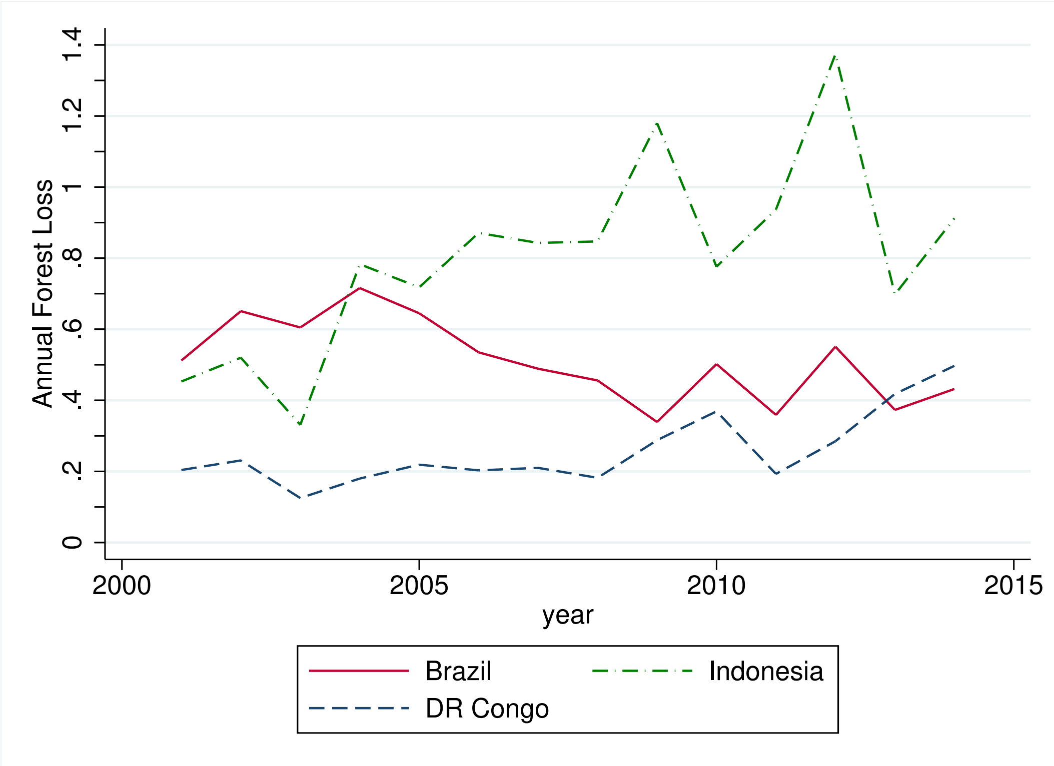

Figure 1: Forest Change, 2001-2014, by Country

This figure shows the annual forest loss in Brazil as a whole (including non-Amazon areas), in the Democratic Republic of the Congo and Indonesia. Forest loss is measured as the share of forest cover in each country that was lost in each year – that is, the share of the share of forest cover in year $t-1$ that was lost in year t.

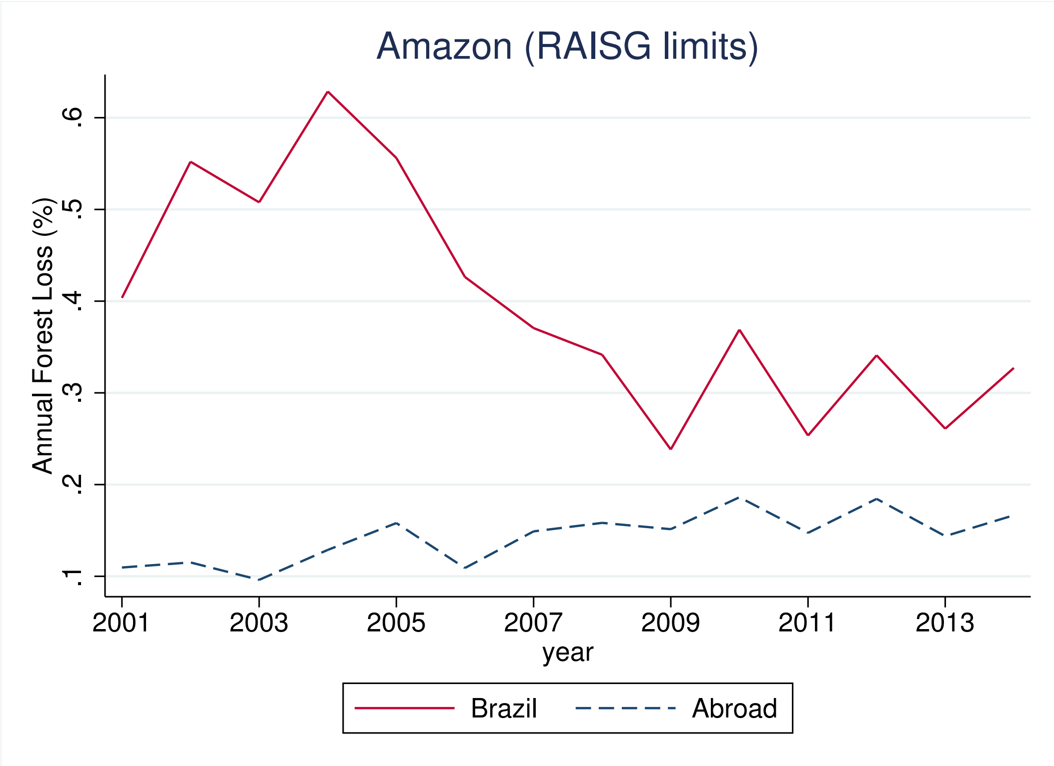

Figure 2: Forest Change, 2001-2014, in the Amazon Area

This figure shows the annual forest loss in the Amazon each year between 2001 and 2014 in Brazil (red line) and other countries (red dashed line). We use the Amazon limits provided by RAISG. Forest loss is measured as the share of forest cover in each country that was lost in each year – that is, the share of the share of forest cover in year $t-1$ that was lost in year t.

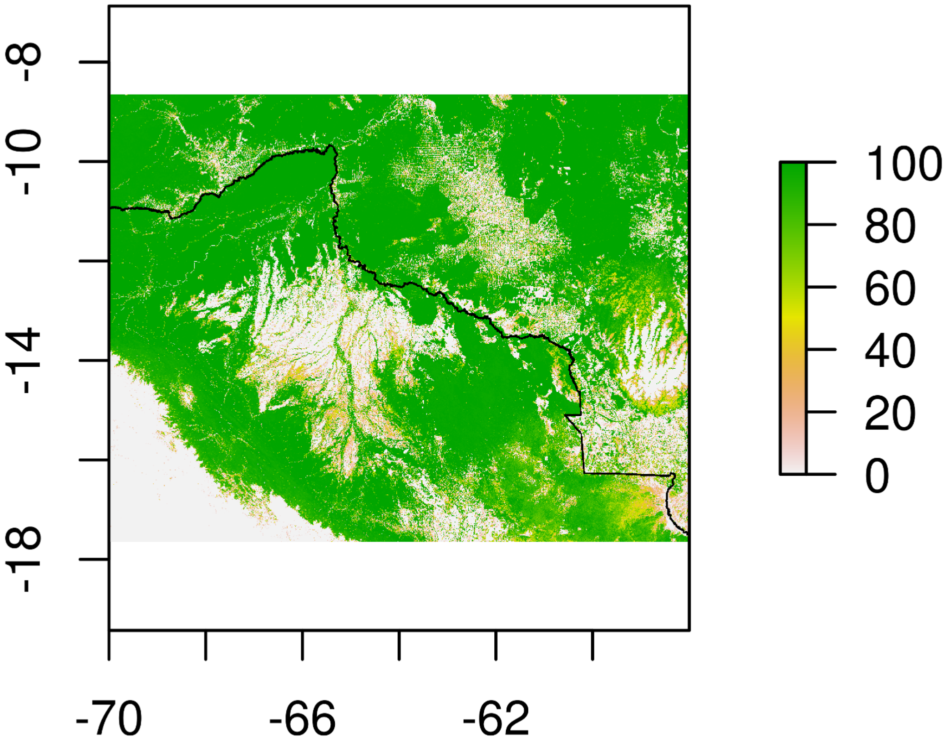

Figure 3: Example Google Earth Photo of a Border Segment (Percentage of Forest Cover in 2000)

This figure shows the percentage of forest cover in 2000 by 30 meter pixels of a segment of the border between Brazil (North of the border) and Bolivia and Peru (South of the border).

