Land speculation and conservation policy leakage in Brazil

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The Brazilian Amazon and Cerrado biomes have been subject to strong pressure from agricultural expansion over the past decades. It is frequently claimed that the associated tree cover loss was partly driven by land speculation. In the mid-2000s, the Brazilian government implemented an innovative policy regime to combat deforestation with a strong focus on the Amazon region. While there is solid evidence that the new environmental governance approach was effective in reducing Amazon forest loss, some research indicates that leakage effects have contributed to increasing land conversion in the Cerrado. In this paper, we contribute to investigating these hypotheses using land market data covering the period from 2001 to 2012. Based on land rent and hedonic valuation theory, we use a first difference panel regression analysis to decompose forestland prices into land rent, conversion costs, and speculative attributes. We then assess whether, where, and to what extent conservation policy shocks affect forestland prices over time. Our measures of speculation and conservation are significant in all our model specifications. Our findings suggest that land prices represent an indicator for spatially and temporally shifting land demand and related speculative behavior, and the presence of conservation policy leakage in Brazil.

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Abstract

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Keywords: land price, speculation, conservation policy, leakage

I. Introduction

At a global scale land resources are subject to strong pressure to fulfill the world's demand for agricultural products (Tilman et al., 2011; Leblois et al., 2017). In this context, Brazil represents a major player to satisfy local and global needs. It holds a vast amount of land resources, while at the same time its agricultural sector has grown due to productivity improvements and structural adjustments (OECD, 2015). Yet, global and local demands for products such as soy and beef enhance expansion of the agricultural frontier into natural vegetation (McAlpine et al., 2009; Karstensen et al., 2013) with considerable environmental tradeoffs of major concern for policymakers (Nepstad et al., 2013). In this paper, we want to contribute to a better understanding of the incentives that affect land conversion decisions in Brazil by looking at the effects of land speculation, and conservation policies in land markets.

A better understanding of Brazilian land markets can reveal information on the incentives of deforestation and related speculative behavior (Margulis, 2003; Merry et al., 2008; Sills and Caviglia-Harris, 2009). Conversion of natural vegetation in the Brazilian forest frontier is a quest for claiming land. Asset accumulation in land is common by colonist agents in these areas; many with the objective to occupy properties to sell once a land market emerges (Caldas et al., 2007). Typically, land in the Amazon has been relatively cheap compared to other areas and was subject to little law enforcement on illegal conversion and related ownership up-to mid-2000s. During the 1970s and 1980s small farmers in the south transferred their demand for land to the north contributing to rising land prices, and pushing landless settlers and expansive cattle ranching further into frontier areas (Margulis, 2003). With the advancement of the agricultural frontier, land prices rise inducing land speculation in a context where land markets do not depend on the presence of formal land titles (Reydon, 2011; Holland et al., 2016; Barreto et al., 2013).

Speculation in Brazilian frontier areas happen when forest is converted to pastureland, as a mean to secure land ownership, and later expect to profit from selling the land when the cropland frontier advances, or by increasing production as infrastructure improves (Strassburg et al., 2014; Barreto et al., 2008). Besides the profitability of beef production, forest conversion into pasture is fueled by factors such as: establishment of land ownership of cleared land (Reydon, 2011), capture of land rents identified by ranchers created by altered economic conditions (Walker et al., 2009), and land speculation (Hecht, 1985; Fearnside, 2002; Margulis, 2003). It comes with no surprise that in the Brazilian Amazon pastureland has been identified as culprit of most cumulative direct deforestation in the past decades(Chomitz and Thomas, 2001; Zaks et al., 2009; Barona et al., 2010). Planned improvements in infrastructure also fuel speculative behavior in the Amazon (Laurance et al., 2004; Hecht and Mann, 2008), as an increase on the demand for land by different agents is expected. As the productive potential of cattle ranching in forest areas increases, we would expect that land selling prices will also rise. A speculative behavior, we hypothesis, would enhance this increase in forestland prices.

The great expansion of the agricultural frontier in the Amazon biome raised environmental concerns by the Brazilian Federal Government during the 2000s. Legal protection of forestland resources has existed since 1934 by the creation of the Forest Code (Arima et al., 2014); yet, the real breakthrough in conservation governance came in 2004 when it was launched the Action Plan for Prevention and Control of Deforestation in the Legal Amazon (PPCDAm). This plan called for actions on land tenure regularization, improve monitoring and control for conservation compliance, use of economic incentives for sustainable agriculture and forest management, and environmental sustainability guidelines for infrastructure projects (May et al., 2011; Gebara and Thuault, 2013). Additionally, the different levels of government increased the extension of areas protected, as well as those of conservation units (Arima et al., 2014). Interventions in the supply chain followed. In July 2006 major soybean traders sign an agreement to not buy products from areas deforested after that year, the so-called Soy Moratorium (Gibbs et al., 2015). Further efforts to halt deforestation were made in 2008 with the creation of a priority list in which those districts with historic high rates of deforestation were subject to special conservation enforcement until some conservation milestones were achieved (Cisneros et al., 2015). As a result by 2016, deforestation was reduced in 71% compared with its levels in 2004 (INPE, 2017); a success related to this innovative conservation governance and supply chain interventions (Nepstad et al., 2014; Arima et al., 2014; Cisneros et al., 2015).

Despite this apparent conservation success, it exists concerns regarding the presence of conservation policy leakage.[1] Great efforts to reduce deforestation from agriculture and cattle ranching within the Amazon biome might cause higher pressure in relatively less protected areas like the Cerrado savannah (Gibbs et al., 2015; Oliveira and Hecht, 2015).[2] Moreover,

[1] Other concerns beyond the scope of our analysis had been highlighted: tradeoffs between environmental law compliance and agricultural production (Sparovek et al., 2012; Nepstad et al., 2014); less credibility of law enforcement as amnesty was offer to some offenders in recent revisions of the law (Soares-Filho et al., 2014); or the importance of macroeconomic factors (Santana and Nascimento, 2012; Richards et al., 2012; Almeida de Menezes and Piketty, 2012; Macedo et al., 2012).
[2] Cerrado savannah is the second largest biome in the country hosting an important biodiversity richness (Ratter et al., 1997). It also highly susceptible to infrastructure improvement, as it can considerably increase agricultural productivity in this area (Rada, 2013).

agri-business expansion into already cleared areas can push cattle ranching into frontier areas (Lapola et al., 2010; Arima et al., 2011; Richards et al., 2014). Within a stringent conservation context, lower profits and lower likelihood of land titling from illegal clearance are expected; thus, the cost of clearance in the Amazon would level with that in other biomes shifting incentives for clearance in areas like Cerrado. Such type of leakage has been described as out-to-out leakage (Fearnside, 2009; Soares-Filho et al., 2010), in which land-grabbers once prone to deforest in the Amazon would redirect their attention to less protected areas after a stringent conservation is in place.

