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The Effects of land Use Regulation on Deforestation: Evidence from the Brazilian Amazon

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Abstract

To reduce deforestation rates in the Amazon, Brazil established in the period 2004-2010 conservation zones covering an area 1.5 times the size of Germany. In the same period, Brazil experienced a large reduction in deforestation rates. By combining satellite data on deforestation with data on the location and timing of the conservation zones, we provide spatial regression discontinuity estimates and difference-in-difference estimates indicating that the policy cannot explain the large reduction in deforestation rates. The reason is that the zones are located in areas where agricultural production is likely to be unprofitable. We also provide evidence that zones reduce deforestation if the incentives for municipalities to reduce deforestation are high. We rationalize these finding with a spatial economics model of land use, with endogenous location of conservation zones and imperfect enforcement. Our findings point to the need for other explanations than the conservation zones to explain the sharp decline in deforestation rates in the Brazilian Amazon since 2004.

Keywords: regulation, conservation policies, deforestation, Brazil

JEL: Q28, Q58, R11, R14

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1 Introduction

The importance of reducing deforestation received much recognition in the climate agreement reached in Paris 2015, with 60 countries including REDD (Reducing Emissions from Deforestation and Forest Degradation) in their commitments and a separate REDD-clause in the final agreement (The Economist, December 2015). The backdrop is that tropical deforestation is a major contributor to greenhouse gases in the atmosphere, accounting for about 32% of the world's total CO2 emissions during the 1990-2005 period (World Development Report, 2010). From 2000 to 2012, Hansen et al. 2013 found increasing forest loss in the tropics, driven by countries such as Indonesia, Malaysia and others. In contrast, Brazil stood out with the largest decline of all countries globally, with more than halving its annual loss of forest cover from 2003/2004 to 2010/2011. An understanding of the factors behind the Brazilian success could guide the efforts of other countries in reducing their deforestation rates. However, academics are still debating the importance of the different policies and corporate actions that have been implemented since 2004.[1]

In this paper we examine the contribution of forest conservation to the deforestation slowdown in the Brazilian Amazon. As shown in the left panel of figure 1, forest under strict regulation (conservation zones) increased from 12% to 22% of the entire legal Amazon area in the period 2003-2010. Many observers assign an important role to this aggressive policy effort in the remarkable drop in deforestation rates over the same period, which can be seen in the right hand side panel of the figure. However, it is clear that most of the drop took place outside of the zones rather than inside of the zones, as the level inside was low also before 2004.

High resolution spatial data (we use 1 km^2 grid cells) allow us to zoom in and compare areas just inside with areas just outside the conservation zones, i.e. we implement a spatial regression discontinuity design, like Turner et al. 2014. We follow Turner et al. 2014 in focusing on straight parts of the zone boundaries, to deal with potentially endogenous zone location due to micro variations in the natural geography. The idea is that nothing in nature is straight, in contrast to policy lines. We focus on zones established from 2004 to 2010, and annual data on deforestation (2002-2013) allow us then to investigate the discontinuities at zone boundaries before and after the zones were established.

Our first empirical finding is that zones in general have not reduced deforestation. Although the areas inside the zones do have lower deforestation rates, with a discontinuity at the boundaries, we

[1] See for example the Editorial of Nature April 2nd 2015 and the two Science articles Gibbs et al. 2015 and Nepstad et al. 2014.

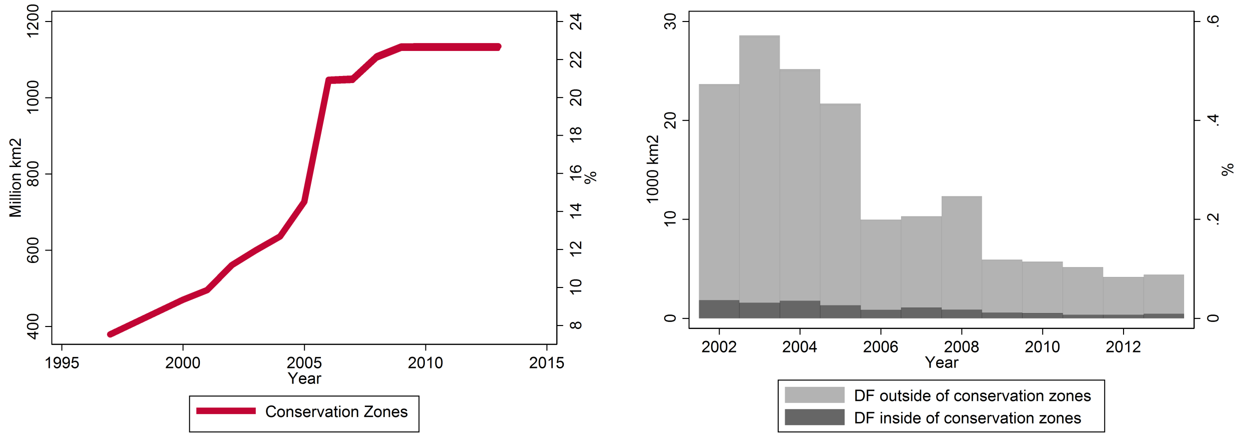


Figure 1: Total area covered by conservation zones and deforestation rates

Notes: Conservation zones (left panel) and deforestation rates inside and outside zones (right panel). Zones established in the years 1959-2012. Figure B.1 presents the same graphs including only zones established in 2004-2010. Source: Authors own calculations based on data from INPE.

find that the discontinuity in deforestation was present also before the zones were established. This observation suggests that the zones did not reduce deforestation. Difference-in-difference estimates, based on the difference between inside and outside cells, before and after zones were established, confirm that zones did not reduce deforestation.

Our second empirical finding is that zones were placed were agricultural production is likely to have low profitability. A linear probability model reveals that the conservation zones established from 2004 to 2010 were likely to be placed away from areas where agricultural production is expected to be profitable. In the same vain, high past deforestation rates also correlate negatively with the likelihood of the area being put under regulation. These results suggest that the location of zones were dominated by minimizing the efficiency loss of the policy, at the expense of the effectiveness of the policy in terms of reducing deforestation rates. In turn, this can explain our first empirical finding.

Our third empirical finding points to the importance of enforcement. It is obvious that enforcement issues matter in designing and assessing any regulatory regime. We exploit a policy implemented by the federal government in 2008, in which municipalities with particularly high deforestation rates were put on a “shame list” and faced the risk of losing federal monetary transfers over the state budget. We find that zones located in municipalities on the list were more effective than other zones.

Our three empirical findings can be rationalized with a simple spatial model with land regulation, endogenously placed conservation zones and imperfect enforcement. We base the theory on the monocentric city model, as Fujita and Krugman 1995 and Robalino 2007. A central location, city, is surrounded by land and the returns from agriculture (deforestation) are shown to decrease with the distance from the city.[2] The point at which the return equals zero determines the frontier of the agricultural production. The model thus formalizes the importance of distance to markets and emphasizes demand factors as a driver of deforestation.

The conservation policy is assumed to remove land that could have been developed for agriculture. The optimal placement of conservation zones trades off the opportunity cost of land against the costs of establishing the zone and enforcing the regulation. The former is the forgone agricultural production measured through its impact on the welfare of workers. We show that economic efficiency considerations push the location of the zone beyond the agricultural frontier. Concerns about reducing the contemporary deforestation rates, on the other hand, pull the location of the zones inside of the agricultural frontier, although their location will still be in the periphery.[3]

The theory predicts there to be a discontinuity of the land rent curve, and hence deforestation, at the boundaries of conservation zones. The drop in the agricultural rent varies with the level of enforcement: lower monitoring costs are associated with higher level of enforcement and consequently lower expected rents and lower deforestation inside the conservation zones.

Our finding that the conservation zones established from 2004 to 2010 play a little, if any, role for the large reduction in deforestation rates observed in the Brazilian Amazon since 2004, stands in stark contrast to the going conventional wisdom. For instance, Assunção et al. 2015 argue that approximately half of the deforestation that was avoided in the Brazilian Amazon during 2005-2009 was the result of government conservation policies. Soares-Filho et al. 2010 came to a similar conclusion, asserting that the expansion of the protected areas account for 37% reduction in deforestation in the Brazilian Amazon between 2004 and 2006, without facilitating leakage. Nolte et al. 2013 found that protected areas have contributed to reducing deforestation rates. Furthermore, as they compare different types of protected areas, they conclude that strictly protected (SP) areas have avoided more deforestation than sustainable use (SU) areas, with the former being effective under conditions of limited government enforcement. In contrast, our estimates do not reveal any qualitative differences between SU and SP zones.

For countries like Indonesia, Malaysia and Congo, that are in need for policies that can reduce

[2] Agricultural production is in our setting interpreted widely as anything that requires deforestation.

[3] These results formalize empirical observations on the historical locations of conservation zones across different countries, which suggest that areas were more likely to be protected if they were further away from high quality agricultural land or lands with existing timber and mining concessions, and if they had higher historical forest cover (Sims 2010, Dixon and Sherman 1990)

deforestation, this paper contributes by pointing out that conservation zone policies can reduce current deforestation rates if incentives to enforce the regulation are high for the local authorities, and only if they are placed where agricultural profitability is positive.

Relative to the existing literature on the effects of conservation zones on deforestation, which is dominated by empirical studies[4], this paper's first contribution to the understanding of how zones work, lies with the economics model that is based on the first principles of utility maximizing agents, profit maximizing firms, market access and a government that takes into account enforcement costs and economic efficiency in the design of the forest conservation policy. It allows us to coherently analyse how these key factors affect deforestation and the location of zones. The model gives clear predictions for the circumstances under which conservation zones can be expected to reduce deforestation[5].

The second contribution of the paper lies in the empirical identification strategy. The current empirical literature has used matching on observables to deal with the potential non-random selection of zone location. Our empirical design is an improvement over this, as it allows us to take into account selection also on unobservables. Such unobservables are found to be crucial for the location of the zones. For the Brazilian zones established in 2004-2010 that we study, the endogenous selection of zone locations introduces a biases such that zones appear more effective than they are in reality. The spatial regression discontinuity (RD) design in combination with straight borders that we borrow from Turner et al. 2014 aims to account for unobservables in that, close to the border, the factors relevant for deforestation are plausibly the same on both sides of the border. In our context, however, this may not be sufficient to deal with unobservables as there is a discontinuity in deforestation also before the zones were established. The difference in differences estimation allows us to control for time-invariant unobservables as wells as differential trends inside and outside of the zones. In the absence of randomly placed zones, these strategies give the best hope of achieving unbiased estimates of the

[4]e.g., Assunção et al. 2015, Blackman et al. 2015, Bruner et al. 2001, Nolte et al. 2013, Soares-Filho et al. 2010 and Pfaff et al. 2014

[5]There is a larger literature on deforestation more generally (Barbier and Burgess 2001, Lopez and Galinato 2005, Rudel et al. 2005, Alix-Garcia 2007, Burgess et al. 2012, Chomitz and Thomas 2003, Foster and Rosenzweig 2003, Pfaff 1999, Rodrigues et al. 2009, Zhao et al. 2011). The work in our paper complements the existing literature by focusing on issues pertaining to endogenous location of conservation zones, emphasizing the spatial dimension of economic activity in driving deforestation. Empirically, none of these studies employ regression discontinuity designs to study the effect of policies across space. This paper also belongs to the urban economics literature that evaluates the effects of land regulation. Our approach is most closely related to Turner et al. 2014, whose conceptual framework can be regarded as a reduced form derivation of the land rent curve. Our micro founded framework demonstrates the mechanisms, which give predictions for the circumstances under which the zones can reduce deforestation and these predictions are confirmed in the data.

effect of the zones. The set of results presented in this paper gives a remarkably consistent picture. Note, however, that had we relied on RD alone, i.e. not brought in the time-variation, we could easily have concluded that the zones did reduce deforestation.

The third contribution of the paper is that we explain the location of the zones, both theoretically and empirically. Nolte et al. 2013 also discusses the importance of "deforestation pressure", and our paper complements their paper by adding economic structure and empirical estimates of key determinants of zone location.

A final contribution is that we take advantage of a program of the federal government that raised the stakes of reducing deforestation for certain municipalities, and show that conservation zones reduced deforestation in incentivized municipalities. This is consistent with Assunção and Rocha 2014, who study the effects of the listing in a municipality-time panel analysis. They find that the listing reduced deforestation primarily through monitoring and law enforcement. Our contribution is to investigate the effect of the listing in the context of zones, zooming in precisely on where the deforestation happened within municipalities.

The rest of the paper is organized as follows. In Section 2 we present the theoretical framework. In Section 3 we describe the empirical approach and the data. Empirical findings on the effects of zones on deforestation rates are in Section 4. Section 5 investigates the factors that affect the location of the zones. Section 6 examines the role of incentives in reducing deforestation rates in the context of the zones. Section 7 discusses the role of conservation zones in reducing deforestation rates in Brazil. Section 8 concludes.

2 Theoretical framework

In this section we build a spatial economics model of land use, with endogenous location of conservation zones and imperfect enforcement. Our theory has three parts. The first part introduces the baseline framework and examines the effects of exogenous placement of conservation zone on incentives to deforest. The second part examines the endogenous location of the zones. The third part introduces imperfect enforcement explicitly into the model and examines implications of providing incentives to enforce regulation.

2.1 The baseline model

Consider a spatial economy comprised of cities and land. We assume that the area of the country is represented by a one-dimensional location space $z \in [0, z_{max}]$, and take point 0 as the central location, the city. The quality of land is homogeneous and the density of land is equal to 1 at every location. The labor force of the country takes the size N and consists of homogeneous workers, each endowed with a unit of labor. They are free to choose the location and sector where they supply their labor. The consumers of the country comprise workers and landlords. All landlords are attached to their land and consume the land rent at their location.

There are two consumption goods, manufacture (M), which is only produced in cities using labor, and an agricultural good (A), which is produced at locations $z > 0$ using land and labor. Each location has a predetermined pattern of trade: it delivers excess production of agricultural goods to the city and imports M-goods from there. We assume iceberg transport costs for both goods: if a unit of good i, $i = A, M$, is shipped over a distance d, only $e^{-t_i d}$ arrives at destination, where t_i is a positive constant. Production of manufacturing goods follows a simple linear function, with constant marginal productivity of labor. One unit of the agricultural good is produced by a unit of land and a_A units of labor.