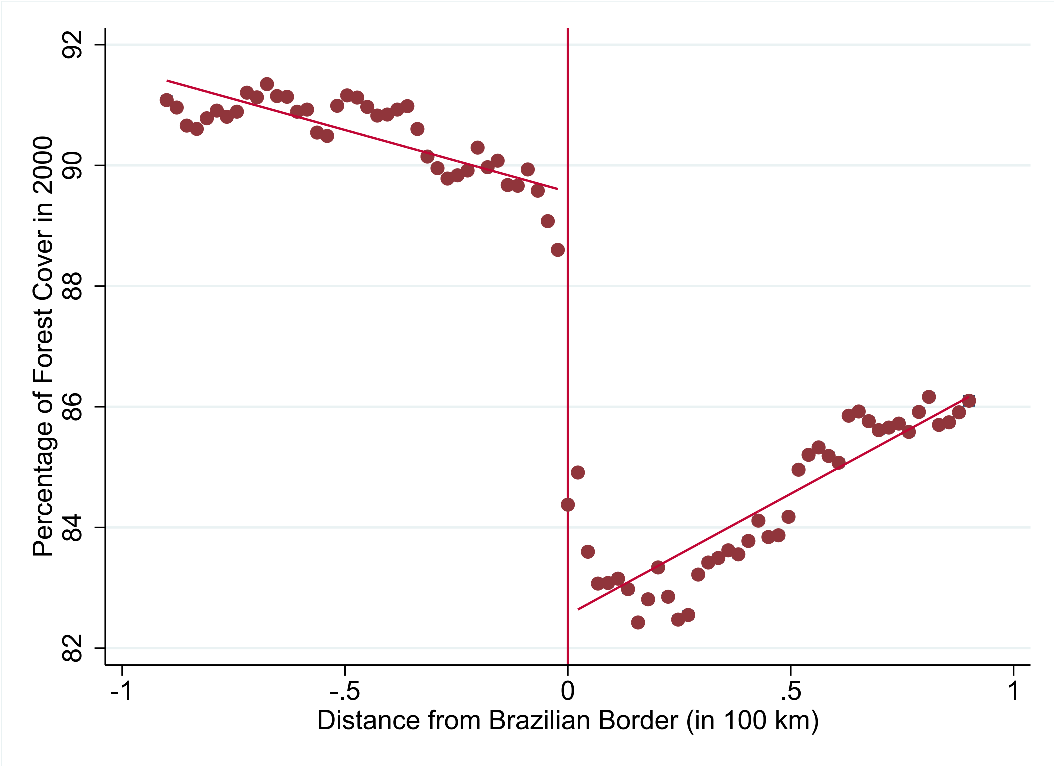

Figure 4: Average Forest Cover in 2000 by Distance from Brazilian Border

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 represent Brazilian land, while negative distance represent non-Brazilian land. The vertical bars (not always visible) depict 95% confidence intervals of the local average within each bin. The red line shows the linear function of distance weighted by the number of observations in each bin.

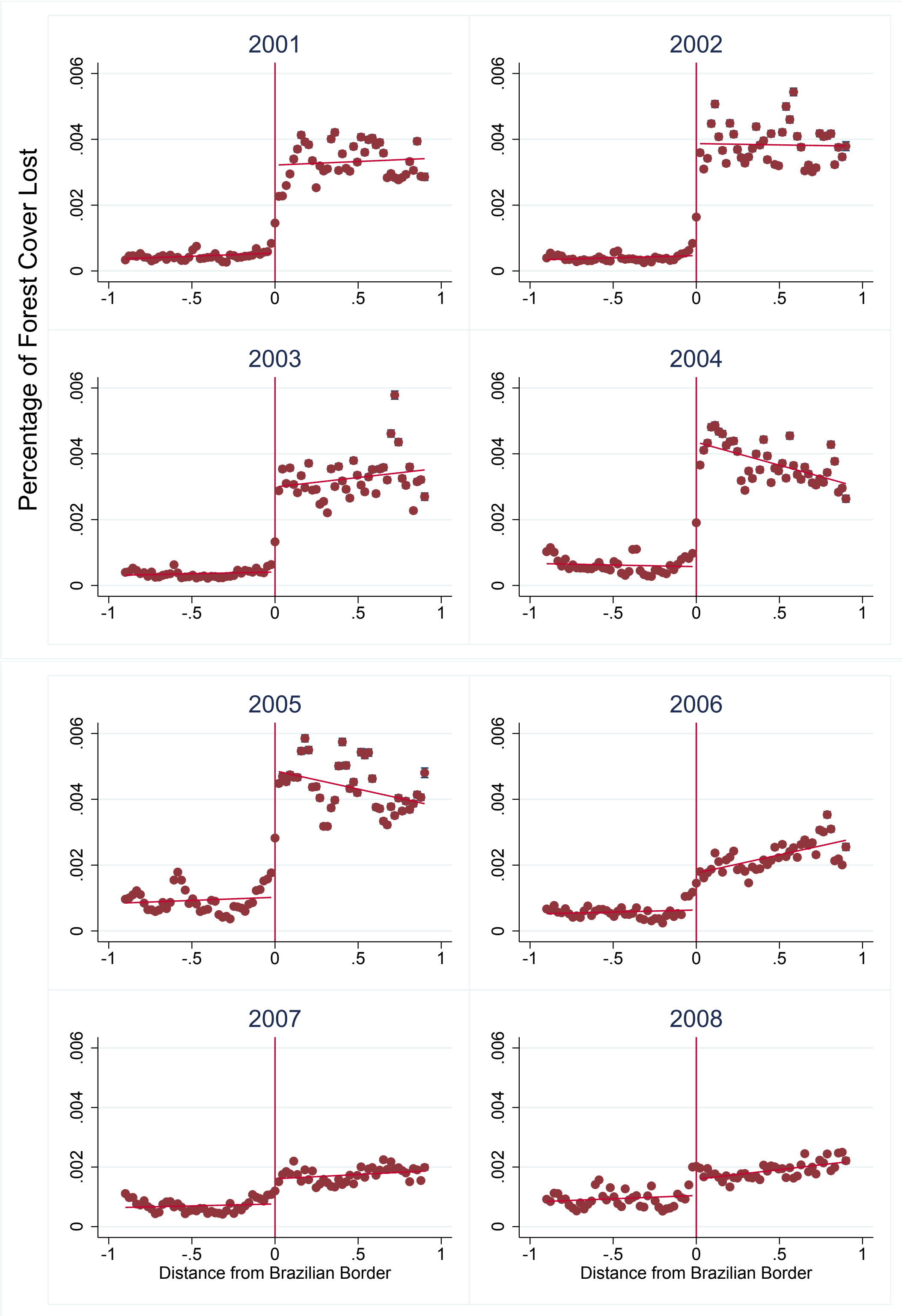

Figure 5: Average Annual Forest Loss at the Border by Year – 2001-2008

This figure shows the average annual forest cover lost each year between 2001 and 2008 by 80 equal-sized bins of distances from the Brazilian border. Each figure present pixels more distant from the border, up 1 hundred kilometers away from the border. Positive distance represent Brazilian land, while negative distance represent non-Brazilian land. The vertical bars (not always visible) depict 95% confidence intervals of the local average within each bin. The red line shows the linear function of distance weighted by the number of observations in each bin.