Land markets can reflect potential leakage effects of conservation. Under PCCDAm, offenders are linked to remotely-sensed deforestation patches, and if liability is established, they could be subject to confiscation of assets, monetary fines, or cross-compliance mechanisms such as conditional access to credit and commercialization channels (Börner et al., 2015). This set of measures makes harder for new settlers to claim ownership on illegally deforested areas, and thus reduces the expected profits envisioned by the conversion. Further, regularization of public land by extending protected areas reduces the likelihood of those areas of ever receive a title for the land, discouraging a speculative behavior (Nepstad et al., 2014). We expect that land prices incorporate the effect of conservation policies by reducing the value of land as the likelihood of its expected net profits reduces, but increasing the value in areas not subject to stringent conservation.

In this paper, we use forestland prices as an indicator of shifting land demand and related speculative behavior. We then test the impacts of conservation, as we hypothesized that changes in forestland prices can be seen as a symptom of leakage in which deforestation is its consequence. The analysis is founded on land rent theory and hedonic theory valuation of land. We aim to answer the question: *do forestland prices convey information on future land conversion?*

The paper is divided into five sections. Our first section is the present introduction to the topic of land markets, speculation, conservation and potential leakage effects in Brazil. The following section describes the theoretical framework in which forestland prices are analyzed. The third section lays out the empirical approach implemented and provides an explanation of the data used in our analysis. A fourth section presents our results on the effect of speculation and conservation in forestland prices. Followed by a discussion and a conclusion section based on our results.

II. Theoretical Framework

II.1. Land rent and forest conservation

Land rent theory interprets how access to relevant markets affects land rents, land use, and rural landscape differentiation (Holland et al., 2016). Key assumptions of this theory are that land rents are a function of a) distance to sources of trade or relevant markets (Thünian notion), and b) land productivity (Ricardian notion) determined by bio-geophysical factors (e.g. topography, soil fertility, climate conditions)(Munroe et al., 2002) and agricultural practices. Thus this theory offers insights on impacts of political economy into loss of tropical forest by exemplifying a policy process and its effect on land rents and landscape, and related incentives faced by landowners (Walker et al., 2009).

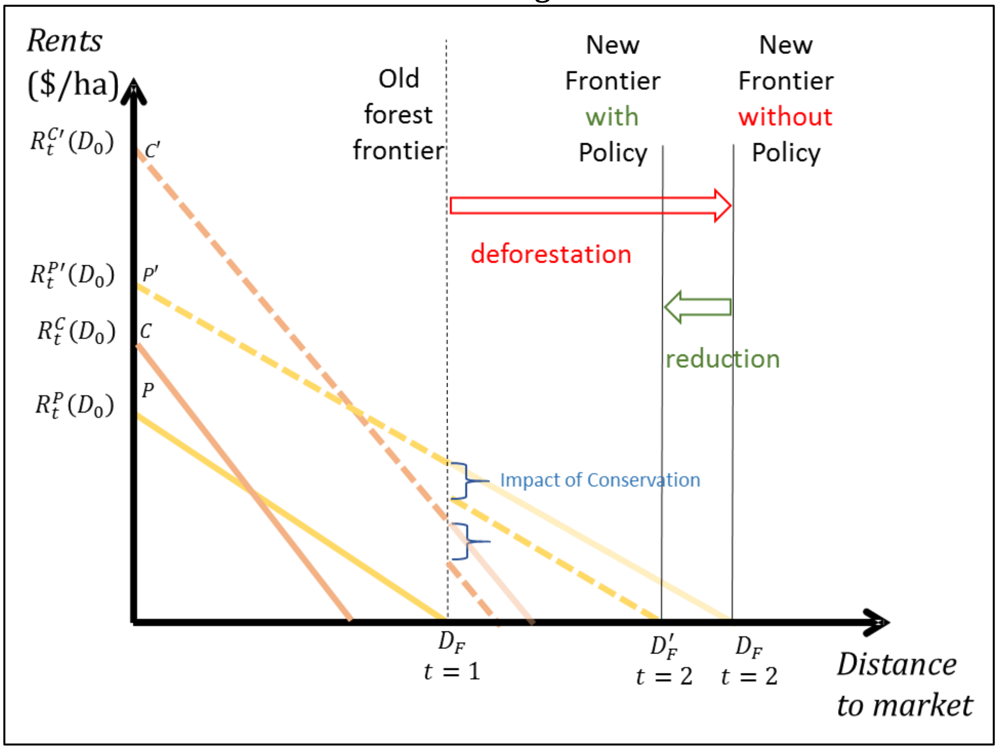
Following Angelsen (2010), land rents are accrued from a use *h* of land at location *i* at time *t* as a diminishing function of distance to relevant markets.[3] In this model, land is set into production to a use *h* that brings higher rents. Incentives to expand land uses into forest areas will exist until they bring zero rents. If one observes a case in which markets are functioning properly, then "…land rent will be equal to the net [to costs] yield of the highest and best use of the land" (Mendelsohn et al., 1994 p. 755).

Figure 1 depicts a land rent theory framework for two land uses in two time periods. Yellow and orange lines represent cropland and pastureland use, respectively. Straight bold lines represent equilibrium in a first period. Broken dotted lines represent effects of a shock in a second period in the contexts with or without implementation of forestland conservation policy, e.g. (*de facto* collected) fines, that increase costs of production (Börner et al., 2014). The shock is represented by shifting land rent lines outwards from the origin due to, for instance, infrastructure improvements and higher agricultural prices. With a higher conservation enforcement, expansion towards forested areas will be lower in this scenario ($D_F' < D_F$ in Fig 1).