All consumers have identical utility functions:

$$u(M, A) = A^{\alpha_A} M^{\alpha_M} \tag{1}$$

where $\alpha_A + \alpha_M = 1$. Given the consumer's budget constraint $p_A A + p_M M = Y$, the indirect utility function of a consumer at location z can be written as (for more details, see appendix A.1):

$$u(z) = \alpha_A^{\alpha_A} \alpha_M^{\alpha_M} Y(z) p_A^{-\alpha_A}(z) p_M^{-\alpha_M}(z) \tag{2}$$

where $p_A(z)$ and $p_M(z)$ are the prices of agricultural and manufacturing goods at location z. We let the price of the M-goods be normalized such that $p_M(0) = 1$ and $W(z)$ denote wage in location z. The land rent in z is then given by:

$$R(z) = p_A(z) - a_A W(z) = p_A e^{-t_A z} - a_A W(z) \tag{3}$$

where $p_A \equiv p_A(0)$. Given iceberg transport costs, there exists a location z^* ("the fringe"), beyond

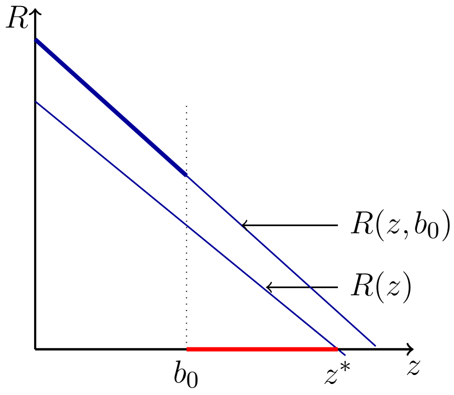


Figure 2: Land rent and conservation policy

which land rents are negative and agriculture unprofitable, i.e. $R(z^*) = 0$.

As in Fujita and Krugman 1995, it can be shown that a spatial equilibrium exists in this setting. For details, please see the appendix A.1. It can also be shown that the rent curve is a *strictly* decreasing function of the distance from the city, z.

2.2 Conservation policies

Consider the case that a conservation zone is established at location $z \in [b_0, b_1]$. To simplify the presentation, we assume that the regulation removes land from agricultural development just to the left of the agricultural frontier, so that $b_1 \equiv z_{max}$.[6] Appendix A.2 provides details on how the equilibrium of this model can be found. As shown formally in the appendix, conservation policy means an upward shift in the land rent curve. Intuitively, a decline in the amount of land available for agriculture increases return of each parcel of land where production of A-goods is allowed. Graphically, this is demonstrated in figure 2: rent curve $R(z)$ corresponds to the one under the baseline model (without conservation zones) and $R(z, b_0)$ is the rent curve of the model with the conservation policy. The figure demonstrates that there is a discontinuity in the land rent curve at the border of the conservation zone. This underpins our use of a regression discontinuity design when we later estimate the effect of regulation.

[6]Establishment of similar conservation zones have been considered in Robalino 2007 who modifies the framework of Fujita and Krugman 1995 to study how land conservation affects rents and real wages. Under the case when conservation zones are entirely established outside of the agricultural frontier, namely $b_0 > z^*$, the equilibrium and land rents are not affected. Thus the interesting case to consider is when $b_0 < z^*$. The assumption $b_1 \equiv z_{max}$ is a simplification to make the algebra and exposition of the intuition simpler. In general there is a leakage associated with the establishment of the zone. We conjecture that relaxing this assumption does not change the key insights of this basic set up.

2.3 Endogenous zones placement

This section presents a simple extension of the baseline model illustrating factors that may drive the placement of conservation zones closer to, outside or inside of agricultural frontier. The main intuition of the framework is straightforward: economic efficiency considerations push the location of the zones beyond the agricultural frontier, z^*. But concerns about reducing the contemporary deforestation rates pull location of the zone to the left of z^*.

Our approach is motivated by literature on optimal location of spatial public goods, such as green belts (e.g., Lee and Fujita 1997, Franco and Kaffine 2008). As in Lee and Fujita 1997, the size of the zone, d, is a given parameter, whereas the policy parameter is a location of the zone (left-end point) b_0.

Appendix A.3 shows that the placement of conservation zones closer to the city reduces the welfare of workers by more than when regulation places the zone further away from the city. Intuitively, removal of most productive land closer to the city reduces supply of the A-goods as such that, even with leakage, the prices of the agricultural goods rise, and utility of workers decline. Thus, if regulators seek to maximize economic efficiency (measured through workers' welfare), then they locate the zones beyond the agricultural frontier z^*.

Regulatory agencies likely to take enforcement budget into consideration when deciding the placement of the zones. The costs associated with enforcement of the regulation, $E(d, b_0)$, could depend on the size as well as the distance to the zone, capturing the direct enforcement costs and costs of travel to location, respectively. For the government, there is a trade-off: the closer to the city, the lower the travel costs, but also the higher are the risks of deforestation and thus more efforts need to be put into enforcing the regulation. If, costs of enforcement on the ground far exceed the costs of travel, then it is optimal to locate the zones far away from the markets.

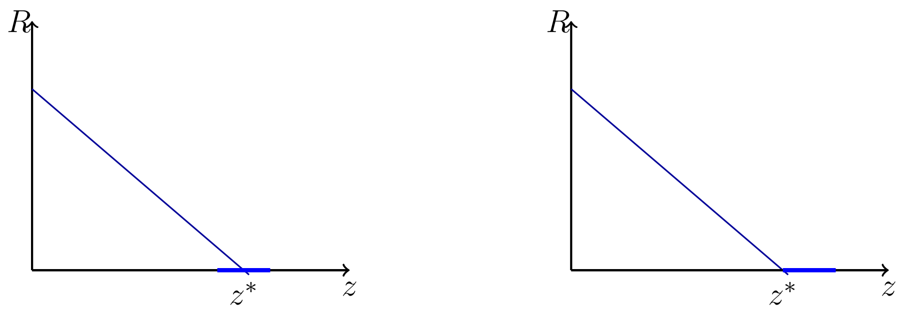
There are also benefits of regulation. They could come in two different forms. First, it could provide the symbolic value as pure public good. Within our context, this means that the zones can be regarded as indication of intension of government to address deforestation issues. Second, local regulatory authorities can receive funding for implementing policies that would preserve forest. These transfers tend to be conditional on performance, that is, they are based on an observed decrease in deforestation compared with to a baseline deforestation level[7]. The land quality is homogeneous in our framework, so that, from environmental point of view, it does not matter which parcel of land is

[7] Such linear conservation contracts observed in reality (examples are REDD+ policies). See also e.g. Harstad and Mideksa 2015 who present a tractable model of conservation and also formalize linear contracts of such type.

removed. On other hand, in the model the *observed* deforestation rate can be reduced only if the zones (or some part of it) are located to the left of the agricultural frontier, z^*, that is where deforestation is profitable. Thus, there are no extra benefits from placing the zones inside of the agricultural frontier. These consideration therefore support location of the zones at periphery, even with some (or all) of the zones being potentially inside the conservation zone.

In summary, the considerations above suggest that the optimal location of zones can be at one of two general areas: (a) the agricultural frontier lies inside of the zone, figure 3a (the figure also plot the baseline rent curve); (b) next to or outside the actual agricultural frontier, figure 3b. Our model is static, but we conjecture that the force that sets up the left point of conservation zone (b_1) at the border of agricultural frontier (z^*) is that the government wants to create a "buffer" to future potential deforestation: if the price of the A-goods increases due to exogenous rise in world commodity prices in the future, this would shift up the rent curve resulting in deforestaion in land next to z^*.

Finally, it is important to note that by-product benefit of placing the zone far away from the city is a smaller leakage. The closer the location of the conservation zones to the city, the larger reduction in the supply of agricultural goods and thus higher shift in the land rent and consequently larger increase in deforestation outside z^* (Kaimowitz and Angelsen 1998).



(a) $b_0 < z^* \leq b_0 + d$

(b) $z^* \leq b_0$

Figure 3: Optimal location of zones and baseline land rent

2.4 Imperfect enforcement and conservation zones

The baseline model implicitly assumes that everyone complies with the regulation. In reality, this requires perfect enforcement, which is costly. We then analyze how consideration of imperfect enforcement can changes the baseline predictions of the model.

Consider the conservation zone located at $(b_0, z^*]$ in figure 2. No compliance is the same as no

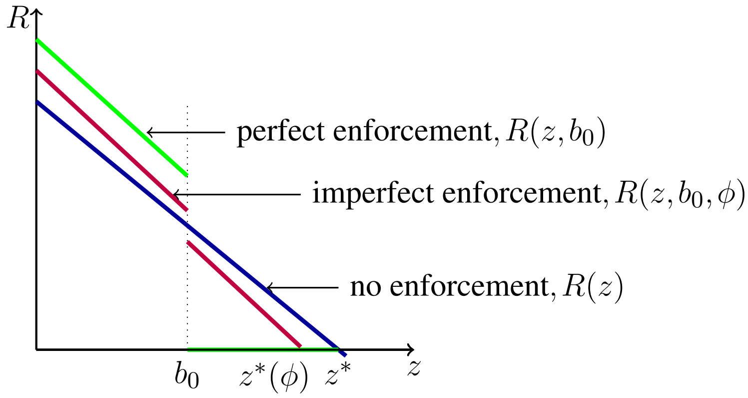


Figure 4: Land rent and effectiveness of regulation

regulation and implies the rent curve $R(z)$. The land owner in location z complies with enforcement if and only if his expected return is no greater than zero:

$$E[V(z)] = (1 - \phi(z))p_A(z) - a_A W(z) \leq 0 \tag{4}$$

where $z \in [b_0, z_{max}]$ and $\phi(z)$ is the probability of detection in location z. For simplicity, consider evenly distributed enforcement $\phi(z) \equiv \phi$. Then it is clear that enforcement deters any development in some areas of the conservation zone, $(z^*(\phi), z^*]$. This implies that the regulation with imperfect enforcement is associated with an equilibrium rent curve which is likely to be lower than the rent curve under perfect enforcement, as in figure 4.

Suppose the effectiveness of the enforcement is a function if the budget of the regulatory authority. In situations when the local enforcement budget can be relaxed particularly through transfers conditional on performance, then the larger the incentive, the more effective the enforcement. In the empirical section we take advantage of a policy that raised the stakes for municipalities of reducing deforestation. The idea would be that those municipalities directly or indirectly affected enforcement and hence made the regulation more effective.

3 Empirical strategy and data

3.1 Empirical strategy

The model presented above informs our empirical analysis. The rent related to the use of land for production of agricultural goods (the opportunity cost of forest conservation), can be expressed as:[8]

$$\log(p_A - e^{t_A z} R(z)) = \log(\lambda) + \log \bar{u} + (\alpha_M t_M - \alpha_A t_A) z + t_A z + \alpha_A \log p_A \tag{5}$$

where the land rent at location z, $R(z)$, enters with a negative sign on the left hand side. λ is a constant. Higher utility of the residence in the reservation location, $\bar{u}$, leads workers to migrate. Since utility has to be equalized for workers across space, the wages in a given location have to increase, so that the land rent goes down, all else being equal. The third term reflects that if the transport costs for M-goods (weighted by the expenditure share α_M) is high in comparison with that of A-goods, then consumers/workers prefer to live "closer" to the city, where M-goods are produced. This reduces the demand for A-goods in a given location z and thus lowers the rent. The fourth term means that the higher distance from a given parcel of land to the market/city, the less incentives to produce agricultural goods on that parcel and land rent is lower due to higher transportation costs. The final term simply means that the higher the price of agricultural goods, the higher the rent.[9]

Figure 2 illustrates the effect of a conservation zone on the land rent curve, which gives us the first prediction that we take to the data:

I) **Effective conservation zones generates a discontinuity in deforestation at zone boundaries**

First we investigate graphically if there is a discontinuity in deforestation at the borders of the conservation zones. This follows a standard spatial regression-discontinuity design, like Turner et al. 2014 and Cust and Harding 2014. For each zone, we know the year of establishment and we look for discontinuities in the period the zone was active, as well as in the years before the zone was active.

To formally estimate the effect of conservation zones, we use a standard difference-in-difference regression (like, e.g., Greenstone et al. 2010):

[8] See the derivation in the appendix. Equation 5 is obtained by combining equations 23 and 17.

[9] The partial derivative of $R(z)$ with respect to p_A is positive, since p_A appears in both sides of the equation and $\alpha_A < 1$.

$$DF_{pzt} = \alpha + \beta_1 Ever_z + \beta_2 Ever_z x Post_{zt} + \beta_3 Post_{zt} + f(dist_{pz}) + Ever_z * f(dist_{pz}) + Z'_{pzt}\theta + \epsilon_{pzt} \quad (6)$$

where p indicates cell, z zone and t year, i.e. grid-cells observed annually are our units of observation and we know whether they are located in an active conservation zone or not. DF measures deforestation in fraction of the area of the cell, $Ever$ is a dummy that takes 1 if the cell will be or is in a conservation zone, $Post$ is a dummy taking 1 for the years the conservation zone is active. β_2, the coefficient on the interaction between $Ever$ and $Post$ picks up the difference-in-difference estimate and is our coefficient of interest. $dist$ is the distance from the cell p to the conservation border. f is a polynomial and we allow for it to have separate effect on each side of the border. We use a polynomial of order 2 in our baseline specification.[10]

The land rent curve, equation 5, informs us about the controls to include in the vector Z. We interpret agricultural production widely (anything that requires deforestation), and the distance z as the distance to the relevant markets. z also represents anything that is correlated with agricultural productivity. The appropriate measures would in principle vary across agricultural products. We focus on distance to city and soil quality. We also control for the fraction of the cell that is coded as non-forest (water, cities etc.) as well as for lagged forest cover.[11]

β_2 in equation 6 is identified to the extent the error term is uncorrelated with the variable $Ever_z\ x\ Post_{zt}$. Non-random allocation of zones represents a considerable identification challenge. We control for observables as explained above, whereas unobservables are controlled for by the following. The RD-set up, with the flexible polynomials in the distance to the conservation zone border controls in principle for unobservables in terms of natural geography. The idea is that very close to the border, the natural geography is the same. Furthermore, we follow Turner et al. 2014 and use only straight parts of the borders.[12] The idea is that nothing in nature is straight, in contrast to policy lines. A discontinuity

[10]In an earlier version of this paper, we included separate time-trends inside and outside of the zones, and it did not change the conclusion that zones in general do not reduce deforestation. Given our conclusion of no-effect, we view it as more prudent to not saturate the model with controls, and therefore use a more parsimonious formulation as our baseline model.