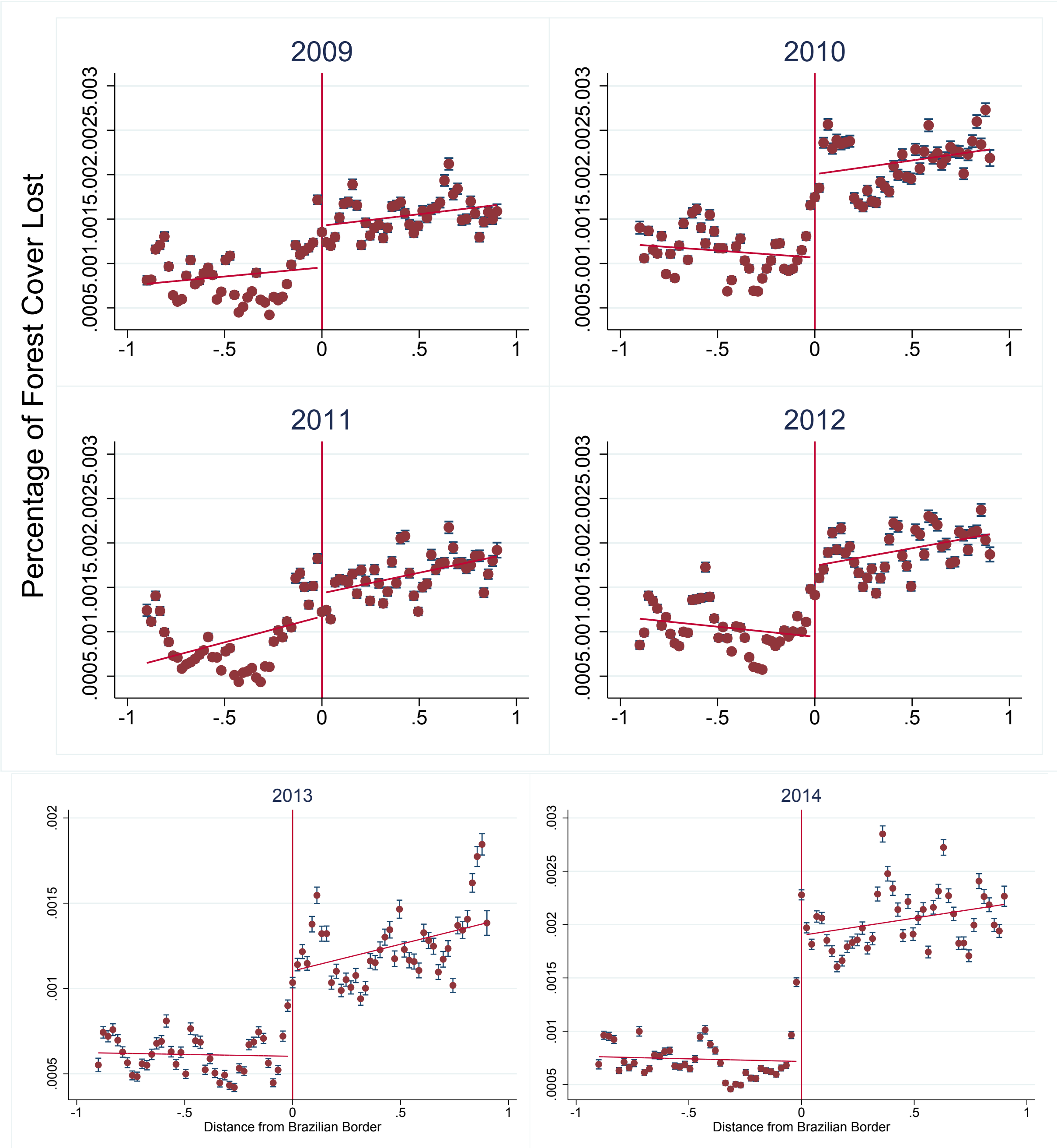

Figure 6: Average Annual Forest Loss at the Border by Year – 2009-2014

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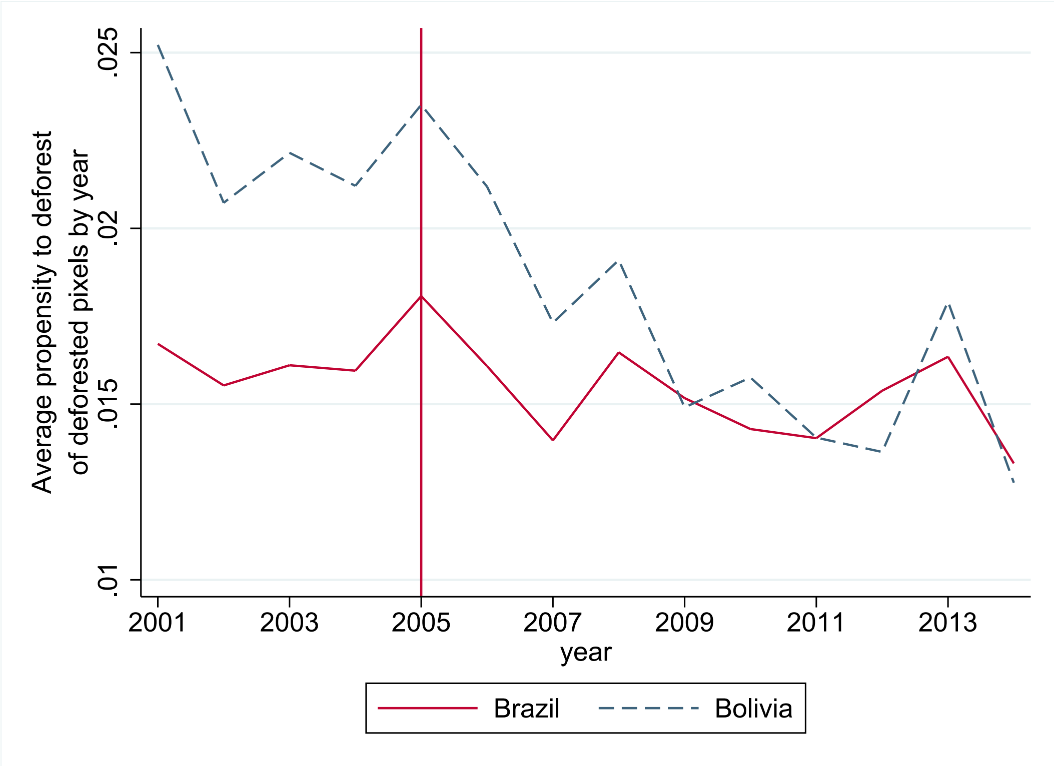

Figure 7: Average Probability of Deforestation of Deforested Pixels by Year

This figure shows the *ex ante* predicted probability that each pixel would be deforested for all pixels actually deforested each year in Brazil and Bolivia. To construct this graph, we first restrict the sample to pixels in Brazil within 17 km from the border with Bolivia and estimate a logistic model of forest loss in 2001 on slope and distances (linear and quadratic) from water, roads and urban areas. We use these estimates to predict the probability that each pixel would be deforested given their geographical characteristics. Last, we average the predicted propensity to be deforested among all pixels that where actually deforested in Brazil (solid red line) and in Bolivia (dashed blue line) each year (indicated in the horizontal axis). We restrict this exercise to a 17 km bandwidth across the Brazil-Bolivia border.

Table 1: Summary Statistics

	Bandwidth 17km		Bandwidth 100km	
	Brazil	Abroad	Brazil	Abroad
	(1)	(2)	(3)	(4)
# Observations	10,258,587	10,279,125	52,646,804	52,636,853
Forest cover in 2000 (%)	83.481	89.03	84.29	90.36
Forest loss in 2001 (%)	.279	.065	.329	.047
Forest loss in 2002 (%)	.38	.059	.381	.042
Forest loss in 2003 (%)	.303	.052	.322	.037
Forest loss in 2004 (%)	.422	.083	.372	.063
Forest loss in 2005 (%)	.453	.144	.437	.096
Forest loss in 2006 (%)	.19	.083	.223	.059
Forest loss in 2007 (%)	.172	.103	.172	.071
Forest loss in 2008 (%)	.18	.127	.187	.097
Forest loss in 2009 (%)	.141	.129	.153	.088
Forest loss in 2010 (%)	.224	.123	.213	.115
Forest loss in 2011 (%)	.142	.154	.163	.092
Forest loss in 2012 (%)	.186	.114	.191	.105
Forest loss in 2013 (%)	.127	.068	.124	.062
Forest loss in 2014 (%)	.197	.094	.205	.076
Land slope	89.766	89.733	89.77	89.742
Dist. to water (km)	44.5	45.9	41.3	38.3
Dist. to urban (km)	90.6	92.7	88.6	92.7
Dist. to roads (km)	41.5	46.1	34.6	50.8
Roads within 5km (%)	16.3	16.1	16.9	12.9
Protected Areas (%)	50.7	1.7	45.8	2
Area in Black Listed Counties (%)	3		1.5	
Mount Roraima's Buffer (%)	7.4	7.9	5.2	8.1

This table presents the summary statistics of the variables used in the paper. Each column present results for a different bandwidth or segment of the border in *Brazil* and *Abroad* (bordering countries) as indicated. The bandwidth of 17km is the average optimal bandwidth of our dependent variables. Units of observations are 120 meter pixels around the whole Brazilian Amazon border.