This model represents a key idea behind expectations of profitability of land with and without conservation policies. If an infrastructure improvement is planned but a stringent conservation is in place; then the expected rents will be reduce dissuading speculative behavior.

[3] See Angelsen (2010) for a comprehensive discussion on land rent theory in frontier areas.

***Figure 1*. Land rent for two land uses and stringent forestland conservation**



Note: This graph shows bid-rents for cropland (orange) and pastureland (yellow). Beyond D_F, rents of pastureland become zero and native vegetation is kept intact. In a second period, a driver of deforestation (e.g. a price shock or infrastructure improvement) shifts bid-rents outwards and induces frontier expansion. If conservation policies are implemented effectively, they will reduce the impact of this effect on deforestation by incrementing the cost of converting forestland beyond the old frontier.

We use the intuition behind land rent theory to explain forestland prices and associated incentives for landscape development in Brazil. In the next section, we use a present value perspective on rents as a framework to understand forestland prices.

II.2. Forestland price

Following a land rent model perspective, forestland is converted to pastureland when it brings higher rental incomes (*Fig. 1* above). In the present analysis is assumed that decision of conversion of forestland will happen in the future which brings uncertainty on expected rent incomes; thus different land use patterns must be considered. Using a present value formulation on net land rents (Shiller, 1981; Burt, 1986; Tegene and Kuchler, 1991; Engsted, 1998) forestland prices can be expressed as:

$$P_{it}^F = EdR_{it}^F + EdR_{it}^G - EdCC_{it} \qquad \textbf{(1)}$$

In eq (1) the price of forestland at location *i* at time *t*, P_{it}^F, is the sum of expected discounted stream of forestland rent, EdR_{it}^F, and discounted stream of pastureland rent, EdR_{it}^G, net of the expected discounted conversion costs, $EdCC_{it}$. This structural equation allows us to decompose different aspects that affect forestland prices.

A first element is given by the expected stream of forestland rents. When land is left as forest at the end of time *t*, its rents equal the marginal productivity net of transportation costs, R_{it}^{F} (as proposed in the von Thünen model). We assume a probability ρ_t that forestland is converted to pastureland at the beginning of time *t*. Decisions are faced with a discount rate r_t. To reduce complexity one can make the strong assumption that ρ_t, r_t , and R_{it}^{F} are constant over time. An additional assumption made is that forestland rent income occurs only when forestland has not been converted to pastureland, thus one can express the forestland rent element as:

$$EdR_{it}^{F} = (1-\rho)R_i^F \sum_{t=0}^{\infty} \left(\frac{1-\rho}{1+r}\right)^t = \frac{(1+r)(1-\rho)R_i^F}{r+\rho} \tag{2}$$

Expected stream of pastureland rent income is the second element of forestland prices. Pastureland rent income R_{it}^{P} occurs on original forest land only after the land has been converted to pasture land. If we again assume that probability of conversion, interest rate, and pastureland net rents are constant over time we obtain:

$$EdR_{it}^{P} = \sum_{t=0}^{\infty} \rho \left(\frac{1}{1+r}\right)^t R_i^P + \sum_{t=1}^{\infty} \rho(1-\rho) \left(\frac{1}{1+r}\right)^t R_i^P + \sum_{t=2}^{\infty} \rho(1-\rho)^2 \left(\frac{1}{1+r}\right)^t R_i^P + \dots \tag{3.a}$$

Which can be simplified to:

$$EdR_{it}^{P} = \frac{\rho R_i^P (1+r)^2}{r(r+\rho)} \tag{3.b}$$

The third element, conversion costs τ are assumed to be constant in time and space, and only occur at the time of the conversion from forest to pasture land. They can be expressed as:

$$EdCC_{it} = \rho\tau + \frac{(1-\rho)\rho\tau}{1+r} + \frac{(1-\rho)^2\rho\tau}{(1+r)^2} + \cdots$$

$$= \rho\tau \sum_{t=0}^{\infty} \left(\frac{1-\rho}{1+r}\right)^t = \frac{(1+r)\rho\tau}{r+\rho} \tag{4}$$

With the calculations from above, we obtain the price of forestland, including the value and cost of converting the land to pastureland as follow:

$$P_{it}^{F} = \frac{(1+r)\left(-r\rho\tau+(r-r\rho)R_i^F+(1+r)\rho R_i^P\right)}{r(r+\rho)} \quad \textbf{(5)}$$

When conversion probability ρ equals zero, then forestland price is no longer as in equation (5); instead, one obtains a forestland price that only considers the stream rents of forestland (i.e. $P_{it}^{F} = EdR_{it}^{F} = \frac{R_i^F}{r} + R_i^F$).

II.3. Comparative static analysis

In order to derive testable hypothesis, we calculate the total derivative of forestland prices after some key components. Here with the assumption that land prices capture expected rents from forest conversion. The alternative would be that land conversion is not reflected in forestland prices and only determined by rental prices. Based on our theoretical model and the objective in this paper we are interested in two main components. First, the conversion probability ρ is considered in our model as the main source of a speculative behavior. If high expectations exist of ripping profits from conversion to pastureland, then ρ would be close to or equal to 1. However, in a more stringent conservation scenario, we would expect a smaller likelihood of pastureland conversion even if it might be profitable. Taking the derivate of the forestland price with respect to ρ (and without indexes to ease explanation), we obtain:

$$\frac{dP^F}{d\rho} = -\frac{(1+r)(r\tau+(1+r)R^F-(1+r)R^P)}{(r+\rho)^2} \quad \textbf{(6)}$$

The expression is always positive if $R^P - \frac{r\tau}{1+r} \geq R^F$. Hence, whenever the pasture rent net of the discounted conversion costs is higher than the forest rent (i.e. it would be profitable to convert the land), higher protection stringency (lower ρ) leads to lower forest land prices.