[11]We have also investigated the role of alternative measures of market access and agricultural productivity, such as the distance to nearest river, distance to nearest soy field, the fertility of the soil and past deforestation rates. The choice of variables to be included in Z does not seem to affect the results. Distance to city is found to be the most robust one.

[12]Borders are defined as straight by the rule used by Turner et al. 2014, see their graph on p. 1374 for an illustration. More details are available from the authors.

across a straight border is therefore more likely to be related to the policy than a discontinuity across a non-straight border, whose location is more likely to be partly determined by omitted factors in terms of local natural geography. Finally, by bringing in the timing, we can control for municipality-year fixed effects that pick up anything that affects the average level of deforestation in a given municipality in a given year, i.e. we identify β_2 from within municipality variation.[13] In robustness checks, we also present results with cell fixed effects in addition to the municipality year fixed effects. We cluster the standard errors on the level of treatment, i.e. on zone-time, to take into account potential Moulton bias and spatial correlation.[14]

The second prediction we take to the data is on the location of the zones. Economic efficiency considerations in terms of maximization of the welfare of workers as well as minimization of leakage of deforestation into previously unprofitable areas push the location beyond the agricultural frontier. The force that sets up the left point of conservation zone (b_0) at the border of agricultural frontier (z^*) is that the government wants to create a "buffer" to future potential deforestation. If, however, the government faces an additional incentive and is forced to reduce *historical* rates of deforestation to some reference point, then the government has to locate the zones inside of the agricultural frontier. In such case, the agricultural frontier is to be located inside the conservation zone.

II) **Economic efficiency concerns push the zone location out of areas with high rents in agriculture (towards and beyond $z*$), whereas concerns about reducing contemporary deforestation rates push the zones to be located (at least partly) inside the agricultural frontier**

To test this prediction, we estimate the following linear probability model:

$$Ever_{pz}xPost_{pz} = \alpha + Z'_{pz}\gamma_1 + \epsilon_{pz} \tag{7}$$

Importantly, here we estimate where the zones are located in the cross section, i.e. we limit the sample so all cells are only represented once. We compare in principle all cells across space, and the dependent variable is simply the ever-treated dummy. The first set of determinants are variables correlated with transportation costs and land productivity, representing economic efficiency concerns. The second set is past deforestation rates. A negative effect of past deforestation rates would indicate that economic efficiency concerns are working also through past deforestation (unobserved land rent

[13]Using instead year fixed effects, municipality fixed effects, zone fixed effects, or combinations of the above does not seem to alter the results.

[14]One could argue that we should implement two-way clustering to take into account serial correlation. However, given our conclusion of no effect, we regard it as more prudent to run with less conservative clustering.

determinants are captured by past deforestation), whereas a positive effect of past deforestation would indicate that the zones were placed where there had been high deforestation in the past and hence they would be an attempt to curb those rates in the future. We also condition on the initial level of forest cover. The linear probability model reveals how the location of the zones correlates with characteristics such as distances to city, river, nearest soy field, soil quality and past deforestation. The variables are either predetermined or related to natural geography. In the linear probability model, we cluster standard errors on the municipality level to take into account spatial correlation.

Finally, the theoretical model illustrates that higher enforcement costs or lower enforcement budgets result in higher deforestation rates within conservation zones. This implies that policy interventions that increase enforcement efforts can result in lower deforestation rates.

III) The drop in deforestation at the border varies with enforcement

We take advantage of an initiative from the federal government introduced in 2008, which put a set of municipalities with particularly high deforestation rates on a "shame list" (or "priority list") with the threat of reduction in federal funds for the municipalities' general budgets if deforestation rates did not come down. These municipalities therefore faced higher incentives than others to reduce deforestation and hence may have increased the enforcement of the zones. We expand the difference-in-difference model of equation 6 with an interaction term between the treatment dummy and a time varying dummy taking one if the municipality where a given cell is located was on the list in a given year:

$$\begin{aligned} DF_{pzt} = \alpha + \beta_1 Ever_z + \beta_2 Ever_z x Post_{zt} + \beta_3 Post_{zt} \\ + \beta_4 Ever_z x Post_{zt} x List_p t + \beta_5 Ever_z x List_p t + \beta_6 Post_{zt} x List_p t + List_p t \\ + f(dist_{pz}) + Ever_z * f(dist_{pz}) + Z'_{pzt}\theta + \epsilon_{pzt} \quad (8) \end{aligned}$$

A negative β_4 suggests that the zones reduced deforestation more in the municipalities on the list. To avoid complicated interpretation, we exclude for these estimates zones established after 2008, i.e. in 2009 and 2010. The rest of the set up is identical as for the difference-in-difference estimation described around equation 6.

3.2 Institutional setting

Brazil was for long the world leader in tropical deforestation, estimated to have cleared an average of 19,500 km^2 per year from 1996 to 2005. In 2008, the Brazilian government committed to reduce deforestation by 80% of the historical baseline by 2020 (Government et al. 2007). However, efforts started before 2008.

Brazil's law regulating deforestation on private land is the Forest Code (FC), which was created in 1965, and through various presidential decrees in 90s was transformed into de factor environmental law (Soares-Filho et al. 2014).[15] Even though the FC severely restricted deforestation on private land, it was hardly enforced. That changed under the minister of environment from 2003-2008 Marina Silva. In 2003 she launched a National Plan for the Prevention and Control of Amazon Deforestation that ramped up law enforcement and established 600,000 km^2 (roughly the size of France) of new protected areas, with the area in conservation zones adding up to 22% of the Amazon in 2010. A key component was also to fight illegal activities.[16]

The Amazon protected areas (PAs) are broadly defined as all public areas under land-use restrictions that contribute to the conservation of the natural resources. In addition to the conservation zones we study in this paper, PAs include indigenous lands and military areas.[17] The conservation zones are managed by the federal, state, or municipal governments, and they are classified into two groups: strictly protected areas (SP) and sustainable-use units (SU). Each group can be further sub-classified into diverse categories, according to the degree of conservation and use. In SP areas, harvesting of forest products or minerals as well as settlements of traditional and non-traditional populations are not allowed. SU areas are designed for both biodiversity conservation and sustainable extraction of natural resources. In those areas the extraction of timber and other forest products are permitted to some extent under a sustainable management standard. Traditional populations may remain within the area as long as they undertake activities in a sustainable way (Verissimo et al. 2011). In the late 1980s, the SP areas accounted for the majority of the areas under conservation (92%). Over time, and in particularly after year 2000, the share occupied by SU zones has increased.

[15]The FC establishes a percentage of rural properties to be maintained as a permanent forest reserve. The FC originally dictated that at least 50% of private properties in the country's northern region should be maintained as reserves. Following a major increase in forest clearing rates in the middle 1990s, the fraction of person's property held in reserve has changed. As of 2001, the FC stipulates that 80 percent of Amazon rain forest on private property must be held in reserve, meaning that landowners can clear 20 percent (Soares-Filho et al. 2014).

[16]See interview with Silva in the Financial Times, October 5, 2009

[17]PAs covered a total area of about 2.2 million km^2 by December 2010, encompassing 43.9% of the territory of the Brazilian Amazon (Verissimo et al. 2011), with conservation zones accounting for 22.2% and indigenous land covering the remaining 21.7%. From 2004 to 2013, deforestation declined to 35.9% of its historical levels.

Provision in the Forest Code also requires that property owners register their land; the system called the Rural Environmental Registry System (Portuguese acronym SICAR), which should improve transparency and compliance. However, as Gibbs et al. 2015 argue property registration does not protect forests. They note that only few registered properties in states such as Mato Grosso (9%) and Para (4%) had the forest cover at least 80% as dictated by the FC. This may be about to change, with recent efforts of implementing comprehensive land registration.

Also the enforcement has ramped up significantly in recent years, enforcing environmental laws across the huge area as of the Brazilian Amazon is a great challenge for regulators. For instance, the Brazilian regulator (IBAMA) uses satellite data and field visits to issue fines and embargo economic activities on properties with illegal deforestation. However, as Gibbs et al. 2015 note, government's monitoring is limited: as of May 2014, they estimate that "roughly half of the registered properties with deforestation $\succeq$ 25 ha, 2009-2013, were not embargoed".

3.3 Data

We study the legal Amazon, an area of 5,032 million km2 in the north and west of Brazil (for comparison, the U.S. area of land + inland water is 9.4 million km^2). The data on deforestation cover the entire area, for the period 2002-2013.[18] These are based on NASA satellite images which have been processed at INPE, the Brazilian National Institute for Space Research. They come with high spatial resolution (about 200 meters) and we aggregate them up to grid-cells of 1 km^2.

Using the coordinates of the centroid of the grid cells, we assign geo-specific information, such as distances to city, river, soy fields, road and political boundaries. We also use data on soil quality, stock of forest cover in 2000, lagged forest cover and share of non-forest. For the conservation zones, we observe their exact locations (their boundaries) and the year of establishment. All data come from either INPE or the Brazilian Institute of Geography and Statistics (IBGE).[19]

We focus on zones established in 2004-2010 only, which ensures that we have deforestation data before and after for all the zones.[20] We define "treated" cells as those located within an "active"

[18] In addition, the stock of historical deforestation prior to and inclusive of 1997 has been calculated, as wells as the deforestation that took place between 1997 and 2000. Therefore we observe the stock of deforestation taking place before 2001. 2001 was the first year of annual deforestation data, but we have currently chosen to exclude 2001, as the data suggest very high deforestation rates and closer investigation of the maps reveals patterns we have yet to understand.

[19] Detailed information is available from the authors.

[20] The maximum years we could use before/after is eight/nine. Since there are very few observations in the ends, we use seven years to avoid any influence of outliers: For the RD-plots, we use averages across the 7 years before (t=-7) and 7 years after (t=7), in the regression we use annual data for for 2002-2013 limited to t=-7 and t=7. We always exclude t=0, because the deforestation data is recorded September-August instead of on calendar years, explained elsewhere in

conservation zone, with active referring to years for which the zones existed. "Control" cells are cells located outside active conservation zones, and we assign each outside cell to its nearest conservation zone. We define the $Ever$ dummy as taking 1 for all cells that appear in a conservation zone at some point, and zero for cells that are never in a conservation zones. the $Post$ dummy takes 1 for the years a zone is active, for all cells assign to that particular zone. This set up allows us to compare inside with outside cells, before and after the zone was established.

The deforestation data are recorded as the deforestation from September to August, i.e. the deforestation recorded for the year 2006 cover the deforestation that occurred from September 2005 to August 2006. Since annual zone establishment dates follow the calendar year, we exclude deforestation coded to have happen in the year of establishment (say 2006), to avoid that the deforestation assigned to 2006 in our data set occurred before the zone was established.

In terms of the samples, we include in the RD-plots all cells, whereas we include only those cells within 10 km from the border in the difference-in-difference estimation, to make the RD-assumption of identical cells in terms of unobservables more likely to hold.[21]

4 Empirical results I: The effect of zones

4.1 Graphical evidence

The left hand side panel of figure 2 depicts a discontinuity in the land rent at the conservation border under perfect enforcement. As deforestation is assumed to be driven by the land rent, we expect the same discontinuity in deforestation. The green/thick lines in figure 5 represent the empirical counterpart to figure 2; they plot the deforestation outside (negative distances, plotted the the left) and deforestation inside (positive distances, plotted to the right) of *active* conservation zones. Deforestation is in the graphs measured as the % of the covered area that was deforested annually. There is clearly a drop in deforestation as the border of the conservation zone is crossed from the left to the right, consistent with the predictions from the theory. However, the blue/thin lines show that the discontinuity was present also before the zones were established, suggesting that the zones were located in areas with low profitability of deforestation. The lower deforestation on both sides of the border

this section. An alternative would be to lag the Post-dummy one period, but we find it cleaner to simply exclude the introduction year, $t = 0$.

[21] We present robustness checks where we vary this between 5 km to 30 km. the deepest zone we have in the data is about 65 km.

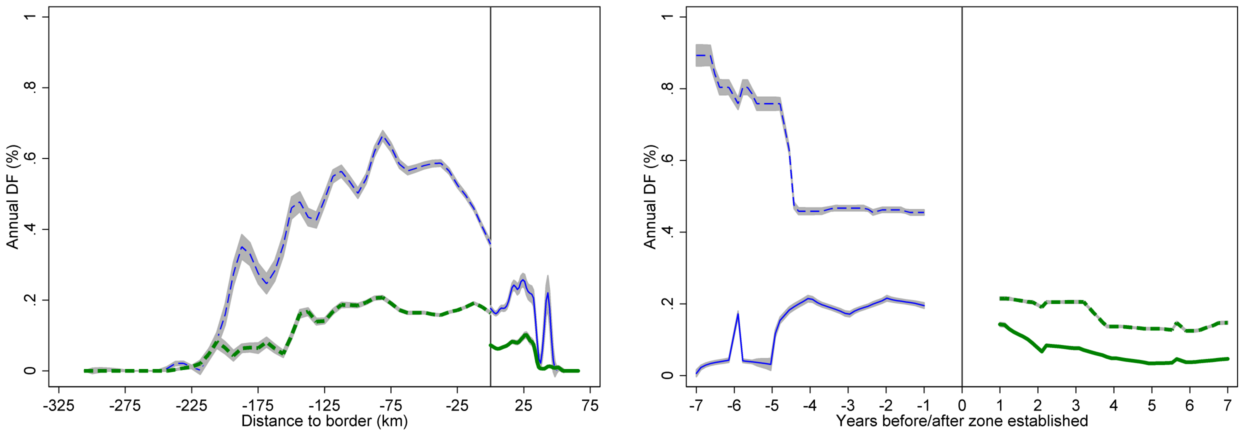


Figure 5: Deforestation outside vs. inside and before vs. after

Left panel: Outside (left dashed) vs inside (right solid), before (thin blue) vs after(thick green).
Right panel: Outside (dashed) vs inside (solid), before (thin blue) vs after(thick green). We include only cells within 30 km of the conservation zone boundaries.
Mean DF across up to 7 years before and 7 years after. Zones established in the period 2004-2010, DF in t=0 excluded. Inside and outside cells are matched to a given zone, i.e. the timing for the control cells corresponds to the timing of their nearest zone.

in the treatment period (green thick lines), reflects the general decline in deforestation rates in Brazil in our sample period. Note that the drop in deforestation over time is higher outside than inside the zones.