Table 2: Covariates Balance Check

	Land			Distance from								
	Slope			Urban Area			Water			Roads		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Panel A. *Maximum Distance from Border* 17 *km*												
Brazil dummy (γ)	.08	.08	.05	0	0	0	0	0	0	0	0	.01
	(.08)	(.09)	(.16)	(.02)	(.02)	(.04)	(.01)	(.01)	(.02)	(.01)	(.01)	(.02)
Panel B. *Maximum Distance from Border* 5 *km*												
Brazil dummy (γ)	.02	.02	.03	0	0	.01	0	0	0	0	0	.01
	(.13)	(.14)	(.19)	(.01)	(.01)	(.03)	(0)	(0)	(.01)	(0)	(0)	(.01)
Panel C. *Maximum Distance from Border* 50 *km*												
Brazil dummy (γ)	.08	.08	-.09	-.02	-.02	0	-.02	-.03	0	-.02	-.02	-.02
	(.07)	(.08)	(.13)	(.06)	(.06)	(.06)	(.02)	(.02)	(.04)	(.03)	(.03)	(.04)
Panel D. *Maximum Distance from Border* 100 *km*												
Brazil dummy (γ)	.07	.08	-.15	-.03	-.03	.03	-.05*	-.06**	-.03	-.05	-.05	.05
	(.08)	(.08)	(.17)	(.07)	(.07)	(.09)	(.03)	(.03)	(.04)	(.04)	(.04)	(.05)
Excluding Mount Roraima		Y			Y			Y			Y	
Artificial Borders			Y			Y			Y			Y

This table presents the regression estimates of the Brazilian dummy, γ, on land slope (columns 1-3), distance from water (columns 4-6), distance from roads (columns 7-9) and distance from urban areas (columns 10-12), from equation (1) with *linear polynomials*. Each panel shows results for a different bandwidth, Panel A refers to the average optimal bandwidth of our dependent variables, and Panel B refers to the optimal bandwidth of forest cover in 2000. Units of observations are 120 meter pixels around the whole Brazilian Amazon border. We present results for three segments as indicated in the columns: the whole border, the border excluding a 220km buffer around the peak of Mount Roraima, and artificial borders only. Number of observations (whole border, excluding Mount Roraima, artificial border): Panel A (20537712, 18961163, 2016027), Panel B (6239668, 5750468, 558906), Panel C (56024296, 51982251, 5029133), Panel D (105283103, 98296660, 7289279). Standard errors clustered at 50km grids in parentheses, number of clusters for the respective border segments: Panel A (301, 282, 39), Panel B (223, 205, 27), Panel C (510, 480, 58), Panel D (788, 747, 72). Significance levels: *10%, **5%, ***1%.

Table 3: Results Forest Loss by Year

	Forest Cover in 2000	Forest Loss in year													
		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Panel A. *Maximum Distance from Border* 17 *km*															
Brazil dummy (γ)	-3.28***	.1**	.19***	.21***	.21***	.21***	.04	.03	-.01	-.05	.03	-.04	.02	.02	.06*
	(.99)	(.04)	(.06)	(.06)	(.06)	(.08)	(.05)	(.04)	(.05)	(.04)	(.04)	(.04)	(.04)	(.02)	(.03)
Panel B. *Maximum Distance from Border* 5 *km*															
Brazil dummy (γ)	-1.19**	.09**	.16***	.09***	.09**	.13**	.06	-.03	-.02	-.05	-.01	-.01	.02	0	.04
	(.55)	(.04)	(.05)	(.03)	(.04)	(.07)	(.04)	(.03)	(.06)	(.03)	(.03)	(.03)	(.03)	(.02)	(.03)
Panel C. *Maximum Distance from Border* 50 *km*															
Brazil dummy (γ)	-5.05**	.2***	.29***	.24***	.33***	.3***	.1**	.06*	.04	-.01	.09**	-.04	.06	.05*	.08**
	(1.99)	(.05)	(.08)	(.06)	(.08)	(.11)	(.04)	(.03)	(.04)	(.04)	(.04)	(.06)	(.04)	(.03)	(.04)
Panel D. *Maximum Distance from Border* 100 *km*															
Brazil dummy (γ)	-5.67**	.24***	.31***	.23***	.34***	.35***	.1**	.07*	.04	.03	.07*	.01	.07*	.04*	.1***
	(2.21)	(.06)	(.08)	(.06)	(.07)	(.11)	(.04)	(.04)	(.04)	(.03)	(.04)	(.05)	(.03)	(.02)	(.04)

This table presents the regression estimates of the Brazilian effect, γ, on the percentage of forest cover in 2000 (column 1) and annual forest loss (columns 2-15), from equation (1) with *linear polynomials*. All regressions control for the slope of the terrain and distance to water. Each panel shows results for a different bandwidth, as indicated. Panel A refers to the average optimal bandwidth of our dependent variables, and Panel B refers to the optimal bandwidth of forest cover in 2000. Units of observations are 120 meter pixels around the whole Brazilian Amazon border. Standard errors clustered at 50km grids in parentheses. Number of clusters and observations: 301 and 20537712 (Panel A), 223 and 6239668 (Panel B), 510 and 56024296 (Panel C), and 788 and 105283103 (Panel D). Significance levels: *10%, **5%, ***1%.

Table 4: Robustness – Forest Loss by Year

	Forest Cover	Forest Loss by Year													
	in 2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Panel A. *Whole Border and No Controls – Linear Polynomials*															
Brazil dummy (γ)	-3.24***	.1**	.19***	.21***	.21***	.21***	.04	.03	-.01	-.05	.03	-.04	.02	.02	.06*
	(1.01)	(.04)	(.06)	(.06)	(.06)	(.08)	(.05)	(.04)	(.05)	(.04)	(.04)	(.04)	(.04)	(.02)	(.03)
Panel B. *Border Excluding Mount Roraima Area – Linear Polynomials*															
Brazil dummy (γ)	-3.87***	.11***	.21***	.23***	.23***	.23***	.04	.04	-.01	-.05	.03	-.05	.02	.02	.07**
	(.99)	(.04)	(.06)	(.06)	(.06)	(.08)	(.05)	(.04)	(.05)	(.04)	(.04)	(.04)	(.04)	(.02)	(.03)
Panel C. *Whole Border – Quadratic Polynomials*															
Brazil dummy (γ)	-1.55**	.11***	.15***	.12***	.12**	.18***	.05	-.03	-.04	-.06	-.02	-.04	.01	-.01	-.01
	(.7)	(.04)	(.06)	(.04)	(.05)	(.07)	(.05)	(.04)	(.06)	(.04)	(.03)	(.04)	(.03)	(.02)	(.02)
Panel D. *Whole Border and Infrastructure Controls – Linear Polynomials*															
Brazil dummy (γ)	-3.31***	.1**	.19***	.21***	.21***	.21***	.04	.03	-.01	-.05	.03	-.04	.02	.02	.06*
	(.99)	(.04)	(.06)	(.06)	(.06)	(.08)	(.05)	(.04)	(.05)	(.04)	(.04)	(.04)	(.04)	(.02)	(.03)
Panel E. *Artificial Borders Only – Linear Polynomials*															
Brazil dummy (γ)	-10.06**	.27***	.27*	.47**	.56**	.1	.09	.03	-.22	-.26*	-.19	-.13	-.01	.01	-.01
	(3.96)	(.1)	(.16)	(.2)	(.25)	(.08)	(.14)	(.07)	(.3)	(.15)	(.26)	(.11)	(.05)	(.08)	(.06)

This table presents the regression estimates of the Brazilian effect, γ, on the percentage of forest cover in 2000 (column 1) and annual forest loss (columns 2-15), from equation (1). Maximum Distance from Border 17 km (the average optimal bandwidth of our dependent variables). All regressions, except those in Panel A, control for the slope of the terrain and distance to water. Each panel shows results for a different specification: Panel A uses only linear polynomials of distance to the border as controls; Panel B excludes a 220km buffer around the peak of Mount Roraima; Panel C controls for quadratic polynomials of distance to the border; Panel D adds controls for the distance from roads and distance from urban areas; and Panel E restricts the sample to the areas around artificial borders (i.e., straight line borders). Units of observations are 120 meter pixels around the whole Brazilian Amazon border. Standard errors clustered at 50km grids in parentheses. Number of clusters and observations: 301 and 20537712 (Panel A, C and D), 282 and 18961163 (Panel B), and 39 and 2016027 (Panel E). Significance levels: *10%, **5%, ***1%.