The second component of interest is the effect of a change in conversion costs τ. Taking the derivate of the relative forest price after the conversion costs, we get:

$$\frac{dP^F}{d\tau} = -\frac{(1+r)\rho}{(r+\rho)} < 0 \quad \textbf{(7)}$$

which is always negative. Thus, higher conversion costs such as areas with dense vegetation, or subject to *de facto* collected fines, reduce the relative price of forest land.

In the next section, we explained our empirical approach to test the hypothesis that forest prices convey information on future land conversion with sign tests as presented in Table 1.

***Table 1*. Hypotheses Summary**

	Impact on forestland price	
Relevant components	*Anticipation of land conversion*	*No anticipation of conversion*
Conversion probability ρ	+	0
Conversion costs τ	-	0

Note: The signs for the anticipation case partially depend on the assumption that (pure) forestland rents are (sufficiently) lower than pure rents from pastureland which is a common case for consolidated frontier areas as well as land that is expected to become part of a consolidated frontier area.

III. Empirical Strategy and Data Sources

III.1. Reduced-form Model

In our empirical strategy, we aim to test the hypothesis that forestland prices convey information on future land conversion. To achieve our objective we need to decompose land prices into its different components, mainly the probability of conversion and the conversion costs. We used an econometric panel model to evaluate the relative importance of attributes influencing forestland prices based on hedonic theory (first exposed by Rosen (1974)). The hedonic modeling rest on the key assumption that the price of a parcel of land is the sum of the unobserved prices of a bundle of attributes associated with that good (Snyder et al., 2008), allowing the possibility to account for heterogeneity in the quality of land (Chicoine, 1981). The fundamental hedonic equation is $P^F = h(Z)$. In which $h(\cdot)$ represents a functional relationship between the forestland price and its different attributes, z_i. One can derive the marginal implicit price, $\partial P^F/\partial z_i = \partial h(Z)/\partial z_i$, for each attribute which represents the additional value people would pay for a small change in the specific attribute (Ma and Swinton, 2011; Shultz and King, 2001; Snyder et al., 2008).

This approach is also attractive as we cannot observe the key components of the theoretical model. We then investigate the effect of some relevant attributes that strongly influence those relevant components. Thus our strategy evaluates the transformation on levels of certain attributes that influence land prices (Sills and Caviglia-Harris, 2009).

Our reduced-form model of forestland price is given by the following equation:

$$P_{it}^F = \sum_{k=1}^{n} \alpha_k R_{kit} + \sum_{k=2}^{j} \gamma S_{kit} + \theta_l (t * W_{li}) + \sum_{k=2}^{t} \delta_k d_k + \mu_i + \epsilon_{it} \qquad \textbf{(8)}$$

We applied a first difference (FD) econometric model (Wooldridge, 2007) to equation (8) to test whether forestland prices convey information on future land conversion. Here P_{it}^F represents forestland prices at district *i* at time *t*, and it is a function of different attributes which are averaged at the district level. First, we include R_{kit}, a vector of *n* attributes related to land rents and conversion costs. Second, a vector S_{kit} of j attributes with influence on the probability of conversion, i.e. our indicator of speculation (see Data section below). We also include an "initial condition", W_{li}, that is related to costs of conversion. This term is interacted with time variable *t* to keep it in our econometric estimation after taking first difference (Cisneros et al., 2015). In our different specifications, we also include a vector d_k of trend dummies for each period analyzed. Finally, forestland prices are influenced by an unobserved heterogeneity term μ_i for each district and an idiosyncratic error, ε_{it}.

We used equation eight as based on different specifications of our model. In each specification, the dependent variable is the log transformation of average forestland prices. The first specification only considers those attributes that affect land rents and disentangles the effect of speculation. Three additional specifications include the impact of conservation mechanisms to test further existence of land conversion information, and conservation policy leakage in forestland prices. Below we elaborate further on the different attributes considered in our empirical estimation.

III.2. Data

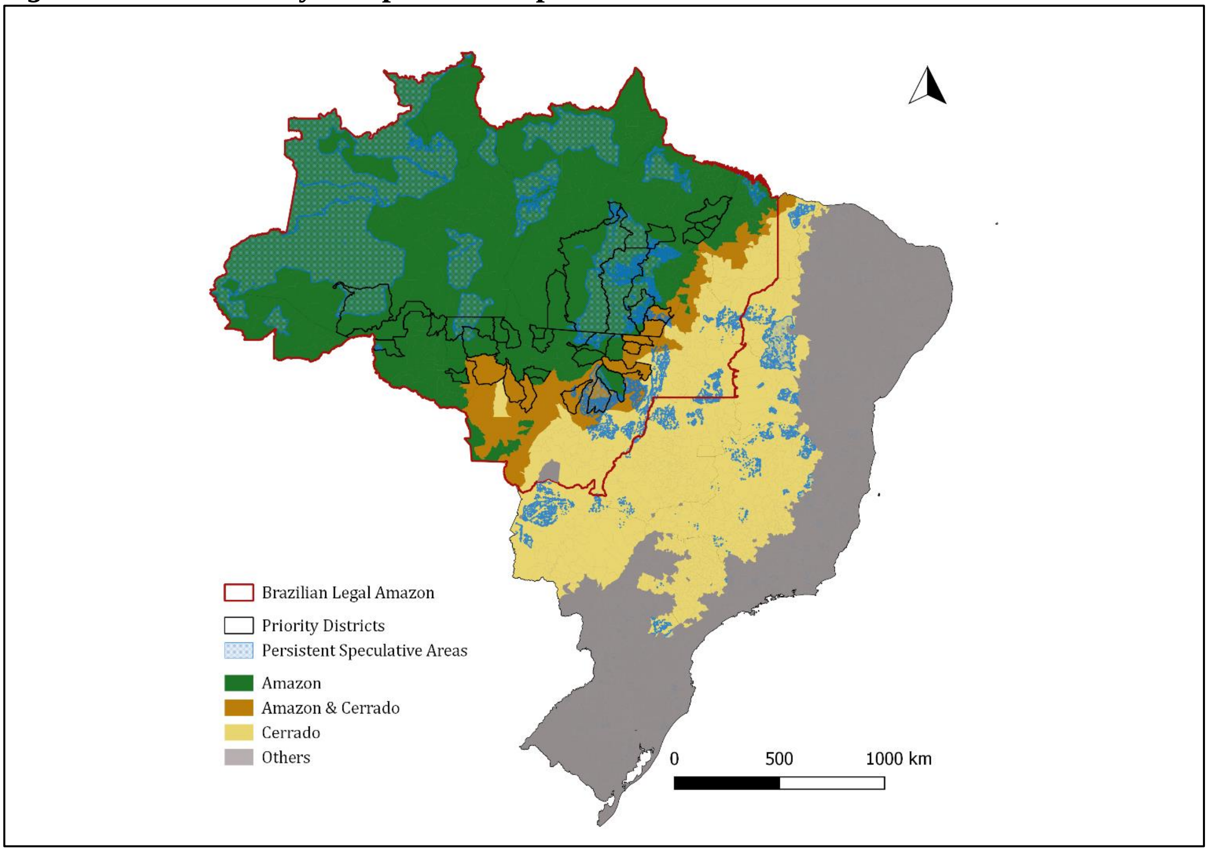
For our empirical approach, we used the district as unit of analysis. From the approximately 5.5 thousand districts in the entire country, we analyzed 1,456 for which forestland price information was available, and that are located within the Amazon and/or Cerrado biomes (see Figure 2).