The right hand side panel of figure 5 is a difference-in-difference graph, showing mean deforestation over time. Zones are established at $t = 0$. Using the same marking of lines as in the left hand side panel, solid lines show the deforestation rates inside the zones, which are lower than the outside deforestation rates (dashed lines). Outside, there was a downward-sloping time trend over the entire period, whereas inside, the negative trend seems to have started around $t = -2$. After the zones were established, the trends are similar outside and inside, with deforestation rates levelling out on relatively low levels, i.e. about 0.2% a per year outside and 0.1 % pr year inside the zones. In terms of the effect of the zones, i.e. the drop around $t = 0$, we observe again that the drop in deforestation is larger for the outside cells than for the inside cells. It is not clear that there is a discontinuity around $t = 0$. Next, we investigate this more formally by estimating a difference-in-difference model.

4.2 Econometric estimates

Table 1 presents estimates of equation 6. Theory prediction I, that deforestation drops at the border of conservation zones under non-zero enforcement, is tested by the parameter on the ever-treated dummy

($Ever$) interacted with the post dummy ($Post$), β_2. Focusing on column 1, which pools SP and SU zones, the second row shows a non-significant β_2. The ever dummy always takes a negative and significant coefficient, indicating that deforestation inside the zones was always lower than outside of the zones.

In contrast, Nolte et al. 2013 find that conservation zones have reduced deforestation in Brazil. Furthermore, they find that strictly protected (SP) zones have been more effective in doing so than the sustainable use (SU) zones. Column 2 and 3 present estimates for the two types of zones separately, without revealing any qualitative difference between them.[22]

Table 1: D-i-D estimates of the effect of zoning

	(1) All	(2) SP	(3) SU
D=1 ever in CZ	-0.0010*	-0.0025***	-0.0004
	(0.0005)	(0.0009)	(0.0006)
D=1 ever in CZ x Post	0.0007	0.0010	0.0005
	(0.0006)	(0.0007)	(0.0007)
Post	-0.0014	0.0002	-0.0011
	(0.0009)	(0.0012)	(0.0012)
Observations	1033058	282701	747769
R-sq	0.037	0.013	0.043
Clusters	877	207	680
Meters from CZ incl.	10000	10000	10000

Notes: ***p<0.01, **p<0.05, *p<0.10. Standard errors clustered at zone-t level. Based on t +/- 7 years max, zones 2004-2010, straight borders only. Dependent variable: DF, i.e. the share of a 1 km^2 cell, the unit of observation, that is deforested in a given year. $Ever$ is a dummy taking one for all cells ever to be located inside one of the zones we consider and zero for cells outside the zones, $Post$ is a dummy taking one for years when a given zone is active (both for inside and outside cells assigned to that zone), and the interaction $Ever * Post$ picks up the difference-in-difference effect of interest, β_2. We control for, separately on each side of the border, second-order polynomials in the distance to the border. In addition we include as controls the log distance to nearest city, lagged forest cover and share of non-forest at the cell level, and municipality-year fixed effects. See appendix table B.1 for the full table. All refers to all zones, SP to strictly protected zones and SU to sustainable use zones.

We emphasis in the theory section that zones may reduce deforestation rates only if deforestation would be profitable without the conservation zones. I.e., only zones located "to the left" of the agriculture frontier $z*$ in figure 2 would reduce deforestation rates. To explicitly test this assertion, we interact in table B.2 the treatment variable $Ever\,x\,Post$ with an indicator of the soil quality. The soil quality is based on natural geography. To simplify the interpretation, we use the average soil quality across all cells within a municipality as the measure. In addition, we subtract the average soil quality,

[22] Appendix figures B.1 and B.2 present graphs for SP and SU separately. The figures show that the pattern of deforestation is not strikingly different across the two types of zones, except that deforestation is markedly lower inside of SP zones, after the zones have become active. This is consistent with the regulation, which permits some deforestation in the SU zones, subject to a licensing process.

so the variable can be interpreted as the deviation from the average soil quality. For the SP-zones, the interaction with the ever treated dummy is positive, whereas the coefficient on the interaction with the treatment variable is negative. This indicate that the deforestation before the zones became active was higher in areas with high soil quality and that the activation of the zones did reduce deforestation in such areas. The coefficients for "All" and "SU" are insignificant.[23]

We present a large set of robustness checks in the online appendix B.2. In table B.3-B.5 we demonstrate that the results of no effect of zones are robust to changing the set of controls. The only exception is when we include cell fixed effects and lagged forest cover as a control. We then identify β_2 from variation across time for each 1 km^2 cell (conditional on the forest cover in the previous period and municipality wide time shocks). In other words, the fixed effect result is necessarily driven by cells in which the deforestation actually changed over time. This points to zones having an effect when they are placed where there is some deforestation to reduce.

In tables B.6 and B.7, we vary the distance from the borders of the conservation zones, down to 5 km and up to 30 km, respectively. The picture is still the same, perhaps with the exception that 30 km produces a significant positive β_2 for SP zones. Finally, table B.8 presents estimates of our baseline model based on all borders, instead of only straight borders. β_2 is positive and significant for the full sample and for the SP-zones separately. The positive β_2 may reflect a larger reduction in deforestation outside compared to inside the zones, consistent with for example figure 5.

Our overall conclusion from the evidence presented in this section is that the zones have not reduced deforestation in general. But SP-zones located in areas with high soil quality, presumably indicating that the zone is located to the left of $z*$, seem to reduce deforestation rates. In the next section we study where the government choose to place the zones.

5 Empirical results II: The location of zones

The theory predicts the optimal location of a conservation zone (cz): If cz is a "buffer", cz is located next to and outside the agriculture frontier z^*. If a reduction in DF-rates matters to the government, however, cz must lie partly inside agriculture frontier z^*. In this section, we take these predictions to the data by first showing graphical evidence on where the zones are and by describing the zone locations by estimating a linear probability model (LPM). In the latter, we consider variables correlated with land rent/P_A, such as distances to soy field, city, river as well as the quality of the soil and

[23]Using alternative measures of agriculture productivity has not produced robust results.

past deforestation. If the latter takes a negative sign, the zones are located away from where deforestation is profitable. On the other hand, if it takes a positive sign, it is indicative of the government strategically placing the zones where they could bite and reduce deforestation.

Appendix figure B.3 shows the zones on a map, together with current deforestation rates in 2005 and 2008.[24] It seems zones have been placed as buffers.

Table 2: Linear probability model of zoning

	(1) D=1 if inside CZ	(2) D=1 if inside SP	(3) D=1 if inside SU
ln Dist soy (-1)	0.0058	-0.0027	0.0079*
	(0.0064)	(0.0033)	(0.0045)
ln Dist city	0.0877***	0.0549***	0.0455***
	(0.0213)	(0.0158)	(0.0128)
ln Dist river	-0.0009	0.0055	-0.0049
	(0.0049)	(0.0036)	(0.0047)
DF (-1)	-0.1285***	-0.0505***	-0.0931***
	(0.0337)	(0.0132)	(0.0305)
DF (-2)	-0.1034**	-0.0486***	-0.0677*
	(0.0434)	(0.0142)	(0.0396)
Soil quality (1-8)	-0.0033	-0.0034	-0.0006
	(0.0067)	(0.0040)	(0.0048)
RF 2000	0.0596**	0.0197	0.0484**
	(0.0243)	(0.0152)	(0.0196)
Constant	-0.9111***	-0.5617***	-0.4836***
	(0.2519)	(0.1961)	(0.1391)
Observations	4242278	3906500	4030014
Clusters	742	742	742
R-sq	.0923	.0648	.0507

Notes: ***p<0.01, **p<0.05, *p<0.10. Standard errors clustered at the municipality level. Dependent variable: Dummy taking 1 if the cell was located in a zone established in 2004-2010, and zero if a cell was outside any zone in 2010 or before. Lagged DF are for 2002-2003 and initial RF is for 2000.

The evidence presented in table 2 points to zone locations away from where agricultural production is expected to be profitable, as variables presumably positively correlated with agriculture profitability predict low likelihood of zoning. E.g., the closer to a soy field or a city, the lower the likelihood of the cell to be subject to zoning, and the higher the past deforestation rates, the lower the likelihood for zoning. These results suggest that the location decisions for the zones were dominated by minimizing the efficiency loss of the policy, at the cost of the effectiveness of the policy.

[24]We would like to thank Julika Herzberg for producing these maps.

6 Empirical results III: Incentivicing municipalities

The theory assigns a central role to enforcement to make the conservation policy reduce deforestation. As exogenous variation in enforcement efforts are hard to come by, we present in this section indirect evidence on the role of enforcement. In 2008, the federal government established a list of municipalities, called priority municipalities (MPs), that should significantly reduce deforestation. The incentives for the municipalities on this priority list to reduce deforestation were high, as they ran the risk of losing federal monetary transfers over the state budget. These municipalities were subject to more rigorous environmental monitoring and law enforcement from Brazil's environmental protection agency, IBAMA, as well as being subject to fines, embargoes of farms and changes in subsidized credit contracts.

Figure 6 presents the difference-in-difference graph for the priority municipalities (SP left hand side panel, SU right hand side panel). The priority municipalities had much higher deforestation rates inside the zones, especially before the zones were active, compared to the other municipalities (see appendix figure B.4 for a comparison with the non-listed municipalities). From the right hand side panel of figure 6, it seems that the effectiveness of the zones have increased over time for the SU zones, consistent with the introduction of the list at some point for $t > 0$.

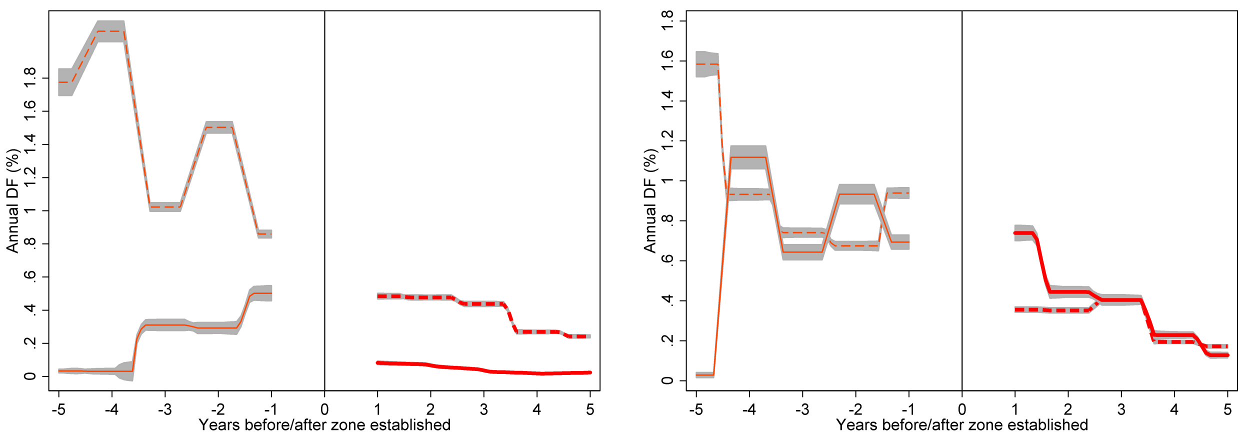


Figure 6: Priority municipalities

Left panel SP-zones, right panel SU-zones; otherwise as figure 5. Figure B.4 includes also the non-priority municipalities, for comparison. We cap the figure at five years before/after, as we have little data for 6 and 7 years before.

To test if getting on the priority list made the zones bite more, we expand the model from table 1 by including an interaction term between our treatment variable, $Ever\,x\,Post$, and a dummy taking 1 for the years the municipality was on the list. We estimate this model on the sample of municipalities that were on the list at some point. The results, presented in table 3, reflect what we already saw in figure 6. The list seem to have made no difference for the SP-zones, but for the SU-Zones, getting on the list corresponds with a reduction in deforestation inside the zones (the coefficient on the triple interaction term is negative and significant). Note also that the deforestation rates inside the SU-zones is higher than outside before the list was introduced (the coefficient on the treatment variable is positive and significant), again this can also be seen in figure 6. As deforestation in SU-zones may be allowed subject to a licensing process, this may indicate lenient licensing practices in these municipalities. The enhanced effect on SU-zones may have worked via better enforcement and/or less lenient licensing practices. We do not observe either enforcement efforts or licensing practices directly.

Assunção and Rocha 2014 argues that the MPs policy significantly reduced deforestation in municipalities that were responsible for an important part of deforestation in the Brazilian Amazon. They control for the number of fines applied by IBAMA to show that the list-policy worked through increased monitoring and better targeting of law enforcement in these municipalities, and not through other consequences of being on the "shame" list, such as political and economic sanctions.