Table 5: Heterogeneity by Country Border (in Percentage Points) – Part 1

	Forest Cover in 2000	Forest Loss in year													
		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Panel A. *Border with Bolivia*															
Brazil dummy (γ)	-16.34***	.39***	.75***	.86***	.86***	.85***	.18	.11	-.03	-.17	.14	-.16	.1	.14**	.29***
	(2.46)	(.13)	(.19)	(.19)	(.2)	(.27)	(.2)	(.15)	(.2)	(.14)	(.14)	(.15)	(.13)	(.07)	(.11)
Panel B. *Border with Peru*															
Brazil dummy (γ)	-.56**	.04*	.03	.02	.04	.09	.02	.03	0	.03	-.01	.01	.03	.02	.05
	(.25)	(.03)	(.02)	(.01)	(.03)	(.05)	(.01)	(.02)	(.02)	(.02)	(.03)	(.02)	(.03)	(.03)	(.03)
Panel C. *Border with Colombia*															
Brazil dummy (γ)	.48	-.03	0	-.01	-.02	-.07	-.04	0	-.03	-.09	-.02	-.03	-.09	-.06	-.09
	(.31)	(.04)	(.01)	(.01)	(.04)	(.06)	(.04)	(.04)	(.04)	(.08)	(.04)	(.03)	(.08)	(.06)	(.07)
Panel D. *Border with Venezuela*															
Brazil dummy (γ)	2.57**	0	.01	.01	0	0	-.02	-.02	0	-.01	-.02	0	0	-.01	-.01
	(1.29)	(.01)	(.01)	(.01)	(0)	(0)	(.02)	(.02)	(.01)	(.01)	(.01)	(0)	(.01)	(0)	(.01)

This table presents the regression estimates of the Brazilian effect, γ, on the percentage of forest cover in 2000 (column 1) and annual forest loss (columns 2-15), from equation (1) with *linear polynomials*. All regressions control for the slope of the terrain and distance to water. Bandwidth 17km from the border, the average optimal bandwidth of our dependent variables. Each panel refers to the border segment with a different country. Units of observations are 120 meter pixels around the whole Brazilian Amazon border. Standard errors clustered at 50km grids in parentheses. Number of clusters and observations: 74 and 5033811 (Panel A), 58 and 3801663 (Panel B), 54 and 3478926 (Panel C), and 54 and 3720069 (Panel D). Significance levels: *10%, **5%, ***1%.

Table 6: Heterogeneity by Country Border (in Percentage Points) – Part 2

	Forest Cover	Forest Loss in year													
	in 2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Panel E. *Border with Guyana*															
Brazil dummy (γ)	1.54	.01	.03	.02	.01	.03	.03	.01	.04	.01	.02	.01	0	-.02	-.01
	(3.32)	(.02)	(.02)	(.01)	(.01)	(.02)	(.02)	(.01)	(.03)	(.01)	(.01)	(.01)	(.01)	(.02)	(.01)
Panel F. *Border with Suriname*															
Brazil dummy (γ)	1.82	.01	.01	.01*	0	.01	0	0	0	.02	.01**	0	.05	0	.01
	(4.09)	(.01)	(.01)	(.01)	(0)	(.01)	(0)	(0)	(.01)	(.02)	(0)	(0)	(.03)	(0)	(.01)
Panel G. *Border with French Guyane*															
Brazil dummy (γ)	-.71	.01	.01	0	-.02*	.02	-.01	.05	.01	-.01	-.03	0	.02	-.01	-.01
	(1.43)	(.02)	(.03)	(0)	(.01)	(.02)	(.01)	(.03)	(.03)	(.01)	(.03)	(0)	(.02)	(.01)	(.01)

This table presents the regression estimates of the Brazilian effect, γ, on the percentage of forest cover in 2000 (column 1) and annual forest loss (columns 2-15), from equation (1) with *linear polynomials*. All regressions control for the slope of the terrain and distance to water. Bandwidth 17km from the border, the average optimal bandwidth of our dependent variables. Each panel refers to the border segment with a different country. Units of observations are 120 meter pixels around the whole Brazilian Amazon border. Standard errors clustered at 50km grids in parentheses. Number of clusters and observations: 38 and 2405912 (Panel A), 14 and 876308 (Panel B), and 25 and 1221023 (Panel C). Significance levels: *10%, **5%, ***1%.

Table 7: Additional Heterogeneity Results (in Percentage Points)

	Forest Cover in 2000	Forest Loss in year													
		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Panel A. *Black Listed Counties*															
Brazil (γ)	-22.07***	1.27***	1.75***	2.35***	2.41***	2.06***	1.51*	.68**	.77**	.19	.53***	.77***	.78***	.25***	.41
	(5.57)	(.33)	(.55)	(.56)	(.25)	(.61)	(.81)	(.31)	(.32)	(.13)	(.14)	(.26)	(.27)	(.07)	(.37)
Panel B. *Counties not Black Listed*															
Brazil (γ)	-2.67***	.06**	.15***	.15***	.15***	.16**	0	.01	-.03	-.06	.01	-.07**	-.01	.02	.04
	(.97)	(.03)	(.05)	(.04)	(.05)	(.07)	(.03)	(.04)	(.05)	(.04)	(.04)	(.03)	(.03)	(.02)	(.03)
Panel C. *Protected Areas in Brazil*															
Brazil (γ)	2.94*	-.05**	-.05***	-.05***	-.08***	-.16***	-.09***	-.06*	-.16***	-.09**	-.07**	-.1***	-.08***	-.05***	-.06
	(1.6)	(.02)	(.02)	(.02)	(.03)	(.05)	(.03)	(.03)	(.04)	(.04)	(.03)	(.03)	(.02)	(.01)	(.04)
Panel D. *Non-Protected Areas in Brazil*															
Brazil (γ)	-8.59***	.23***	.4***	.45***	.47***	.58***	.15*	.1*	.13	-.02	.11*	.01	.11*	.09**	.18***
	(2.01)	(.07)	(.11)	(.11)	(.11)	(.15)	(.09)	(.06)	(.08)	(.05)	(.07)	(.06)	(.06)	(.04)	(.07)
Panel E. *Pixels within 5km to a road*															
Brazil (γ)	-14.5***	.43***	.7***	.61***	.78***	.56**	-.14	-.03	-.32	-.25	-.09	-.11	.12	.1	.25***
	(3.27)	(.13)	(.2)	(.17)	(.24)	(.28)	(.17)	(.16)	(.22)	(.15)	(.14)	(.12)	(.1)	(.07)	(.09)
Panel F. *Pixels more than 5km away from a road*															
Brazil (γ)	-.23	.01	.06*	.11**	.06	.11*	.06	.04	.05*	-.01	.04	-.03	-.01	0	.01
	(1.1)	(.03)	(.04)	(.05)	(.04)	(.06)	(.04)	(.02)	(.03)	(.02)	(.03)	(.03)	(.03)	(.02)	(.03)

This table presents the regression estimates of the Brazilian effect, γ, on the percentage of forest cover in 2000 (column 1) and annual forest loss (columns 2-15), from equation (1) with *linear polynomials*. Each panel refers to the border segment restricted to different areas, as indicated. Units of observations are 120 meter pixels. All regressions control for the slope of the terrain and distance to water. Bandwidth 17km from the border, the average optimal bandwidth of our dependent variables. Standard errors clustered at 50km grids in parentheses. Number of clusters and observations: 9 and 548511 (Panel A), 296 and 19989201 (Panel B), 276 and 15480732 (Panel C), 289 and 15336105 (Panel D), 117 and 3326300 (Panel E), and 296 and 17211412 (Panel F). Significance levels: *10%, **5%, ***1%.