The timeframe of our study goes from 2001 till 2012. This period allows us to see changes in land speculation and conservation policy leakage before and after the innovative conservation governance implemented in the mid-2000s. At the time of the analysis some of the variables were not available for more recent years, therefore a practical reason bound us also to this timeframe.

III.2.a. Land Prices

We used forestland selling prices as dependent variable in our different model specifications. The information was obtained from *Informa Economics FNP* (http://fnp.com.br/), an agribusiness consulting company. The information is divided in micro-regions developed by FNP; we then imputed to each district the average value of its representative region. In the original information, three types of land are distinguished: cropland, pastureland and natural land cover (forestland). In our empirical analysis, we deflated average regional values to 2001 values using Brazil’s General Price Index- Internal Availability (IGP-DI). We also test our model using an interpolation of our dependent variable similar to Richards et al. (2014), but as we obtained consistent results we only reported those of our original variable.

***Figure 2*. Area of study and persistent speculative areas**



Note: This map draws those regions of interest: Amazon and Cerrado biomes, the Brazilian Legal Amazon (PPCDAm’s area of influence), and the priority list districts. It also shows persistent speculative areas, i.e. areas with reduced travel times from forest areas to roads due to expected improvements in road infrastructure throughout the period of analysis.

III.2.b. Rent and conversion costs attributes

A set of attributes are included to control for land rents that can be ripped from conversion of forestland. First, we created an aggregate Paasche ***crop price index*** that includes all seasonal and temporal crops using information from the municipality annual agricultural survey of Brazil (Produção Agrícola Municipal - PAM in Portuguese). We used 2001 as based year. We include this attribute as we expect it to influence average rents of converted forestland in a district. A second attribute is given by current ***fuel prices***. The information was obtained from the Brazilian National Agency for Oil, Natural Gas and Biofuels (ANP in Portuguese). We considered prices on oil fuel, diesel, and ethanol. The data is available as a monthly average record which was translated as an average yearly price of the three types of fuels from 2001 till 2012.[4] Around 10% (or 560) of total municipalities analyzed have a record on fuel prices. Using the location of municipality capitals, we calculate an average fuel price for the rest of municipalities by assigning the average value of the nearest 5 neighbors with a record on fuel prices. We deflated fuel prices to values in 2001 using the IGP-DI. This attribute, we assume, influence negatively rent components of converted land (as input for production), and positively the component of costs of conversion (as input for forest clearance machinery). Number of ***environmental fines*** within a district issued by the Brazilian Institute for the Environment and Renewable Natural Resources (IBAMA) were also included as we assumed that a higher density of fines would affect potential conversion costs and thus land conversion decisions.

Average ***accessibility from forest to roads*** within a district was included to account for location impacts on rents (a discussion on its calculation is offered in the Speculation section below). We also included the proportion of ***soy suitability*** area within non-forest patches in a district. This variable was obtained from Soares Filho et al. (2016) as raster format and we aggregated at district level using a Geographic Information System (GIS). It considers bio-physical characteristics like slope, soils, and climate zones (Gibbs et al., 2015) that favor soy production in particular, and agriculture in general. We consider it as a proxy to control for *in situ* potential rents and the impact of agriculture development within a district. As initial condition, we measured proportion of ***tree forest cover*** area within a district at the beginning of the period. We obtain this variable from Hansen et al. (2013). We assume that it would influence positively the costs of conversion, as dense forest areas are harder to reach making clearance more costly (Andersen, 1996; Margulis, 2003).

III.2.c. Speculative attribute

In Brazil, construction of new roads has been linked to land conversion and land speculation since the beginning of the Amazon colonization till today (Hecht, 1985; Pfaff, 1999; Soares-Filho et al., 2006; Fearnside, 2008). To account for this effect on forestland prices we constructed an indicator on the ***expected impact on travel time from forest areas to roads (EIR)*** due to road network development. To construct our indicator we first measured a district's average accessibility to existing roads from forest areas in time units. We created two layers of accessibility for each year, one calculated with factual roads, and another one including also planned or improved roads. To construct these variables different steps were needed. First, a friction map was created using information on land cover, roads, water bodies

[4] All years reported a monthly price of fuel except for 2001 in which only information from July till December was available.

and the effect of slope. Land cover was classified as areas with primary forest, secondary forest, and non-forest with data made by Hansen et al. (2013). Their tree cover (vegetation over 5 meters in height) map for the year 2000 was compared with yearly areas of tree cover losses (both anthropogenic and non-anthropogenic) between 2001 and 2012. Original data is at a 30x30 pixel resolution, thus to ease our calculations we performed an aggregation of grid-cells of approximately 2x2 km resolution to account for all forest/non-forest pixels of 30 meters. Each new grid cell was classified as primary (60%+), secondary (30%-60%) or non-forest (30%-) based on their percentage of forest pixels from a total of 6,400 in each grid cell. Historical road network information was obtained from Brazil's National Department of Transport Infrastructure (DNIT). Accessibility to roads in hours was calculated using a Knight's move algorithm from standard GIS software. We calculated the mean accessibility value for each district from both layers. Finally, we calculated the difference between the two measures of accessibility and use it in our model as indicator of speculation. As illustration, in Figure 2 we depicted those areas that for all years were potentially subject to speculation due to road development.