Table 3: The priority list

	(1) All	(2) SP	(3) SU
D=1 ever in CZ	-0.0031	-0.0085**	-0.0025
	(0.0021)	(0.0040)	(0.0027)
D=1 ever in CZ x Post	0.0038	-0.0003	0.0060*
	(0.0026)	(0.0032)	(0.0032)
D=1 ever in CZ x Post x pr_post	-0.0010	0.0028	-0.0026**
	(0.0012)	(0.0022)	(0.0011)
Post	-0.0058	0.0010	-0.0099*
	(0.0039)	(0.0034)	(0.0054)
Observations	229444	69354	159157
R-sq	0.038	0.017	0.044
Clusters	280	84	186
Meters from CZ incl.	10000	10000	10000

Notes: ***p<0.01, **p<0.05, *p<0.10. Standard errors clustered at zone-t level. Based on t +/- 7 years max, zones 2004-2008. Includes on each side of the border separate second-order polynomial in the distance to the border, in addition to log distance to nearest city, lagged forest cover, share of non-forest and municipality-year FE. The priority list started in 2008, and for simplification we drop in this part of the analysis zones established 2009-2010. $Post\ x\ pr\_post$, $D = 1\ ever\ in\ CZ\ x\ pr\_post$ and pr_post drop out because of municipality-year fixed effects.

In table 3, only listed municipalities are included. In the online appendix, table B.9 presents results where also the other municipalities are included. We then find that the extra effect in the listed municipalities of SU-zones loses its significance. For SP-zones, the coefficient on the interaction dummy now turns negative and significant, while β_2 turns positive and significant.

Tables B.10, B.11 and B.12 present robustness tests with respect to different distances to the zone boundaries and to the inclusion of also non-straight borders. The significance of the triple interaction term for SU-zones is fragile, whereas the results for the SP-zones are robust.

7 Concluding remarks

Throughout the 2000s, the Brazilian government sought to halt forest clearing by assigning conservation zones to large areas in the Brazilian Amazon. In this paper we have assessed the effectiveness of this policy. We started out with a spatial economics model and derived predictions for the spatial effects of regulation, under endogenous zone location and imperfect enforcement. We took these predictions to high-resolution satellite data on deforestation over 2002-2013 and studied the effects of zones established in the period 2004-2010. We implemented regression discontinuity design and difference-in-difference estimation to identify the effect of the zoning policy on deforestation. In general, the zones did not reduce deforestation, as they were typically placed in areas where deforestation most likely would be unprofitable also in the absence of zones. When zones were placed in areas where deforestation had been profitable in the past, they did reduce deforestation. Furthermore, when the municipalities hosting the zones were faced with high incentives to reduce deforestation, zones were found to be more effective. In spite of such local successes, our findings point out that factors beyond the zoning policies are needed to explain the large decline in deforestation rates seen in Brazil since 2004. This is clearly seen in the right hand panel of figure 1 and in figure 5, as most of the reduction in deforestation took place outside rather than inside the zones. We leave the important task of identifying these factors for future research.

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A Online theory appendix

A.1 section to “The baseline model”

General set-up

All consumers have identical utility function:

$$u(M,A) = A^{\alpha_A} M^{\alpha_M} \tag{9}$$

where $\alpha_A + \alpha_M = 1$. Given the income Y, the consumers maximize their utility subject to constraint:

$$p_A A + p_M M = Y \tag{10}$$

and consumer demand functions are given by the following two equations:

$$A = \frac{\alpha_A Y}{p_A} \tag{11}$$

$$M = \frac{\alpha_M Y}{p_M} \tag{12}$$

Substitution of (11) and (12) into (9) yields the indirect utility function of consumer at location z:

$$u(z) = \alpha_A^{\alpha_A} \alpha_M^{\alpha_M} Y(z) p_A^{-\alpha_A}(z) p_M^{-\alpha_M}(z) \tag{13}$$

where $p_A(z)$ and $p_M(z)$ price at which the goods, both manufacturing and agricultural, sold at location z, where z is the distance to the city.

At each rural location, one unit of agricultural good is produced by a unit of land and a_A units of labor. Each location has a predetermined pattern of trade: it delivers excess production of agricultural goods to the city and imports M-goods from there. Following Robalino 2007, we also assume a simple linear manufacturing production function:

$$M(N_M) = \frac{N_M}{c_M} \tag{14}$$

where N_M is the labor employed in the sector and c_M is the quantity of labor needed to produce one unit of M-goods. We assume iceberg transport costs for both goods: if a unit of good i, $i = A$ or M is shipped over a distance d, only $e^{-t_i d}$ arrives at destination, where t_i is a positive constant. So, if we denote the price of agricultural goods in city as p_A, the delivered price must satisfy:

$$p_A(z) = p_A e^{-t_A z} \tag{15}$$

similarly, the price of manufactured goods delivered from city to location z must satisfy:

$$p_M(z) = p_M e^{t_M z} \tag{16}$$

where $p_M \equiv p_M(0)$ and $p_A \equiv p_A(0)$. We denote $W(z)$ as the wage at each location z, and the land rent at $z > 0$ is given as:

$$R(z) = p_A(z) - a_A W(z) = p_A e^{-t_A z} - a_A W(z) \tag{17}$$

and the income of workers is:

$$a_A W(z) = p_A e^{-t_A z} - R(z) \tag{18}$$

There exists location, fringe, beyond which land rents are negative and thus unprofitable to exploit. Denote z^* such $R(z^*) = 0$. This implies that the wage at the fringe is:

$$a_A W(z^*) = p_A e^{-t_A z^*} \tag{19}$$

Equilibrium

The unknown variables of the model are the price of agricultural goods, $p_A(z)$; the price of the manufacturing goods, $p_M(z)$; the agricultural frontier (fringe), z^*; the wages in the city, $W_M(0)$; the wages in agricultural sector, $W_A(z)$; the size of the A-sector, N_A; the size of the M-sector, N_M; the land rent $R(z)$.

In equilibrium, since all workers achieve the same utility level, $\bar{u}$, from indirect utility function (13) we have:

$$\bar{u} = \lambda^{-1} a_A W(z) p_A^{-\alpha_A} p_M^{-\alpha_M} e^{(\alpha_A t_A - \alpha_M t_M) z} \tag{20}$$

where $Y(z) = a_A W(z)$ is the income of workers and λ is a constant:

$$\lambda^{-1} = \alpha_A^{\alpha_A} \alpha_M^{\alpha_M} \tag{21}$$

We assume that the prices of manufacturing goods produced in city are exogenous to each location z and set $p_M = 1$, so that the indirect utility function can be re-written as:

$$\bar{u} = \lambda^{-1} a_A W(z) p_A^{-\alpha_A} e^{(\alpha_A t_A - \alpha_M t_M)z} \tag{22}$$

and

$$a_A W(z) = \bar{u} \lambda p_A^{\alpha_A} e^{(\alpha_M t_M - \alpha_A t_A)z} \tag{23}$$

Combining (23) and (19), we obtain the following wage curve function:

$$a_A W(z) = p_A e^{-\alpha_M (t_A + t_M) z^*} e^{(\alpha_M t_M - \alpha_A t_A)z} \tag{24}$$

Substituting expression for the income of workers from (24) into (17), we can re-write land rent as only function of distance and price of A-goods in the city:

$$R(z) = p_A e^{-t_A z} - p_A e^{-\alpha_M (t_A + t_M) z^*} e^{(\alpha_M t_M - \alpha_A t_A)z} \tag{25}$$

By taking derivative of $R(z)$ with respect to z, we can show (below of this section) that the land rent is *strictly* decreasing function of the distance from the city.

Since every location, $z \neq 0$, employs a_A units of labor, the size of the agricultural sector is:

$$N_A = a_A z^* \tag{26}$$

As the price of manufacturing goods in the city is chosen as numerarie and is set to be equal to 1, the nominal wage in the city is a constant due to the constant marginal productivity of labor in manufacturing, so that:

$$W_M(0) = \frac{1}{c_M} \tag{27}$$

The price of A-goods in the city can be found by equalizing the aggregate supply and demand in the city as follows. By (11), the excess supply of the A-goods per distance $z \neq 0$ equals:

$$1 - \frac{\alpha_A Y}{p_A(z)} = 1 - \alpha_A = \alpha_M$$

since aggregate income $Y(z) \equiv a_A W(z) + R(z) = p_A(z)$. Then, total net supply of the A-goods to city equals:

$$S_A(0) \equiv \int_0^{z^*} \alpha_M e^{-t_A z} dz = \alpha_M t_A^{-1} [1 - e^{-t_A z^*}] \tag{28}$$

while the aggregate demand of the agricultural goods at the city equals $\alpha_A W(0) N_M / p_A(0)$. Hence, the equality of demand and supply determines equilibrium price p_A:

$$p_A = \frac{\alpha_A W(0)(N - a_A z^*)}{\alpha_M t_A^{-1} [1 - e^{-t_A z^*}]} \tag{29}$$

The wage in the city is determined by (24), so that condition (29) can be expressed as:

$$\frac{\alpha_M t_A^{-1} [1 - e^{-t_A z^*}]}{\alpha_A a_A^{-1} e^{-\alpha_M (t_A + t_M) z^*}} = N - a_A z^* \tag{30}$$

As in Fujita and Krugman 1995, the left-hand side function of equation (30) is increasing, and the right-hand side equation is decreasing functions of z^*, the equation (30) uniquely determines the equilibrium value of the fringe distance z^*. Having determined z^*, all other unknown variables can be determined uniquely by (15), (16), (24), (17), (26),(29).

Market clearing for M-goods

The equilibrium defined above, implies that by Walras's law, the market for manufacturing goods would be cleared as well. In this section, we show that formally. Demand for M-goods in z:

$$\frac{\alpha_M p_A(z)}{p_M(z)} \tag{31}$$

supply of M-goods in z:

$$X(z) e^{-t_M z} \tag{32}$$

where $X(z)$ is an amount of M goods delivered to location z, and market clearing for M-goods in location z implies (using the fact that $p_M(z) = e^{t_M z}$):

$$X(z) = \alpha_M p_A(z) \tag{33}$$

supplied or demanded in location z. Then the market is cleared for the M-goods if the following holds in which the aggregate demand for M-goods equals to the aggregate supply:

$$\alpha_M \int_0^{z^*} p_A(z)dz + \alpha_M \frac{W(0)N_M}{p_M(0)} = \frac{N_M}{c_M} \tag{34}$$

or ($p_M(0) = 1$)

$$\alpha_M p_A(0) t_A^{-1} \left[1 - e^{-t_A z^*}\right] + \alpha_M W(0) N_M = \frac{N_M}{c_M} \tag{35}$$

Substituting the expression for the equilibrium price $p_A(0)$, we could re-write the above as:

$$\alpha_A W(0)(N - a_A z^*) + \alpha_M W(0) N_M = \frac{N_M}{c_M} \tag{36}$$

which, using that $W(0) = 1/c_M$ implies identity:

$$\alpha_A + \alpha_M = 1 \tag{37}$$

this proves that the market for the M-goods is cleared

Rents as strictly decreasing function of the distance from the center

In this subsection we prove that land rent is strictly decreasing function of the distance from the city z. The derivative of the land rent function with respect to distance from the city z is:

$$R'(z) = -p_A e^{-t_A z} t_A - p_A(\alpha_M t_M - \alpha_A t_A) e^{-\alpha_M (t_A + t_M) z^*} e^{(\alpha_M t_M - \alpha_A t_A) z} \tag{38}$$

There are two possible cases: (1) $\alpha_M t_M - \alpha_A t_A > 0$, then it is clear that $R'(z) < 0$; (2) $\alpha_M t_M - \alpha_A t_A < 0$, and the proof that $R'(z) < 0$ is as follows. By definition, $R(z) > 0$, which implies that:

$$p_A e^{-t_A z} > p_A e^{-\alpha_M (t_A + t_M) z^*} e^{(\alpha_M t_M - \alpha_A t_A) z} \tag{39}$$

Using (39), we can easily show that:

$$p_A(\alpha_A t_A - \alpha_M t_M)e^{-\alpha_M(t_A+t_M)z^*}e^{(\alpha_M t_M-\alpha_A t_A)z} \quad < p_A \alpha_A t_A e^{-\alpha_M(t_A+t_M)z^*}e^{(\alpha_M t_M-\alpha_A t_A)z} <$$
$$< p_A t_A e^{-\alpha_M(t_A+t_M)z^*}e^{(\alpha_M t_M-\alpha_A t_A)z} < t_A p_A e^{-t_A z}$$

which proves that $R'(z) < 0$:

A.2 section to "Conservation policies"

The new equilibrium with conservation zone can be found in similar manner as the one under baseline case. Under the new equilibrium the size of the agricultural sector is $N_A(b_0) = a_A b_0$; there exists point $z^*(b_0)$, such that $R(z^*(b_0)) = 0$. Since agricultural production is permitted only in locations $z \in (0, b_0]$, the total net supply of the A-goods to the city, counterpart of equation (28), equals:

$$S_A(0, b_0) \equiv \int_0^{b_0} \alpha_M e^{-t_A z} dz = \alpha_M t_A^{-1}[1 - e^{-t_A b_0}] \tag{40}$$

and consequently the equilibrium price of the A-goods in the city is determined by:

$$p_A(0, b_0) = \frac{\alpha_A W(0)(N - a_A b_0)}{\alpha_M t_A^{-1}[1 - e^{-t_A b_0}]} = \frac{\alpha_A (N - a_A b_0)}{\alpha_M c_M t_A^{-1}[1 - e^{-t_A b_0}]} \tag{41}$$

Having determined the price of the A-goods in the city, all other unknown variables, e.g., the land rent, can be determined.

Rents and regulation

In this section we will show that rents go up in response to the regulation in form of conservation zone, when everyone complies with the regulation.