A Timeline of Relevant Events in the Amazon and PPCDAm

1494	Treaty of Tordesilhas, most of the Amazon belong 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.
1851-1871	The precise limits of Brazilian border with Bolivia and Peru are set.
1870-1900	First Rubber Cycle. Incentives to migrate to the region (Brazilians and foreigners). 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. Starting in 1877, the area was occupied by numerous Brazilian migrants attracted by the boom in the rubber production. In the beginning of the XX century, the local population, formed in a large part by Brazilian migrants, declared independence from Bolivia and a diplomatic solution was reached between Brazil and Bolivia.
1940-1945	Second Rubber Cycle (coincides with WWII). President Getulio Vargas promotes the "March to the West" and advertises the "New Eldorado".
1964-1980s	Heavy investments and incentives to occupy the West during the Military Dictatorship.
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.
1980s	Environmental concerns start to emerge and the main local environmental leader, Chico Mendes, is murdered in 1988.
1992	UN Earth Summit ECO-92 in Rio de Janeiro, Brazil. Amazon Forest gains greater international visibility.
1990s	Soybeans plantations and cattle ranching expand into the Amazon. New population influx.
2000	Population in the Legal Amazon 21 million people.

2002 The Amazon Protected Area Program (ARPA) is created to expand and strengthen the Brazilian National System of Protected Areas (SNUC) in the Amazon and to ensure financial resources (Federal Decree 4.326/2002).

Ecological and Economic Zoning (EEZ) are legally institutionalized as a tool of National Environmental Policy (Federal Decree 4297/2002).

2003 Marina Silva is appointed Minister of the Environment.

2004 The Ministry of Environment launches the first phase of PPCDAm.[20]

EZZ's project for BR-163 starts to be elaborated; cooperation between state government is extended.

2004-08 Demarcation of the perimeter of Conservation Units and Indigenous Lands; both are *Protected Areas*.[21]

Banning over 60,000 illegal rural property titles.

Development of the remote-sensing system DETER by INPE.

2005 Demarcation of Conservation Units in the areas surrounding the highways BR-319 (Manaus – Porto Velho) and BR-163 (Tenente Portela – Santarém) (Law 11132/2005);[22] ZEEs reach the states of Roraima, Mato Grosso and Amazonas.

2005-07 Georeferencing of more than 10 million hectares of public lands in black listed counties (none on the border).[23]

2005-07 18 operational basis from IBAMA are constructed.[24]

2006 Law on Public Forest Management (law 11.284/2006) enacted.

IBAMA's Center for Environmental Monitoring (CEMAM) fully functioning and operational centers receiving online deforestation data.

2007 First *Black Listed* counties are defined (Decree 6.321/2007).

ZEE's project for BR-163 are concluded; ZEEs reach the states of Maranhão, Pará and Mato Grosso.

[20]The first phase was originally planned to be implemented from Apr 2003.

[21]Creation of 46 PAs (24 mi ha); out of those, 14 strict PAs (13.2 mi ha) and 32 sustainable PAs (10.8 mi ha).

[22]Also created the Area of Provisional Administrative Limitation along these highways.

[23]Altamira, Anapu, Novo Progresso, Medicilândia, Santarém, Esperança, Pacajá, Cachoeira do Piriá, Coroaci-Paraná, and Alto Alegre

[24]An operational base a local headquarters that centralize the local PPDCAm actions in the area.

2008	Decree 6.514/2008 reestablished the directives to investigate environmental infractions and to apply sanctions. It also determined the administrative processes for environmental crimes and introduced new mechanisms for law enforcement (e.g., seizure of animals and crop production and equipment used for illegal activities[25].
	"Operation Fire Arc" is implemented through public security actions.
2008-10	"Operation Green Arc" is supported by eight federal Ministries (Agriculture, Agrarian Development, Environment, Cities, National Integration, Labor, Justice, and Health) and instituted policies and actions to promote sustainable development in 43 *black listed counties.*
	Resolution conditioning the concession of rural credit in the Amazon Biome upon legal and environmental compliance.[26]
2009	Property titles of federal public land given to squatters with less than 15 fiscal modules. [27]
	Creation of the CICCIA (Committee to Combat Environmental Crimes and Violations) that gathers different units (e.g., Ministry of the Environment, Ministry of Justice, IBAMA, Federal Police, SIPAM, Abin (Brazilian Intelligence Agency), etc.) to plan and execute operations;
	Seven counties are added to the list of black listed counties.
2010-15	Second phase of Amazon Protected Area Program (ARPA) , with the goal to create 13.5 mi ha of new PAs.
2011	Seven counties are added to the list of black listed counties.
2012	New Forest Code (Law 12.651/2012) grant amnesty for past forest crimes.
	Law 12.615/2012 institutes the Environmental Rural Registry (CAR), a mandatory registration for all rural properties including georeferenced property demarcation and land use.
	Two counties are added to the list of black listed counties.

[25]People in the sector has this general idea that seizures are more effective than fines.

[26]Resolution 3545, introduced by the Brazilian National Monetary Council (CMN), for details see Assunção et al (2013b)

[27]The fiscal module ranges from 59 to 87 ha. Legal Land Program (Programa Terra Legal), Law 11.952/2009

B Appendix Figures and Tables

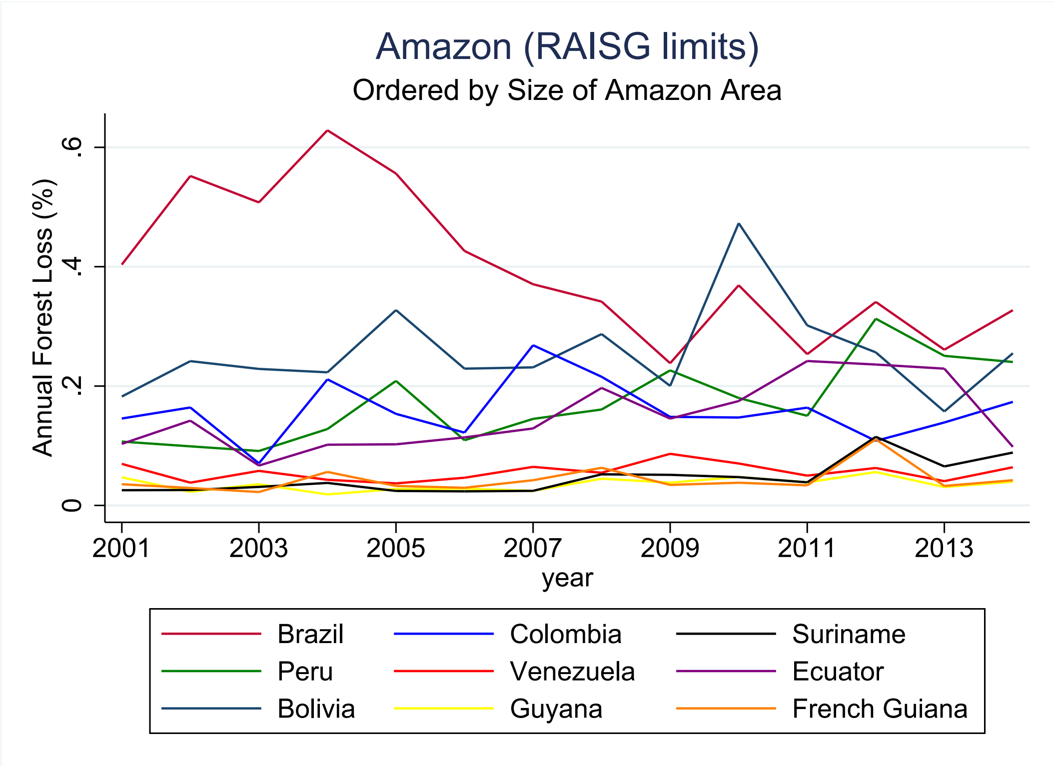

Figure A1: Forest Change in the Amazon Area, 2001-2014, by Country

This figure shows the annual forest loss each year between 2001 and 2014 by country. Forest loss is measured as the share of forest cover in each country that was lost in each year – that is, the share of the share of forest cover in year $t-1$ that was lost in year t.