III.2.d. Stringent conservation attributes

Since the mid-2000s, a stringent environmental governance was implemented in Brazil, particularly to protect the Amazon Biome.[5] To test the impact of these conservation policies on land markets, we included three different specifications of our model for each conservation policy measured. First, we include the effect of two major changes in conservation governance: the ***PCCDAm*** (government sector)**,** and the ***Soy Moratorium*** (private sector). We created temporal shock variables with post-2004 and post-2006 respectively. Finally, we included a dummy variable for those districts that enter a ***priority list*** commonly known as "*blacklist*" (Cisneros et al., 2015). Based on our theoretical model, we would expect lower forestland prices in those areas with stringent conservation. If a conservation policy leakage is present, we also expect that forestland prices rise in areas not subject to a stringent conservation.

[5] We test also the impact of protected areas but no variation prove to be significant, in contrast with other studies that was significant in explaining pasture and cropland values (see Cohn et al. (2016)).

IV. Results

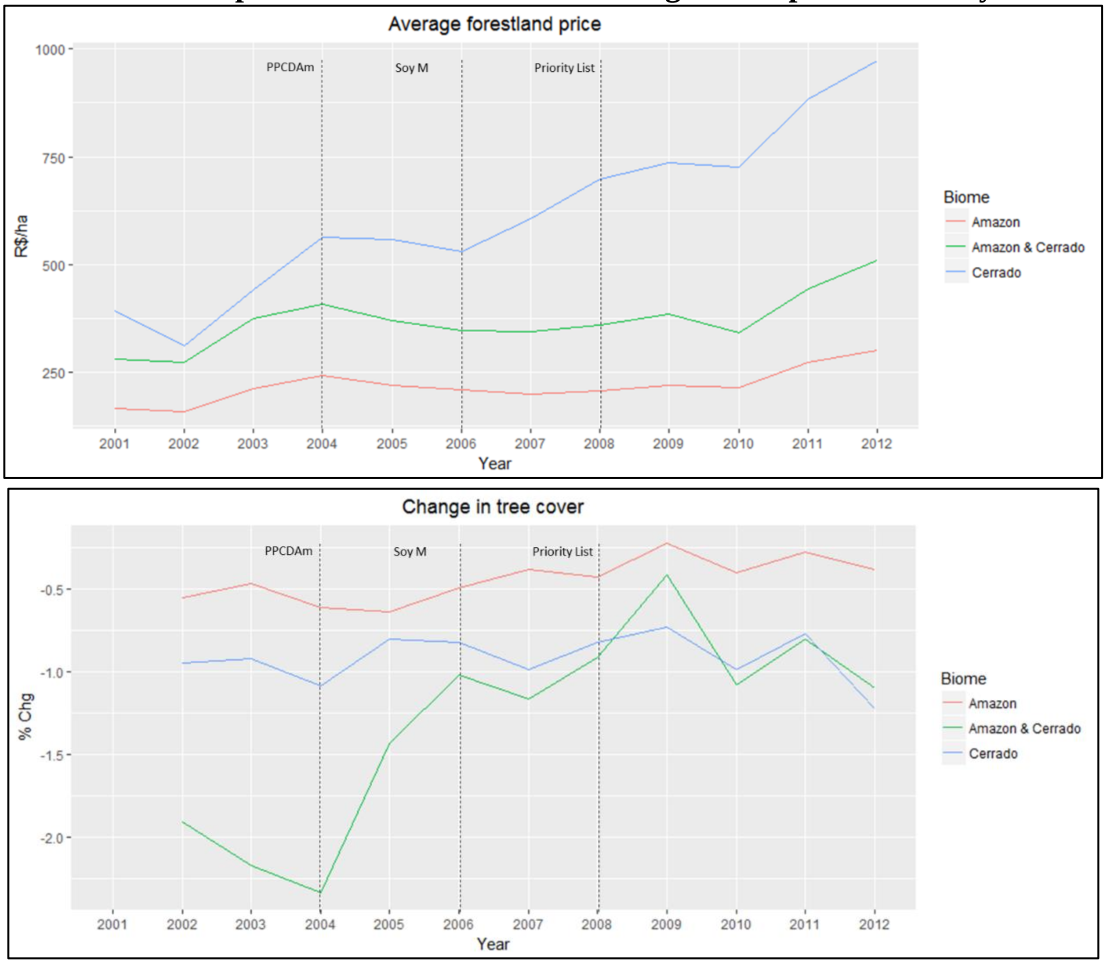
IV.1. Descriptive analysis

In figure 3 we depicted the development of forestland prices and deforestation rates for three groups of districts: only Amazon forest, only Cerrado savannah, or those that hold both biomes within their boundaries.[6] Average forestland prices (top graph) for the three groups were on the rise up to 2004. The implementation of the PPCDAm was followed by average forestland price reductions across regions. Yet, after the soy moratorium was signed in 2006, forestland prices within the Cerrado skyrocketed in following years. By 2012, average values reached levels as four times higher than those in Amazon areas. This signals to the presence of a conservation policy leakage reflected on land prices. It is also interesting that average land price levels were stabilized within the Amazon regions up to 2010. From 2010 till 2012, prices again raised by about 30% in those two years. This change coincides with the time a new Forest Code was in discussion. One criticized modification to the law is related with an amnesty provided to agents of deforestation, e.g. land speculators (Soares-Filho et al., 2014); which might have triggered a renewed race for land in the Amazon as expectations of environmental compliance were reduced.