The wage equation (24) also determines the wage rate in the city:

$$a_A W(0) = p_A e^{-\alpha_M(t_A+t_M)z^*} \tag{42}$$

which in combination with (24) implies:

$$a_A W(z) = a_A W(0) e^{(\alpha_M t_M - \alpha_A t_A)z} \tag{43}$$

Then the rent curve function (17) can be re-written as follows:

$$R(z) = p_A(z) - a_A W(z) = \frac{\alpha_A W(0)(N - a_A z^*)}{\alpha_M t_A^{-1}[1 - e^{-t_A z^*}]} e^{-t_A z} - a_A W(0) e^{(\alpha_M t_M - \alpha_A t_A)z} \tag{44}$$

Using expression for rents (44), total rents in the economy can be computed as:

$$TR \equiv \int_0^{z^*} R(z)dz = \frac{\alpha_A W(0)(N - a_A z^*)}{\alpha_M} - a_A W(0) \frac{e^{(\alpha_M t_M - \alpha_A t_A)z^*} - 1}{\alpha_M t_M - \alpha_A t_A} \tag{45}$$

Total rents under the equilibrium with conservation policy (when everyone complies with regulation) can be computed using the expression for the prices of the A-goods in the city (41) and the fact that productivity of workers in city is constant (i.e., $W(0) = W(0, b_0) = 1/c_M$), so that

$$R(z, b_0) = p_A(z, b_0) - a_A W(z, b_0) = \frac{\alpha_A W(0)(N - a_A b_0)}{\alpha_M t_A^{-1}[1 - e^{-t_A b_0}]} e^{-t_A z} - a_A W(0) e^{(\alpha_M t_M - \alpha_A t_A)z} \tag{46}$$

and

$$TR(b_0) \equiv \int_0^{z^*} R(z, b_0)dz = \frac{\alpha_A W(0)(N - a_A b_0)}{\alpha_M} - a_A W(0) \frac{e^{(\alpha_M t_M - \alpha_A t_A)b_0} - 1}{\alpha_M t_M - \alpha_A t_A} \tag{47}$$

Subtracting (47) from (45), we obtain:

$$\triangle TR = TR - TR(b_0) = \frac{\alpha_A W(0)}{\alpha_M}[b_0 - z^*] - \frac{a_A W(0)}{\alpha_M t_M - \alpha_A t_A} \left[e^{(\alpha_M t_M - \alpha_A t_A)z^*} - e^{(\alpha_M t_M - \alpha_A t_A)b_0} \right] \tag{48}$$

The term inside of the first brackets is negative. The second term is positive, which follows easily from considering two different cases: (1) $\alpha_M t_M - \alpha_A t_A > 0$, then the expression in the second brackets is positive; (2) $\alpha_M t_M - \alpha_A t_A < 0$, and expression in the brackets is negative, but the second term is positive overall. This proves that total rents increase and as $b_0 < z^*$, this implies that rent curve shifts up in the new equilibrium with conservation zones when everyone complies with regulation and $b_1 = z_{max}$

A.3 section to "Endogenous zones placement"

Considerations that push the location of the zones towards (or beyond) z^* or pull inside of agricultural frontier can be formalized assuming that the regulatory agencies have the following objective function:

$$u(M(0, b_0), A(0, b_0)) + \theta_1 d - E(d, b_0) + \theta_2 (x^* - x(d, b_0)) \to \max_{b_0} \tag{49}$$

where $u(M(0,b_0),A(0,b_0))$ is the utility of workers in the city, which depends on equilibrium prices of M- and A-goods in the city $M(0,b_0)$ and $A(0,b_0)$; $\theta_1 d$ captures benefits from establishing the zones in form of indication of promises and attempts by the government to reduce deforestation rates; $E(d,b_0)$ is enforcement costs; x^* is a baseline deforestation rate, absence of any regulation policy, which corresponds to the amount of agricultural land in the baseline model through some function $x^* = f(z^*)$; $x(d,b_0)$ is a level of deforestation in an economy with conservation zone established at location b_0 and size d. Thus, the term $\theta_2(x^* - x(d,b_1))$ captures the compensation, based on actual performance, for efforts to preserve forest.

As discussed in the main text, enforcement costs comprise two components: travel costs of patrol to the zone and actual enforcement costs on the ground. The closer to the city conservation zones are, the lower travel costs, but higher risk of deforestation and thus more efforts need to be put into enforcing the regulation. Thus, a priori it is not clear whether $E(d,b_0)$ will be necessary lower, if the zone is located closer to the city. We assume that the costs associated with enforcing regulation far exceed costs associated with travel so that further away from the city (higher b_0), the lower total enforcement costs, e.g., $E'_{b_0}(d,b_0) < 0$.

The government maximizes the surplus, defined as (49) subject to constraint:

$$b_0 \geq 0 \tag{50}$$

Next, we prove the statements that underlie the economic efficiency argument of the location of the zones. Consider two conservation policies: $(b_0^a, b_1^a]$ ($b_0^a + d = b_1^a$) and $(b_0, z^*]$ (where $b_0 + d = z^*$) such that, the first one removes land closer to the city so that $b_0^a < b_0$.

Claim 1. *Suppose there is no leakage (production beyond z^* is forbidden). Then, equilibrium A-prices in the city under two policies satisfy: $p_A(0,b_0^a) > p_A(0,b_0)$*

Proof of Claim 1.1. *We want to find conditions under which $p_A(0,b_0) < p_A(0,b_0^a)$, or equivalently:*

$$\frac{N_M(b_0)}{1-e^{-t_A b_0}} < \frac{N_M(b_0^a)}{1-e^{-t_A b_0^a} + e^{-t_A b_0^a} e^{-t_A d} - e^{-t_A z^*}} \tag{51}$$

Since the length of the conservation zone is the same, d, and with assumption of no leakage, the size of the manufacturing sector is the same under two conservation policies. Then, $N_M(b_0) = N - a_A b_0$, and, $N_M(b_0^a) = N - (a_A b_0^a + a_A(z^* - b_1^a)) = N - a_A b_0$. After some math manipulation of (51), it can be shown that it holds if $b_0^a < b_0$, which proves the claim.

Now, we discuss how the price changes can be affected by the presence of leakage: since the rents go up in response to withdrawal of land from some locations from agricultural production, some lands which were not profitable before become profitable. With leakage:

1. More workers are employed in the agricultural sector, and thus the size of the manufacturing sector is smaller as well as the demand for A-goods in the city.

2. More land is under agricultural production and thus there is larger supply of A-goods.

Thus, leakage tends to mitigate an increase in the equilibrium prices of agricultural goods as result of conservation policies. If, however, the effect of leakage on the A-price increase is small relative to the effect on A-price of conservation policy, then with leakage the inequality $p_A(0, b_0^a) > p_A(0, b_0)$ tend to hold. This is particularly the case, when z^* is bigger, and transportation costs of A-goods t_A is higher. Thus it is plausible to assume that with leakage, the removal of land closer to the city from agricultural production will result to a higher increase in the prices of agricultural goods.

Next, we investigate the impact of conservation zones on welfare of workers.

Claim 2. *The higher the price of A-goods, the lower the welfare of workers*

Proof of Claim 2.1. *We have shown above that the utility of workers in the economy is:*

$$u(z) = \alpha_A^{\alpha_A} \alpha_M^{\alpha_M} W(0) p_A^{-\alpha_A}(0) p_M^{-\alpha_M}(0) \tag{52}$$

and since $W(0) = 1/c_M$ *and* $p_M(0) = 1$, *the utility of workers in the city (and anywhere in the economy) is an inverse function of prices of A-goods:*

$$u(z) = \Theta p_A^{-\alpha_A}(0) \tag{53}$$

where $\Theta \equiv \alpha_A^{\alpha_A} \alpha_M^{\alpha_M} \frac{1}{c_M}$ *is a constant.*

Thus, the framework highlights the following channels that push the conservation zone inside or outside of the agricultural frontier z^*:

1. the economic efficiency considerations (the first term in the objective function (49)) push the zone locations out of areas with high rents in agriculture, that is beyond z^*

2. enforcement costs, $E(d, b_0)$ also push the location of the zones to areas where the costs of enforcing regulation is lowest, that is areas where the pressure for deforestation is lowest

3. compensation incentives (final term in (49)) push the zones to be located inside the agricultural frontier. Since the quality of land is homogeneous (in terms of agricultural productivity as well as

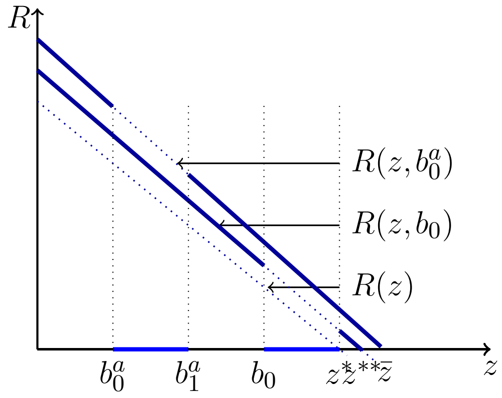

Figure A.1: Alternative locations of a zone and land rents

effect of deforestation on environment), for a given level of reduction in deforestation rates, it is optimal to locate zones at the periphery of agricultural frontier.

B Online empirical appendix

B.1 To the baseline findings

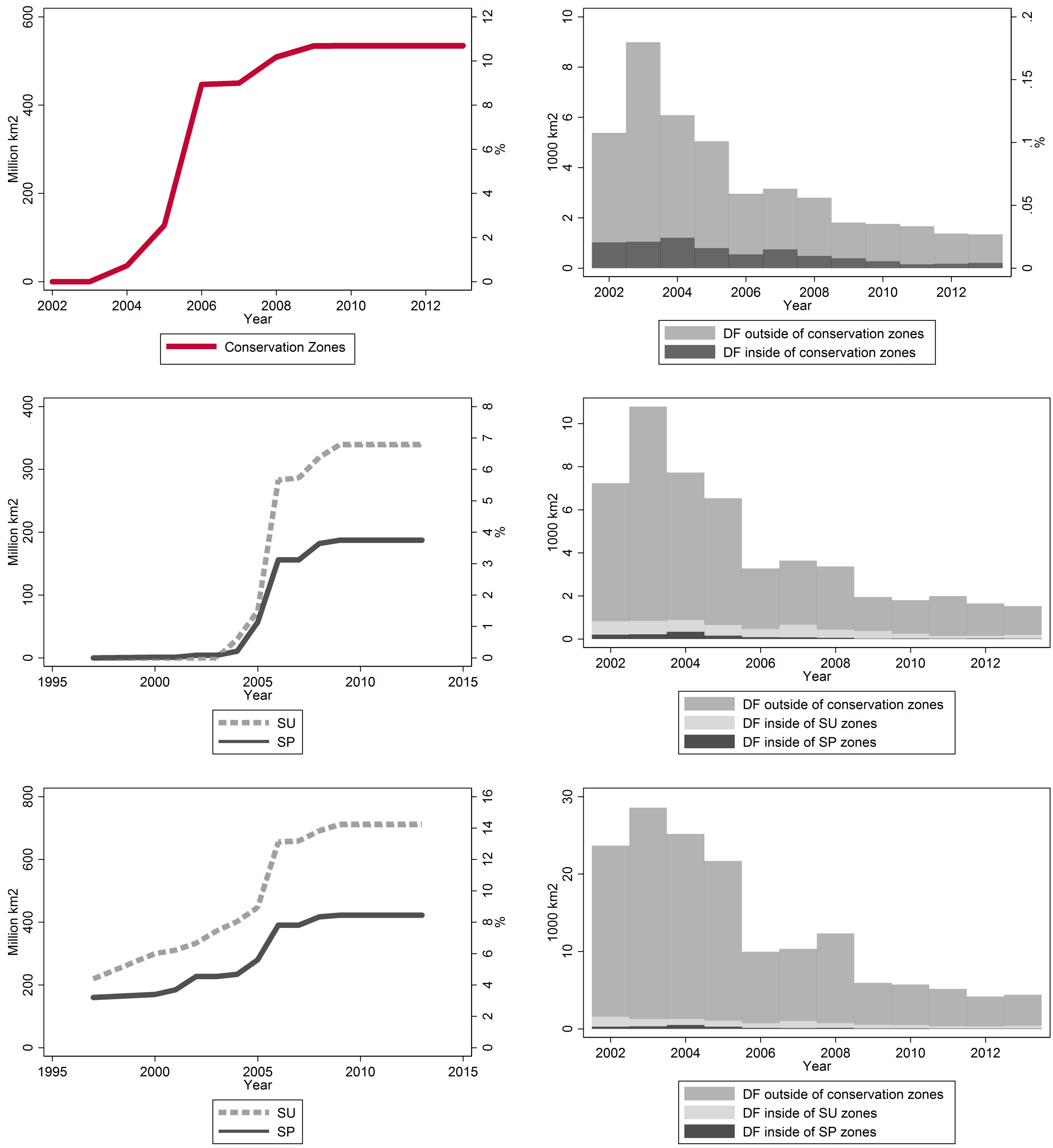

Figure B.1: Areas covered by conservation zones and deforestation rates

Notes: Conservation zones (left panels), deforestation rates (right panel). The four upper panels are for zones established 2004-2010, the two lower panels are for zones established 1959-2012. Figure 1 in the main text presents the two upper panels for zones established 2004-2010. Note that the outside area differs, as we we use outside cells based on the shortest distance to a zone. For the 1959-2012 zones, all cells are included. Source: authors own calculations based on data from INPE.