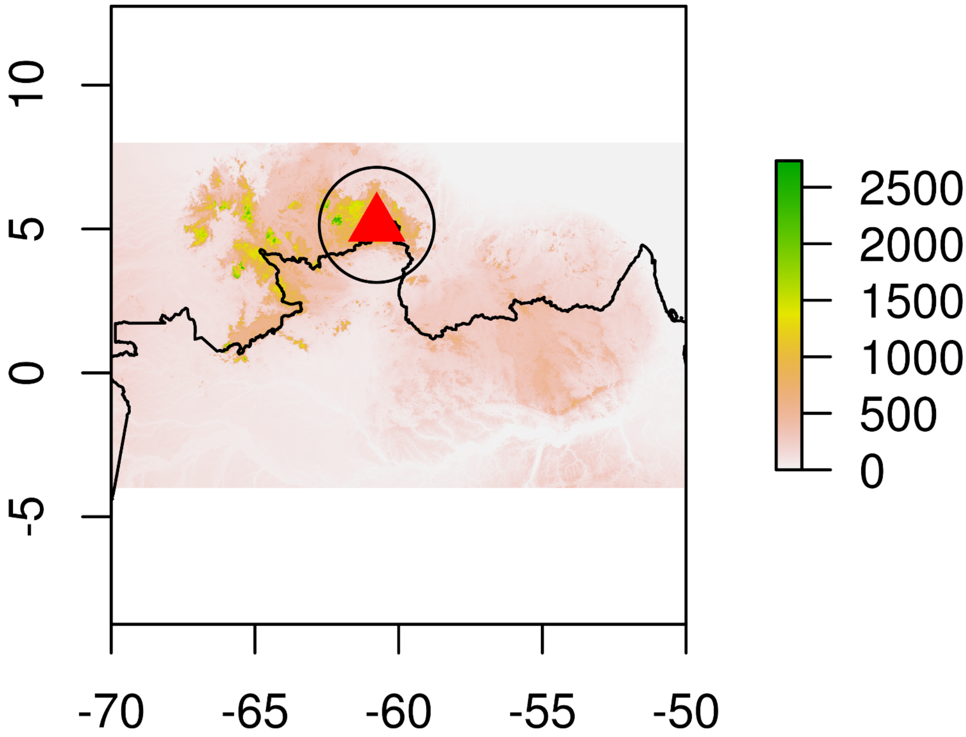

Figure A2: Map of elevation with 220km radius buffer around the peak of Mount Roraima

This map shows the elevation with a 220km radius buffer around the peak of Mouint Roraima in the North segment of Brazilian border with Venezuela and Guyana.

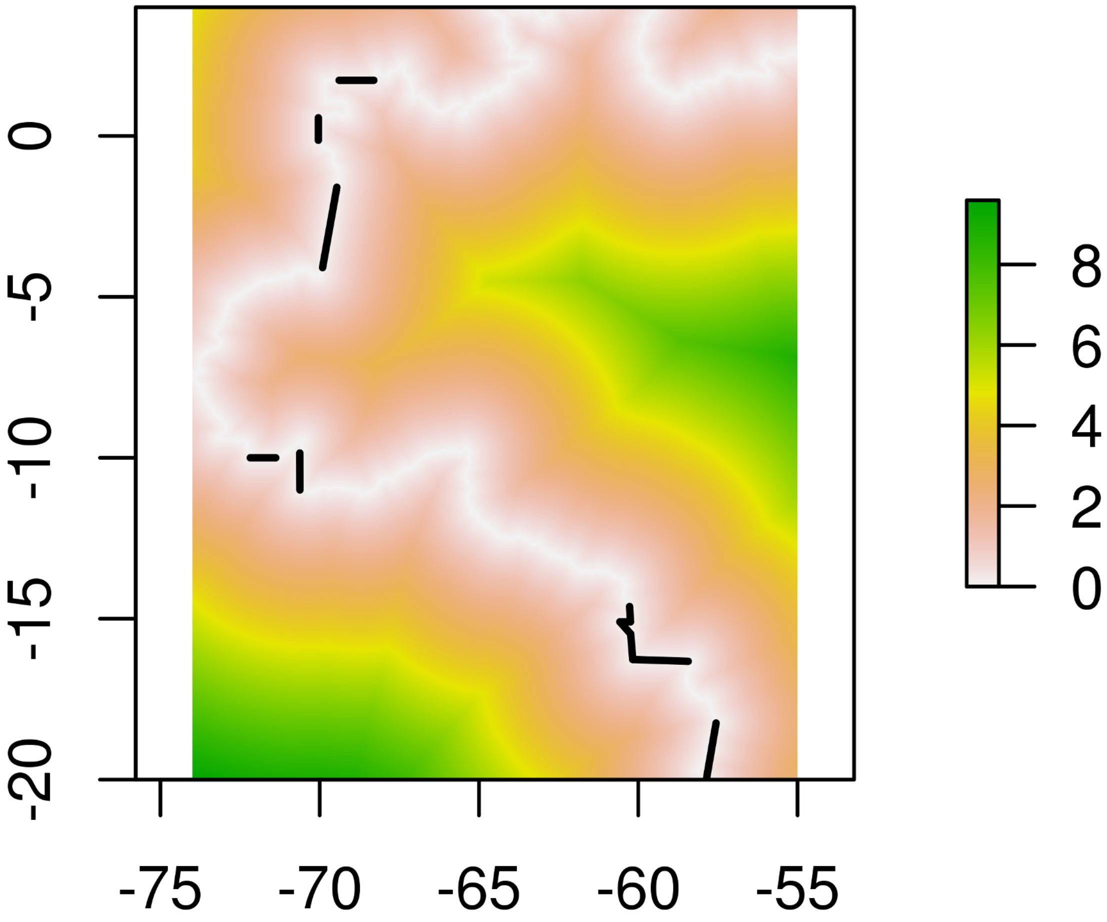

Figure A3: Map of Distance From Border with Artificial Borders Highlighted

This map shows the distance from border measures in latitude degrees. The highlighted sections are the areas where the border are artificially delimited, i.e. where borders are not set by a natural landmark.

Table A1: Amazon area in each country, forest cover and forest loss 2001-2014

Country	Share of Amazon's Area	Forest Cover in 2000	Forest Loss 2001-2014
Brazil	64.9%	77.4%	5.6%
Peru	9.8%	94.8%	2.4%
Bolivia	6.3%	70.7%	3.6%
Colombia	6.2%	92.6%	2.2%
Venezuela	6.0%	83.7%	0.8%
Guyana	2.7%	89.0%	0.5%
Suriname	1.9%	93.7%	0.7%
Ecuador	1.1%	96.1%	2.1%
French Guiana	1.1%	96.6%	0.6%

This table shows the share of Amazon area, as delimited by RAISG, in each country. It also shows the average forest cover in 2000 and overall 2001-2014 deforestation rate within each country's Amazon area.

Table A2: Summary Statistics by Country – Part 1

	Bolivia		Peru		Colombia		Venezuela	
	Brazil	Abroad	Brazil	Abroad	Brazil	Abroad	Brazil	Abroad
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
# Observations	2,544,437	2,489,374	1,940,609	1,861,054	1,662,786	1,816,140	8,423,322	8,394,321
Forest cover in 2000 (%)	61.805	80.603	98.435	98.794	98.558	97.943	81.077	88.579
Forest loss in 2001 (%)	1.009	.182	.048	.02	.032	.048	.335	.074
Forest loss in 2002 (%)	1.43	.178	.045	.02	.021	.027	.458	.068
Forest loss in 2003 (%)	1.148	.165	.029	.012	.009	.023	.364	.06
Forest loss in 2004 (%)	1.6	.264	.062	.027	.03	.048	.511	.098
Forest loss in 2005 (%)	1.707	.468	.093	.039	.022	.103	.55	.173
Forest loss in 2006 (%)	.669	.257	.038	.024	.024	.058	.226	.098
Forest loss in 2007 (%)	.554	.333	.048	.023	.051	.054	.199	.121
Forest loss in 2008 (%)	.62	.43	.051	.039	.019	.047	.216	.153
Forest loss in 2009 (%)	.463	.397	.054	.032	.034	.108	.167	.153
Forest loss in 2010 (%)	.782	.36	.045	.057	.05	.084	.265	.145
Forest loss in 2011 (%)	.509	.555	.04	.026	.02	.052	.171	.185
Forest loss in 2012 (%)	.583	.299	.102	.062	.032	.094	.221	.134
Forest loss in 2013 (%)	.41	.161	.06	.042	.042	.088	.15	.081
Forest loss in 2014 (%)	.665	.241	.08	.046	.04	.101	.235	.112
Land slope	89.544	89.454	89.859	89.951	89.739	89.472	89.728	89.677
Dist. to water (km)	18.3	20.9	48.8	53.6	28.3	27.9	39.1	40.4
Dist. to urban (km)	33.9	34.7	68.2	72.2	79.1	70.2	75.6	75.7
Dist. to roads (km)	10.4	9.4	38	45.9	34.1	32.2	31.7	35.4
Roads within 5km (%)	40.7	43.1	7.6	5.7	4.6	8.3	19.1	18.1
Protected Areas (%)	11.5	2.3	68	.1	77.4	6.4	41.6	2.1
BlackListed Counties (%)	12.1		0		0		3.7	

This table presents the summary statistics as Table 1 according to heterogeneity of Table 5.