The lower graph in figure 3 illustrates deforestation rates measured as the percentage change of total forest tree cover within the three types of districts (Hansen et al., 2013). After 2004 we observed important reductions in the rates of deforestation; particularly for those districts that are within the arc of deforestation. Those districts reduced their rate of deforestation by about 1.5% by 2006. Another pronounced reduction in these districts happened between 2008 and 2009 reaching levels of 0.5%. As expected, districts within Cerrado showed relatively stable rates of deforestation, between 0.75% and 1.25% of forest cover loss throughout the period.

[6] This last group of districts is located within a highly dynamic region, the so-called "Arc of Deforestation".

***Figure 3*. Forestland prices vs. forest tree cover change in the period of study**



Note: We differentiate three regions: districts within Amazon areas, those within Cerrado areas, and those within both biomes. The upper graph shows average forestland price levels. The lower graph shows percentage change in total deforestation per region.

IV.2. Model 1 - Speculative component

We aim to test the hypothesis that forestland prices convey information on future land conversion. Based on our theoretical model and hypothesis related, we expect to find information on land conversion if some relevant components are affecting forestland prices. Here we are mainly interested in the impact of the probability of conversion, as we assumed is the major source of speculation. We applied a first difference model to our reduced-form model in equation 8. We applied a log transformation to our dependent variable as well as to our covariates. Our results are summarized in Table 2.

In the first column, we present a first specification that only considers attributes that affect rents and conversion costs components of land prices. Our different attributes are related to forestland prices as expected. In a district with lower prices received for agricultural production, or faced with higher input prices (fuel prices) in a remote location (accessibility), one would expect on average lower forestland prices. A higher concentration of environmental fines is correlated with lower forestland prices, supporting our hypothesis of increasing conversion costs. This effect might also show that a higher incidence of fines is related to the credibility of law enforcement and thus reducing expected profitability of conversion. Our initial condition measure, proportion of tree cover within a district, shows a strong negative relationship with forestland prices. This relationship reinforces common knowledge that dense forest areas will be less valued, and thus subject to less conversion pressure.

***Table 2*. Model 1 – Forestland prices and its speculative component**

First Difference Model			
	Dependent variable:		
	Δ *ln* Forestland Pr.		Relevant component
	(1)	(2)	
Δ *ln* Agr Pr.	0.033***	0.036***	Rents & conversion costs
	(0.011)	(0.012)	
Δ *ln* Fuel Pr.	-0.585***	-0.718***	
	(0.195)	(0.209)	
Δ *ln* Soy suitability	0.827*	0.896*	
	(0.458)	(0.495)	
Δ *ln* Accessibility	-0.170***	-0.186***	
	(0.034)	(0.055)	
Δ *ln* Tree cover	-0.083***	-0.091***	
	(0.009)	(0.010)	
Δ *ln* Fine Incidence♦	-0.643***	-0.606***	
	(0.155)	(0.154)	
Δ *ln* EIR		0.079***	Speculation
		(0.020)	
Time trends	Yes	Yes	
Observations	15,314	13,509	
R^2	0.262	0.269	
Adjusted R^2	0.261	0.268	

Note: The table reports first difference estimates with change in the log of average forestland price as dependent variable. Standard errors, clustered at district level, are reported in parentheses. *,**,*** denote significance at the 10/5/1% level, respectively. ♦ refers to a rescaling of the coefficient by 100.

The second column includes our indicator of speculation, EIR, in our model. Our estimated coefficient is positively related to land prices and highly significant at the 1% level. On average in a district, with a hundred percent change in the reduction of time required to reach a road from a forest, forestland increase in 8% percent its value. This finding suggests that road development indeed fueled land speculation in Brazil, and it is a symptom reflected in land markets.

Our first results offer some evidence that forestland prices do convey information on land conversion. To reinforce our findings in the next section we show our results after we test the impact of conservation policies and its related leakage effects on land prices.

IV.3. Model 2 – Stringent conservation

To further test if forestland prices convey information on future land conversions, we made three further specifications of our based model by adding up conservation governance shocks that have the Brazilian Amazon as main focus. Our results are presented in Table 3 (see Annex I for complementary results). From left to right, the columns show the effects of PPCDAm, the soy moratorium, and the priority list. Our previous results were maintained in these new model specifications. Particularly our indicator of speculation kept its significance and magnitude on its relationship with forestland prices.

As expected, all conservation governance shocks showed similar results in forestland prices. All our measured effects are significant at the 1% level with a positive effect on land prices. From these stringent conservation measures, PPCDAm and the Soy Moratorium had a greater magnitude effect with approximately 1% increase in forestland prices compared to no improvement on conservation. In contrast, the priority list brought a modest increase in prices compared with the other conservation measures of approximately 0.090 percent increase compared to no implementation of the blacklist.

Equally interesting is the effect of a stringent conservation on areas only within the Brazilian Legal Amazon. Our results suggest that forestland prices increased less in areas subject to stringer conservation, vis-à-vis areas outside an increase law enforcement. However, one can see that this reduction in forestland prices is not enough to outweigh the impact of a speculative behavior. If we include the impact of PPCDAm in our model, a reduction of 0.4% was observed within the focus area of the policy. Meanwhile, an improvement in one percent on accessibility from forest to roads increase forestland prices by 0.08%. A similar but higher effect was presented by the implementation of a soy moratorium, in which a reduction of 0.65% in forestland prices is related to its establishment.

Our results point to the existence of a conservation policy leakage reflected in land markets. On one side, efforts of conservation might induce unwanted incentives by increasing prices on land markets. On the other, by only focusing on certain regions land prices are only partially tamed, and in under protected regions, one could observe deforestation as a consequence.

***Table 3*. Model 2 – Forestland prices and stringent conservation**

First Difference Model				
	Dependent variable:			
	Δ *ln* Forestland P			Relevant component
	(1)	(2)	(3)	
Δ *ln* EIR	0.079***	0.079***	0.081***	Speculation
	(0.020)	(0.020)	(0.020)	
Δ PPCDAm	1.006***			Conservation
	(0.313)			
Δ BLA x PPCDAm	-0.042***			
	(0.012)			
Δ Priority list		0.090***		
		(0.029)		
Δ Soy moratorium			0.991***	
			(0.314)	
Δ BLA x Soy moratorium			-0.065***	
			(0.012)	
Time trends	Yes	Yes	Yes	
Observations	13,509	13,509	13,509	
R^2	0.270	0.270	0.271	
Adjusted R^2	0.269	0.269	0.270	

Note: The table reports first difference estimates with change in the log of average forestland price as dependent variable. Standard errors, clustered at district level, are reported in parentheses. *,**,*** denote significance at the 10/5/1% level, respectively. ♦ refers to a rescaling of the coefficient by 100.