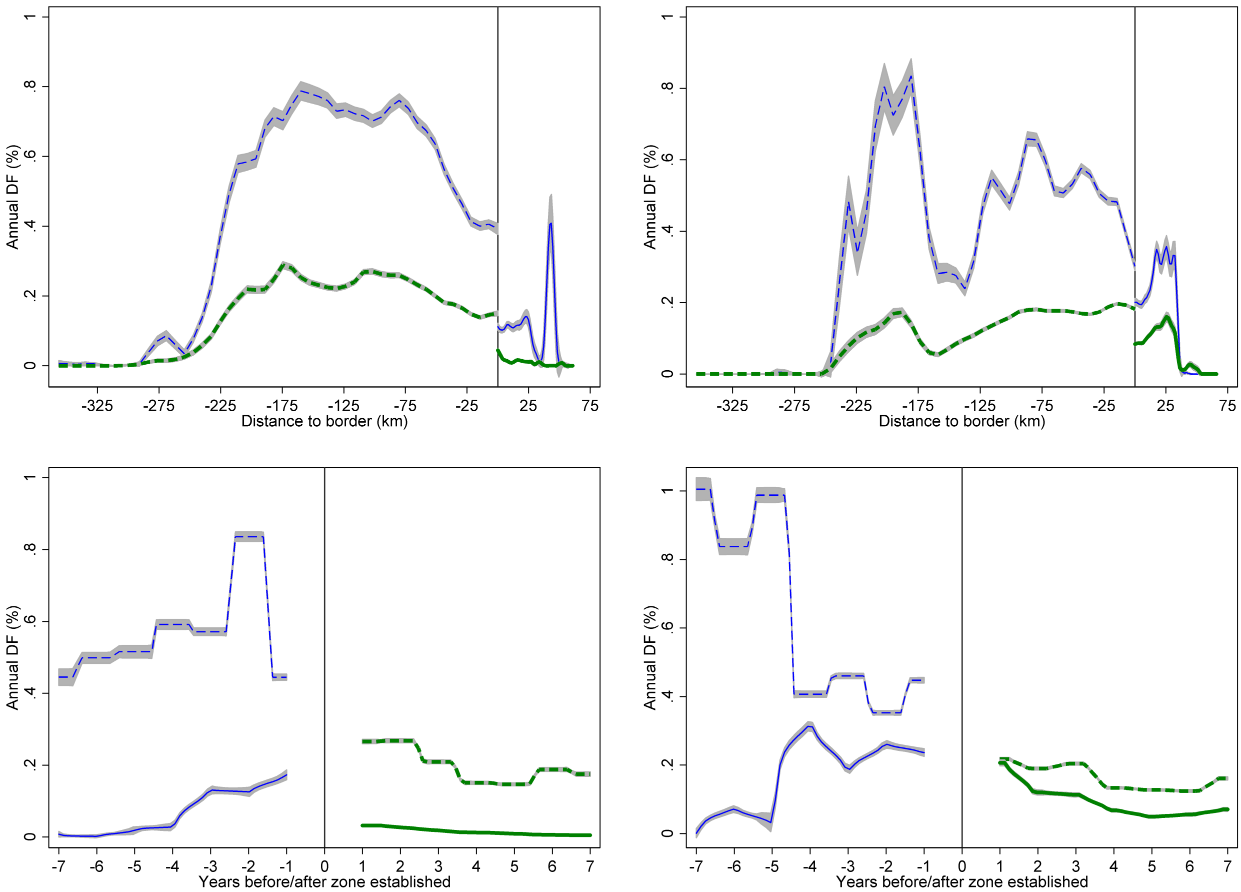

Figure B.2: SP vs. SU zones

Left panel SP-zones, right panel SU-zones, otherwise as figure 5.

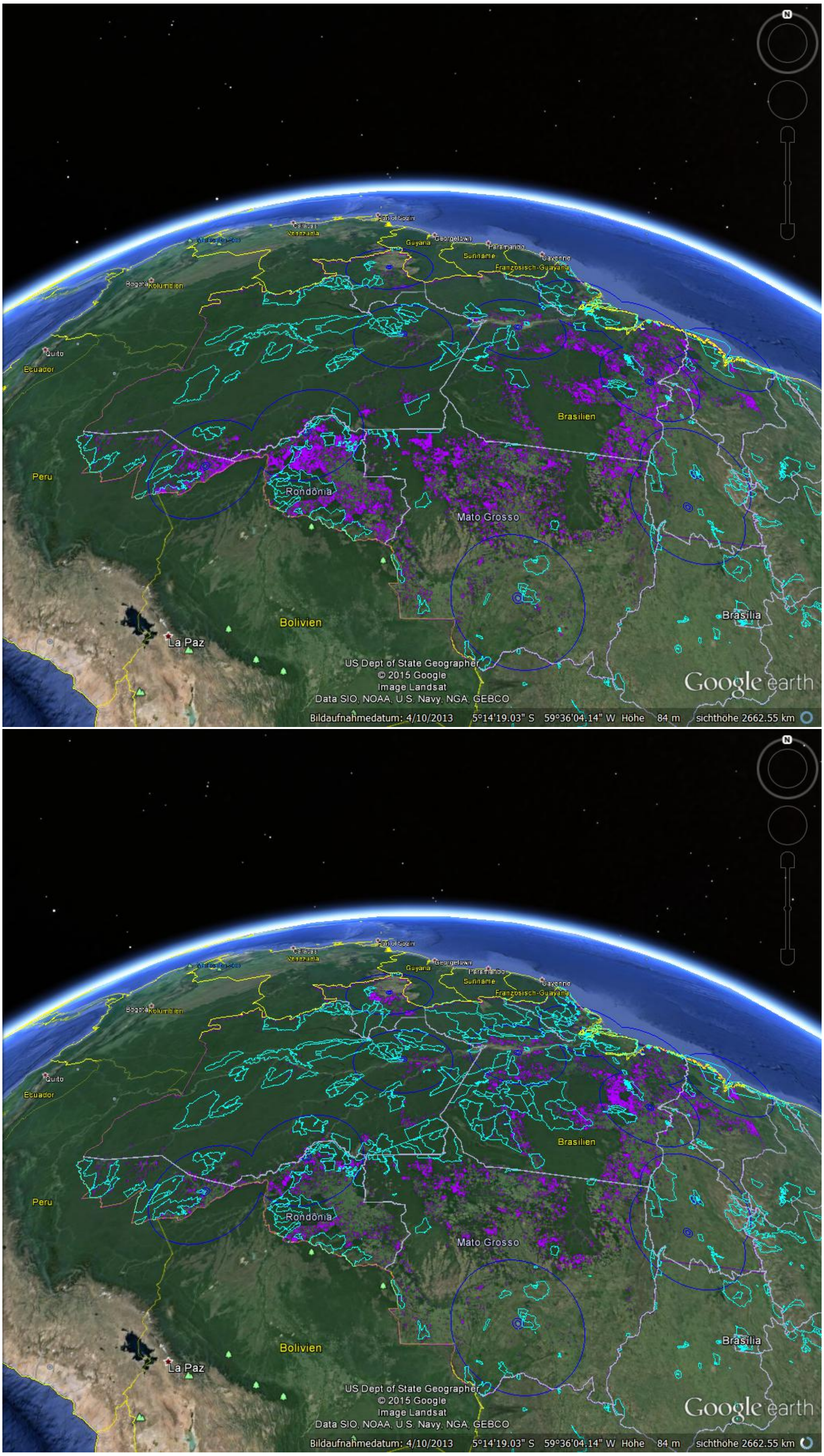

Figure B.3: Zone locations 2005 (upper) and 2008 (lower)

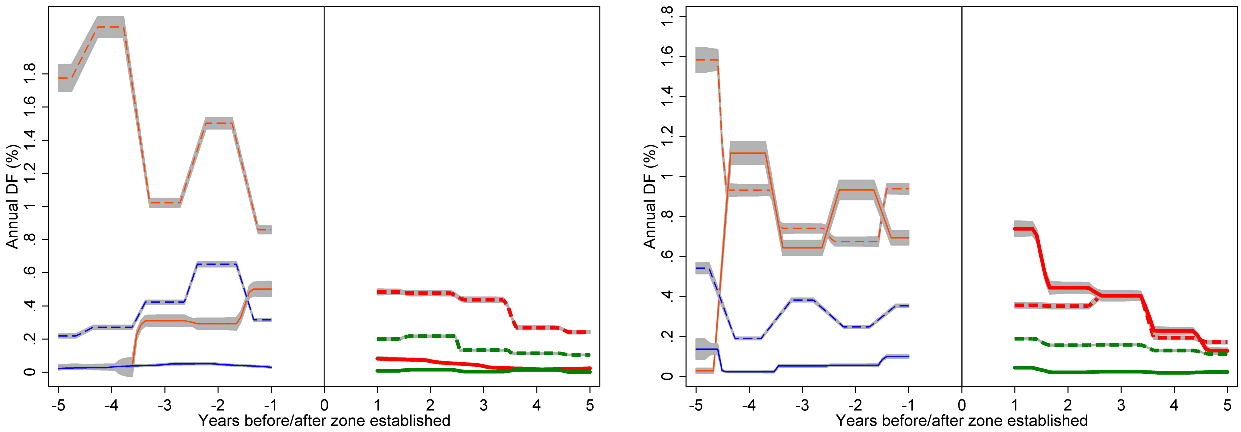

Figure B.4: Priority and non-priority municipalities

Left panel SP-zones, right panel SU-zones, priority municipalities in red; otherwise as figure 5.

Table B.1: D-i-D estimates of the effect of zoning presenting controls

	(1) All	(2) SP	(3) SU
D=1 ever in CZ	-0.0010*	-0.0025***	-0.0004
	(0.0005)	(0.0009)	(0.0006)
D=1 ever in CZ x Post	0.0007	0.0010	0.0005
	(0.0006)	(0.0007)	(0.0007)
Post	-0.0014	0.0002	-0.0011
	(0.0009)	(0.0012)	(0.0012)
ln Dist city	-0.0007***	-0.0002	-0.0008***
	(0.0002)	(0.0002)	(0.0003)
Non-forest	-0.0022***	-0.0022***	-0.0027***
	(0.0006)	(0.0006)	(0.0008)
RF (-1)	0.0003	-0.0020***	0.0014
	(0.0009)	(0.0005)	(0.0012)
Constant	0.0100***	0.0061**	0.0103***
	(0.0023)	(0.0027)	(0.0030)
Observations	1033058	282701	747769
Obs. t<0	389827	104929	283497
Obs. t=0	.	.	.
Obs. t>0	643231	177772	464272
Obs. Evertreated t<0	263007	69424	189413
Obs. Evertreated t>0	432465	119734	307507
R-sq	0.037	0.013	0.043
Clusters	877	207	680
Meters from CZ incl.	10000	10000	10000

Notes: Identical to table 1, but presenting controls.

Table B.2: Soil quality

	(1) All	(2) SP	(3) SU
D=1 ever in CZ	-0.0009*	-0.0024***	-0.0005
	(0.0005)	(0.0008)	(0.0006)
D=1 ever in CZ x Post	0.0007	0.0009	0.0006
	(0.0006)	(0.0007)	(0.0007)
D=1 ever in CZ x Post x msoil	-0.0000	-0.0004**	0.0002
	(0.0001)	(0.0002)	(0.0002)
D=1 ever in CZ x msoil	0.0001	0.0005***	-0.0002
	(0.0001)	(0.0002)	(0.0001)
Post x msoil	-0.0002	0.0030	-0.0015
	(0.0007)	(0.0019)	(0.0012)
Observations	1033058	282701	747769
R-sq	0.037	0.014	0.043
Clusters	877	207	680
Meters from CZ incl.	10000	10000	10000

Notes: As table 1, except soil quality. The soil quality is the mean across all cells per municipality and is measured as an deviation from the average of all cells, i.e. the coefficient on the non-interacted variables shown the effect at the general mean of soil quality. The soil quality variable drops out because of municipality-year fixed effects.

B.2 Robustness checks

Table B.3: Different controls: All zones

	(1) All	(2) All	(3) All	(4) All	(5) All	(6) All	(7) All	(8) All
D=1 ever in CZ	-0.0015***	-0.0015***	-0.0015***	-0.0015***	-0.0010*	-0.0010*	0.0000	0.0000
	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)	(.)	(.)
D=1 ever in CZ x Post	0.0008	0.0008	0.0008	0.0007	0.0008	0.0007	0.0008	-0.0009**
	(0.0005)	(0.0005)	(0.0006)	(0.0006)	(0.0005)	(0.0006)	(0.0005)	(0.0004)
Post	-0.0014	-0.0014	-0.0014	-0.0014	-0.0014	-0.0014	-0.1844	-0.0564
	(0.0009)	(0.0009)	(0.0009)	(0.0009)	(0.0009)	(0.0009)	(8.9801)	(11.9990)
ln Dist city		-0.0006***				-0.0007***		
		(0.0002)				(0.0002)		
Non-forest			-0.0023***			-0.0022***		
			(0.0006)			(0.0006)		
RF (-1)				0.0013*		0.0003		0.2232***
				(0.0008)		(0.0009)		(0.0340)
Dist CZ					-0.0000**	-0.0000**		
					(0.0000)	(0.0000)		
Dist CZ sq					-0.0000*	-0.0000*		
					(0.0000)	(0.0000)		
D=1 ever in CZ x Dist CZ					0.0000*	0.0000*		
					(0.0000)	(0.0000)		
D=1 ever in CZ x Dist CZ sq					0.0000*	0.0000*		
					(0.0000)	(0.0000)		
Constant	0.0028***	0.0100***	0.0030***	0.0018**	0.0023***	0.0100***		
	(0.0007)	(0.0024)	(0.0007)	(0.0009)	(0.0007)	(0.0023)		
Observations	1033058	1033058	1033058	1033058	1033058	1033058	1033058	1033058
R-sq	0.037	0.037	0.037	0.037	0.037	0.037	0.147	0.280

Notes: As table 1, different columns vary by the included controls. Column 7 and 8 include cell fixed effect, in addition to the municipality year fixed effects included in all columns.

Table B.4: Different controls: SP zones

	(1) SP	(2) SP	(3) SP	(4) SP	(5) SP	(6) SP	(7) SP	(8) SP
D=1 ever in CZ	-0.0019***	-0.0019***	-0.0019***	-0.0019***	-0.0025***	-0.0025***	0.0000	0.0000
	(0.0007)	(0.0007)	(0.0007)	(0.0007)	(0.0009)	(0.0009)	(.)	(.)
D=1 ever in CZ x Post	0.0010	0.0010	0.0010	0.0010	0.0010	0.0010	0.0011**	-0.0005*
	(0.0007)	(0.0007)	(0.0007)	(0.0007)	(0.0007)	(0.0007)	(0.0004)	(0.0003)
Post	0.0002	0.0002	0.0002	0.0001	0.0002	0.0002	-0.0012**	0.0000
	(0.0012)	(0.0012)	(0.0012)	(0.0012)	(0.0012)	(0.0012)	(0.0006)	(0.0007)
ln Dist city		-0.0003				-0.0002		
		(0.0002)				(0.0002)		
Non-forest			-0.0003**			-0.0022***		
			(0.0001)			(0.0006)		
RF (-1)				-0.0007***		-0.0020***		0.1423***
				(0.0002)		(0.0005)		(0.0238)
Dist CZ					0.0000	0.0000		
					(0.0000)	(0.0000)		
Dist CZ sq					0.0000	0.0000		
					(0.0000)	(0.0000)		
D=1 ever in CZ x Dist CZ					-0.0000	-0.0000		
					(0.0000)	(0.0000)		
D=1 ever in CZ x Dist CZ sq					-0.0000	-0.0000		
					(0.0000)	(0.0000)		
Constant	0.0012	0.0045*	0.0012	0.0019**	0.0018*	0.0061**		
	(0.0008)	(0.0026)	(0.0008)	(0.0008)	(0.0010)	(0.0027)		
Observations	282701	282701	282701	282701	282701	282701	282701	282701
R-sq	0.013	0.013	0.013	0.013	0.013	0.013	0.144	0.227

Notes: As table 1, different columns vary by the included controls. Column 7 and 8 include cell fixed effect, in addition to the municipality year fixed effects included in all columns.