Table A3: Summary Statistics by Country – Part 2

	Guyana		Suriname		French Guyane	
	Brazil	Abroad	Brazil	Abroad	Brazil	Abroad
	(1)	(2)	(3)	(4)	(5)	(6)
# Observations	1,219,753	1,186,159	9,824,624	9,836,780	9,636,813	9,679,876
Forest cover in 2000 (%)	63.983	70.133	83.715	88.976	82.766	88.535
Forest loss in 2001 (%)	.066	.026	.291	.067	.295	.068
Forest loss in 2002 (%)	.058	.029	.396	.061	.401	.061
Forest loss in 2003 (%)	.049	.017	.316	.054	.322	.055
Forest loss in 2004 (%)	.038	.015	.44	.086	.448	.087
Forest loss in 2005 (%)	.037	.017	.473	.15	.48	.152
Forest loss in 2006 (%)	.054	.025	.198	.087	.2	.088
Forest loss in 2007 (%)	.04	.027	.179	.107	.179	.108
Forest loss in 2008 (%)	.061	.029	.188	.133	.188	.133
Forest loss in 2009 (%)	.034	.027	.146	.135	.149	.137
Forest loss in 2010 (%)	.04	.03	.234	.128	.236	.128
Forest loss in 2011 (%)	.023	.021	.148	.161	.151	.163
Forest loss in 2012 (%)	.045	.038	.191	.117	.194	.118
Forest loss in 2013 (%)	.018	.031	.132	.071	.134	.072
Forest loss in 2014 (%)	.037	.045	.205	.099	.208	.099
Land slope	89.968	89.967	89.756	89.722	89.790	89.743
Dist. to water (km)	64.8	65	43.6	45.3	43.7	45.2
Dist. to urban (km)	88.7	101.4	83.8	86.4	88.8	91.9
Dist. to roads (km)	44.9	57.3	41	45.4	40.8	45.4
Roads within 5km (%)	25.4	12.9	16.9	16.8	17	16.7
Protected Areas (%)	49.4	0	52.9	1.8	54	1.8
BlackListed Counties (%)	0		3.1		3.2	

This table presents the summary statistics as Table 1 according to heterogeneity of Table 6.

Table A4: Summary Statistics: Heterogeneity Results – Part 1

	Black Listed		Non-Black Listed		Protected Areas		Non-Protected Areas	
	Brazil	Abroad	Brazil	Abroad	Brazil	Abroad	Brazil	Abroad
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
# Observations	308,611	239,900	9,949,976	10,039,225	5,201,607	175,113	5,056,980	10,104,012
Forest cover in 2000 (%)	78.622	97.459	83.632	88.825	90.947	97.909	75.802	88.873
Forest loss in 2001 (%)	1.875	.026	.23	.065	.035	.009	.531	.066
Forest loss in 2002 (%)	2.039	.019	.328	.06	.029	.007	.74	.06
Forest loss in 2003 (%)	2.732	.049	.228	.052	.027	.015	.588	.053
Forest loss in 2004 (%)	3.494	.042	.326	.084	.034	.013	.820	.084
Forest loss in 2005 (%)	2.682	.019	.384	.147	.031	.016	.889	.146
Forest loss in 2006 (%)	2.055	.021	.132	.085	.025	.008	.359	.084
Forest loss in 2007 (%)	.878	.026	.15	.105	.047	.014	.301	.105
Forest loss in 2008 (%)	.885	.079	.158	.128	.031	.025	.334	.129
Forest loss in 2009 (%)	.940	.072	.117	.131	.041	.015	.245	.131
Forest loss in 2010 (%)	.757	.016	.208	.125	.058	.018	.395	.125
Forest loss in 2011 (%)	.743	.064	.124	.156	.041	.019	.246	.156
Forest loss in 2012 (%)	1.548	.054	.144	.115	.058	.026	.318	.116
Forest loss in 2013 (%)	.427	.043	.117	.069	.037	.018	.218	.069
Forest loss in 2014 (%)	1.477	.684	.157	.08	.072	.728	.325	.083
Land slope	89.275	89.237	89.781	89.745	89.948	89.567	89.578	89.736
Dist. to water (km)	14.6	13	45.4	46.7	54.5	27.1	34.1	46.2
Dist. to urban (km)	30.9	28.8	92.4	94.2	103.2	52.7	77.6	93.4
Dist. to roads (km)	4.60	6.60	42.6	47	53.4	9.5	29.2	46.7
Roads within 5km (%)	61.2	43.1	14.9	15.5	7.10	35.2	25.8	15.8
Protected Areas (%)	3.4	23.8	52.2	1.2	100	100	0	0
Black Listed Counties (%)	100		0		.2		5.9	

This table presents the summary statistics as Table 1 according to heterogeneity of Table 7.

Table A5: Summary Statistics: Heterogeneity Results – Part 2

	Within 5km roads		Further than 5km roads	
	Brazil	Abroad	Brazil	Abroad
	(1)	(2)	(3)	(4)
# Observations	1,671,379	1,654,921	8,587,208	8,624,204
Forest cover in 2000 (%)	56.407	73.115	88.751	92.08
Forest loss in 2001 (%)	.893	.266	.16	.026
Forest loss in 2002 (%)	1.139	.259	.232	.02
Forest loss in 2003 (%)	.972	.233	.173	.017
Forest loss in 2004 (%)	1.394	.348	.232	.032
Forest loss in 2005 (%)	1.49	.664	.252	.044
Forest loss in 2006 (%)	.591	.373	.112	.028
Forest loss in 2007 (%)	.447	.409	.119	.044
Forest loss in 2008 (%)	.595	.59	.099	.038
Forest loss in 2009 (%)	.361	.497	.099	.059
Forest loss in 2010 (%)	.512	.387	.168	.072
Forest loss in 2011 (%)	.389	.658	.094	.057
Forest loss in 2012 (%)	.485	.303	.128	.078
Forest loss in 2013 (%)	.396	.242	.074	.035
Forest loss in 2014 (%)	.548	.272	.129	.06
Land slope	89.461	89.221	89.825	89.832
Dist. to water (km)	29.8	30.2	47.3	48.9
Dist. to urban (km)	25.2	23.7	103.3	106
Dist. to roads (km)	2.2	2.1	49.1	54.5
Roads within 5km (%)	100	100	0	0
Protected Areas (%)	22	3.7	56.3	1.3
Black Listed Counties (%)	11.3		1.4	

This table presents the summary statistics as Table 1 according to heterogeneity of Table 7.

Table A6: Logit Estimation:

Dep. Variable:	Forest Loss in 2001
Land Slope	3.400**
	(1.601)
Distance from water	3.585***
	(0.966)
Distance from urban area	-2.225
	(1.574)
Distance from roads	4.194
	(5.228)
Sq. Distance from water	-3.345***
	(0.897)
Sq. Distance from urban	1.951
	(2.019)
Sq. Distance from roads	-41.89*
	(24.26)
Constant	-310.1**
	(144.1)

This table presents the estimates of a logit model of the probability that each pixel was deforested in 2001 on pixel characteristics. We restrict our estimation to a 17 km bandwidth on the Brazilian side of the border with Bolivia. Robust standard errors in parentheses. Number of observations: 1,728,442. Significance levels: *10%, **5%, ***1%.