V. Discussion and Conclusions

In our study, we wanted to test the hypothesis that forestland prices convey information on future land conversion. With that aim in mind, this paper also contributed to the understanding of those mechanisms that affect land speculation and conservation policy leakage effects by analyzing land markets in Brazil. In accordance with other studies, we found that both speculation and leakage play a role in land use decisions. Moreover, our results suggest that land markets can serve as an indicator for spatially and temporally shifting land demand in Brazil. Our findings showed with highly significant levels that forestland prices indeed carry information on future decisions of conversion. Our indicator of speculation is related to an increase in forestland prices, yet its magnitude is lower compared with attributes affecting land rents and conversion costs. This can be a clear underestimation of the speculative component of land prices by our analysis. Further extensions of our research can be pointed to include other relevant attributes that can fuel or discourage speculation, like those related to poor land governance. Our indicator of speculation also does not account the effect of secondary roads due to data limitations. These endogenous roads can also boost land speculation in frontier areas.

Our analysis shows a consistent effect when tested different conservation mechanisms. All pointed to an increase in forestland prices in general but a reduction in prices within areas subject to stronger law enforcement. This results might reflect an increase in the race for grabbing land before conservation is *de facto* enforced, and thus making it harder to claim land rights from illegal forest conversion. This also suggests the presence of conservation policy leakage in the area of study. As with our speculation attribute, our conservation measurement might overestimate the effects of conservation policies. Location and available resources play a crucial role to enforce environmental laws, therefore in practice, the effectiveness of enforcement is heterogeneous across the Brazilian Legal Amazon (Börner et al., 2015).

In the past decade, Brazil achieved a considerable reduction in deforestation through implementing an innovative conservation governance with main focus in the Brazilian Amazon biome. However, reforms to the Forest Code in 2012 and recent backdrops to conservation achievements (e.g. reduction of protected areas) reemphasize the shaking grounds in which conservation success is based. With a relaxed conservation governance, it is expected that development of infrastructure projects like dams, mines or roads bring speculative behavior with related deforestation. Moreover, neglecting a strong conservation governance in other biomes can bring unwanted conservation policy leakage effects.

It is imperative to further understand the economic incentives that shaped landscapes in highly dynamic contexts like the one in Brazil. The Southern American country does hold important land resources that can make the difference for local and global well-being by mitigating climate change gas emissions, by producing important farming products, or by regulating important local and regional ecosystem services. Understanding the effects of speculation, and the role of unprotected biomes in the land use change process can hold one piece of the puzzle to reach integrative solutions. We hope that future research efforts can offer more answers on how to manage different objectives of development and conservation in which land and its uses play an anchor role in finding synergic outcomes.

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Annex I – Forestland prices, speculation and conservation model

First Difference Model				
	Dependent variable:			
	Δ *ln* Forestland P			Relevant component
	(1)	(2)	(3)	
Δ *ln* Agr Pr.	0.037***	0.036***	0.037***	Rents & conversion costs
	(0.012)	(0.012)	(0.012)	
Δ *ln* Fuel Pr.	-0.772***	-0.710***	-0.699***	
	(0.210)	(0.209)	(0.209)	
Δ *ln* Soy suitability	0.952*	0.862*	0.849*	
	(0.494)	(0.495)	(0.494)	
Δ *ln* Accessibility	-0.191***	-0.184***	-0.191***	
	(0.055)	(0.055)	(0.055)	
Δ *ln* Tree cover	-0.085***	-0.092***	-0.081***	
	(0.010)	(0.010)	(0.010)	
Δ *ln* Fine incidence♦	-0.610***	-0.606***	-0.609***	
	(0.154)	(0.154)	(0.154)	
Δ *ln* EIR	0.079***	0.079***	0.081***	Speculation
	(0.020)	(0.020)	(0.020)	
Δ PPCDAm	1.006***			Conservation
	(0.313)			
Δ BLA x PPCDAm	-0.042***			
	(0.012)			
Δ Priority list		0.090***		
		(0.029)		
Δ Soy moratorium			0.991***	
			(0.314)	
Δ BLA x Soy moratorium			-0.065***	
			(0.012)	
Constant	0.002	0.002	0.004	
	(0.028)	(0.028)	(0.028)	
Time trends	Yes	Yes	Yes	
Observations	13,509	13,509	13,509	
R^2	0.270	0.270	0.271	
Adjusted R^2	0.269	0.269	0.270	

Note: The table reports first difference estimates with change in the log of average forestland price as dependent variable. Standard errors, clustered at district level, are reported in parentheses. *,**,*** denote significance at the 10/5/1% level, respectively. ♦refers to a rescaling of the coefficient by 100.

Annex II – Summary statistics

Variable	N	Mean	St. Dev.	Min	Max
Forestland Pr. ($R/ha)	17,472	500.083	456.938	8.703	2,787.234
Agr. Pr. index	17,338	2.099	1.019	0.115	5.746
Fuel Pr. ($R/lt)	17,436	1.201	0.136	0.926	1.846
Soy suitability (share)	17,472	0.276	0.320	0.000	1.000
Accessibility (hrs)	16,830	5.166	7.511	0.000	74.040
Tree cover (share)	17,472	0.435	0.297	0.000	1.000
Fines incidence (#)	17,472	0.0001	0.001	0.000	0.028
EIR (hrs)	16,830	-0.621	2.547	-57.456	0.000
PPCDAm	17,472	0.667	0.471	0	1
Priority list	17,472	0.012	0.110	0	1
Soy moratorium	17,472	0.500	0.500	0	1
Dummy BLA	17,472	0.468	0.499	0	1
Dummy Amazon	17,472	0.320	0.467	0	1
Dummy Cerrado	17,472	0.746	0.435	0	1