Table B.5: Different controls: SU zones

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	SU	SU	SU	SU	SU	SU	SU	SU
D=1 ever in CZ	-0.0014**	-0.0013*	-0.0014**	-0.0014**	-0.0005	-0.0004	0.0000	0.0000
	(0.0007)	(0.0007)	(0.0007)	(0.0007)	(0.0006)	(0.0006)	(.)	(.)
D=1 ever in CZ x Post	0.0006	0.0006	0.0006	0.0006	0.0006	0.0005	0.0007	-0.0008*
	(0.0007)	(0.0007)	(0.0007)	(0.0007)	(0.0007)	(0.0007)	(0.0007)	(0.0005)
Post	-0.0011	-0.0011	-0.0011	-0.0011	-0.0011	-0.0011	-0.0003	0.0001
	(0.0012)	(0.0012)	(0.0012)	(0.0012)	(0.0012)	(0.0012)	(0.0002)	(0.0002)
ln Dist city		-0.0007**				-0.0008***		
		(0.0003)				(0.0003)		
Non-forest			-0.0035***			-0.0027***		
			(0.0010)			(0.0008)		
RF (-1)				0.0023**		0.0014		0.2375***
				(0.0011)		(0.0012)		(0.0395)
Dist CZ					-0.0000***	-0.0000***		
					(0.0000)	(0.0000)		
Dist CZ sq					-0.0000**	-0.0000**		
					(0.0000)	(0.0000)		
D=1 ever in CZ x Dist CZ					0.0000**	0.0000**		
					(0.0000)	(0.0000)		
D=1 ever in CZ x Dist CZ sq					0.0000**	0.0000**		
					(0.0000)	(0.0000)		
Constant	0.0029***	0.0103***	0.0031***	0.0010	0.0020**	0.0103***		
	(0.0009)	(0.0031)	(0.0009)	(0.0012)	(0.0009)	(0.0030)		
Observations	747769	747769	747769	747769	747769	747769	747769	747769
R-sq	0.042	0.042	0.043	0.043	0.042	0.043	0.148	0.290

Notes: As table 1, different columns vary by the included controls. Column 7 and 8 include cell fixed effect, in addition to the municipality year fixed effects included in all columns.

Table B.6: Different sample: 5km

	(1) All	(2) SP	(3) SU
D=1 ever in CZ	-0.0007	-0.0018*	-0.0004
	(0.0005)	(0.0009)	(0.0006)
D=1 ever in CZ x Post	0.0009	0.0015	0.0006
	(0.0006)	(0.0010)	(0.0008)
Post	-0.0012	-0.0002	-0.0005
	(0.0008)	(0.0014)	(0.0007)
Observations	630293	164320	463374
Obs. t<0	238120	61189	175681
Obs. t=0	.	.	.
Obs. t>0	392173	103131	287693
Obs. Evertreated t<0	164246	41488	120646
Obs. Evertreated t>0	270064	71021	196393
R-sq	0.029	0.017	0.035
Clusters	877	207	680
Meters from CZ incl.	5000	5000	5000

Notes: As table 1, but includes only cells up to 5 km from the zone boundaries.

Table B.7: Different sample: 30km

	(1) All	(2) SP	(3) SU
D=1 ever in CZ	-0.0012**	-0.0021***	-0.0008
	(0.0005)	(0.0006)	(0.0007)
D=1 ever in CZ x Post	0.0007	0.0008*	0.0005
	(0.0005)	(0.0004)	(0.0007)
Post	-0.0012	-0.0001	-0.0012
	(0.0009)	(0.0007)	(0.0013)
Observations	1690795	548355	1202429
Obs. t<0	633674	201184	453539
Obs. t=0	.	.	.
Obs. t>0	1057121	347171	748890
Obs. Evertreated t<0	384439	114738	260603
Obs. Evertreated t>0	642155	202803	429689
R-sq	0.059	0.012	0.064
Clusters	877	207	680
Meters from CZ incl.	30000	30000	30000

Notes: As table 1, but includes only cells up to 30 km from the zone boundaries.

Table B.8: Different sample: All borders

	(1) All	(2) SP	(3) SU
D=1 ever in CZ	-0.0011***	-0.0021***	-0.0007
	(0.0004)	(0.0006)	(0.0005)
D=1 ever in CZ x Post	0.0008*	0.0016**	0.0003
	(0.0005)	(0.0007)	(0.0006)
Post	-0.0012**	0.0011*	-0.0005
	(0.0005)	(0.0006)	(0.0006)
Observations	5271706	1594140	3675396
Obs. t<0	2042111	610056	1430196
Obs. t=0	.	.	.
Obs. t>0	3229595	984084	2245200
Obs. Evertreated t<0	1249983	385283	843024
Obs. Evertreated t>0	1996427	627736	1337757
R-sq	0.024	0.017	0.029
Clusters	940	229	711
Meters from CZ incl.	10000	10000	10000

Notes: As table 1, but includes all borders.

Table B.9: The priority list, including non-listed municipalities

	(1)	(2)	(3)	(4)	(5)	(6)
	All	SP	SU	All	SP	SU
D=1 ever in CZ	-0.0031	-0.0085**	-0.0025	-0.0011*	-0.0026***	-0.0007
	(0.0021)	(0.0040)	(0.0027)	(0.0006)	(0.0010)	(0.0008)
D=1 ever in CZ x Post	0.0038	-0.0003	0.0060*	0.0011*	0.0016**	0.0009
	(0.0026)	(0.0032)	(0.0032)	(0.0006)	(0.0008)	(0.0009)
D=1 ever in CZ x Post x pr_post	-0.0010	0.0028	-0.0026**	-0.0011**	-0.0033***	-0.0005
	(0.0012)	(0.0022)	(0.0011)	(0.0005)	(0.0012)	(0.0006)
D=1 ever in CZ x pr_post	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	(.)	(.)	(.)	(.)	(.)	(.)
pr_post	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	(.)	(.)	(.)	(.)	(.)	(.)
Post	-0.0058	0.0010	-0.0099*	-0.0035**	-0.0002	-0.0036
	(0.0039)	(0.0034)	(0.0054)	(0.0015)	(0.0013)	(0.0028)
Observations	229444	69354	159157	955793	270887	682044
Controls	64518	14258	52204	316713	91691	230552
Treated	164926	55096	106953	639080	179196	451492
Obs. t<0	88886	24340	63330	340652	97559	241674
Obs. t=0	.	.	.	.	.	.
Obs. t>0	140558	45014	95827	615141	173328	440370
Obs. Evertreated t<0	64428	18681	43732	227118	63087	160503
Obs. Evertreated t>0	100498	36415	63221	411962	116109	290989
R-sq	0.038	0.017	0.044	0.037	0.014	0.043
Clusters	280	84	186	759	176	593
Meters from CZ incl.	10000	10000	10000	10000	10000	10000
Not on pri-list	0	0	0	2	2	2

Notes: Three first columns identical with table 3, three last columns include also municipalities never on the list.

Table B.10: Different sample: 5 km, the priority list

	(1) All	(2) SP	(3) SU	(4) All	(5) SP	(6) SU
D=1 ever in CZ	-0.0013	-0.0024	-0.0010	-0.0010***	-0.0016***	-0.0007
	(0.0009)	(0.0015)	(0.0011)	(0.0004)	(0.0006)	(0.0004)
D=1 ever in CZ x Post	0.0022	0.0038**	0.0021	0.0007	0.0019***	0.0001
	(0.0019)	(0.0017)	(0.0032)	(0.0005)	(0.0007)	(0.0006)
D=1 ever in CZ x Post x pr_post	-0.0008	-0.0008	-0.0014	-0.0002	-0.0014**	0.0006
	(0.0016)	(0.0009)	(0.0029)	(0.0004)	(0.0006)	(0.0006)
D=1 ever in CZ x pr_post	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	(.)	(.)	(.)	(.)	(.)	(.)
pr_post	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	(.)	(.)	(.)	(.)	(.)	(.)
Post	-0.0029**	-0.0025	-0.0036	-0.0023***	0.0002	-0.0010
	(0.0014)	(0.0017)	(0.0023)	(0.0007)	(0.0010)	(0.0007)
Observations	760034	254264	507284	2872876	882386	1976896
Controls	271002	82677	192440	1038177	305791	744624
Treated	489032	171587	314844	1834699	576595	1232272
Obs. t<0	320745	97553	222554	1063094	330886	726333
Obs. t=0	.	.	.	.	.	.
Obs. t>0	439289	156711	284730	1809782	551500	1250563
Obs. Evertreated t<0	204424	65252	137054	676789	214247	452226
Obs. Evertreated t>0	284608	106335	177790	1157910	362348	780046
R-sq	0.019	0.017	0.023	0.021	0.018	0.025
Clusters	313	95	208	822	198	624
Meters from CZ incl.	5000	5000	5000	5000	5000	5000
Not on pri-list	0	0	0	2	2	2

Notes: As table 3, but includes only cells up to 5 km from the zone boundaries. $D = 1$ *ever in CZ x pr_post* and *pr_post* drop out.

Table B.11: Different sample: 30 km, the priority list

	(1) All	(2) SP	(3) SU	(4) All	(5) SP	(6) SU
D=1 ever in CZ	-0.0022*	-0.0039***	-0.0011	-0.0018***	-0.0027***	-0.0011*
	(0.0012)	(0.0014)	(0.0016)	(0.0005)	(0.0006)	(0.0007)
D=1 ever in CZ x Post	0.0034	0.0013	0.0048	0.0012**	0.0017**	0.0006
	(0.0028)	(0.0015)	(0.0051)	(0.0006)	(0.0007)	(0.0009)
D=1 ever in CZ x Post x pr_post	-0.0012	0.0003	-0.0030	0.0003	-0.0006*	0.0011
	(0.0023)	(0.0006)	(0.0046)	(0.0005)	(0.0003)	(0.0008)
D=1 ever in CZ x pr_post	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	(.)	(.)	(.)	(.)	(.)	(.)
pr_post	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	(.)	(.)	(.)	(.)	(.)	(.)
Post	-0.0033	0.0016	-0.0043	-0.0021**	0.0017**	-0.0004
	(0.0020)	(0.0010)	(0.0037)	(0.0009)	(0.0008)	(0.0011)
Observations	2527679	1017781	1688056	9581957	3294216	6611464
Controls	1141388	481437	848252	4533913	1560498	3410036
Treated	1386291	536344	839804	5048044	1733718	3201428
Obs. t<0	1029713	370449	714984	3512898	1212563	2410406
Obs. t=0	.	.	.	.	.	.
Obs. t>0	1497966	647332	973072	6069059	2081653	4201058
Obs. Evertreated t<0	558925	192838	354788	1855820	639970	1168289
Obs. Evertreated t>0	827366	343506	485016	3192224	1093748	2033139
R-sq	0.029	0.017	0.032	0.034	0.021	0.040
Clusters	324	95	229	822	198	624
Meters from CZ incl.	30000	30000	30000	30000	30000	30000
Not on pri-list	0	0	0	2	2	2

Notes: As table 3, but includes cells up to 30 km from the zone boundaries. $D = 1$ *ever in CZ x pr_post* and *pr_post* drop out.

Table B.12: Different sample: All borders, the priority list

	(1) All	(2) SP	(3) SU	(4) All	(5) SP	(6) SU
D=1 ever in CZ	-0.0015	-0.0035**	-0.0006	-0.0012***	-0.0021***	-0.0008
	(0.0010)	(0.0015)	(0.0013)	(0.0004)	(0.0006)	(0.0005)
D=1 ever in CZ x Post	0.0026	0.0029*	0.0032	0.0009*	0.0020***	0.0003
	(0.0023)	(0.0016)	(0.0040)	(0.0005)	(0.0007)	(0.0007)
D=1 ever in CZ x Post x pr_post	-0.0009	-0.0002	-0.0020	0.0000	-0.0013***	0.0009
	(0.0020)	(0.0008)	(0.0037)	(0.0004)	(0.0005)	(0.0006)
D=1 ever in CZ x pr_post	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	(.)	(.)	(.)	(.)	(.)	(.)
pr_post	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	(.)	(.)	(.)	(.)	(.)	(.)
Post	-0.0032*	-0.0012	-0.0042	-0.0024***	0.0006	-0.0011
	(0.0017)	(0.0015)	(0.0030)	(0.0008)	(0.0010)	(0.0013)
Observations	1304259	448009	866825	4916480	1542436	3366648
Controls	486075	156488	344959	1870756	564892	1349618
Treated	818184	291521	521866	3045724	977544	2017030
Obs. t<0	545247	169482	377041	1815318	577122	1233483
Obs. t=0	.	.	.	.	.	.
Obs. t>0	759012	278527	489784	3101162	965314	2133165
Obs. Evertreated t<0	338587	108966	225394	1122219	362831	738808
Obs. Evertreated t>0	479597	182555	296472	1923505	614713	1278222
R-sq	0.022	0.016	0.027	0.024	0.017	0.028
Clusters	324	95	219	822	198	624
Meters from CZ incl.	10000	10000	10000	10000	10000	10000
Not on pri-list	0	0	0	2	2	2

Notes: As table 3, but includes all borders.