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Economic Causes of Deforestation in the Brazilian Amazon: A Panel Data Analysis for 2000s

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Economic Causes of Deforestation in the Brazilian Amazon: A Panel Data Analysis for 2000s

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Abstract: We use newly launched and some never-before analyzed datasets, to assess the recent economic and policy determinants of deforestation in the Brazilian Amazon. We estimate panel data models for the years between 2002 and 2007 for 368 municipalities in the region using municipality fixed effects and GMM. The results show that recent deforestation is driven by fluctuations in meat and soybean prices, it increases with rural credit availability, and with the size of rural reform settlements, while it decreases with protected areas. Moreover we find that higher presence of the Brazilian environmental police (IBAMA) was effective in reducing deforestation rates.

Key words: Deforestation; Amazon; Economic causes; Brazil

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1. Introduction

The Brazilian Amazon is the largest tropical forest on Earth, and its deforestation raises a wide range of environmental issues. Tropical forests play a crucial role in biodiversity preservation and provide essential ecosystem services to the indigenous populations; moreover, as important carbon sinks, they have been receiving an ever-growing attention in the fight against global warming. The conservation of the vast Brazilian Amazon forest is a major priority of the national environmental policy, but it is also a major concern from a global perspective. Improvements in the monitoring technology, and especially the availability of yearly satellite-based information on deforestation at a municipality scale, allow us to study the dynamics of recent deforestation episodes, which contributes to the understanding of how economic incentives and policy forces shape deforestation.

Deforestation of the Brazilian Amazon started in the mid 1960es as a state-driven process, fueled by large scale infrastructure and settlement projects as well as various fiscal incentives which induced yearly deforestation at a scale of around 10,000 square kilometers per year (see e.g., Andersen et al. 2002). The rural settlements policy (executed by INCRA, the National Agency for Land Reform), the building of national highways leading through the forest, or the provision of subsidized rural credits are all still a part of the governments' poverty alleviation program; at the same time all these policies have been argued to raise deforestation.[1] By contrast, some of the more recent government policies are explicitly aimed at forest conservation, like the designation of protected areas[2] and the

[1]Pacheco (2009) and Ludewigs et al (2009) describe INCRA's land redistribution activities and their heterogeneous effects on deforestation; among others, Andersen (1996), Barreto et al. (2008) and Prates (2008) document the strong correlation in the availability of rural credit and deforestation rates. The effects of road building projects have been more controversial: While Andersen et al. (2002) and Weinhold and Reis (2008) find that road building might even have reduced deforestation in some regions by increasing the profitability of alternative activities, these effects are refuted by other studies, based on a considerably finer geographic scale (see e.g. Pfaff et al. 2007).

[2] See on the success of protected areas in forest conservation Fearnside (2003) and Nepstad et al. (2006).

activities of the environmental police (IBAMA, the Brazilian Institute of Environment and Renewable Natural Resources) fighting illegal deforestation.

Starting with the 1980es, deforestation dynamics became also more closely linked to market forces, with cattle ranching and soybean cropping being among its central determinants (see e.g., Andersen 1996). During the 2000s deforestation rates became closely correlated with the prices of these two commodities, both in spatial (Arima et al. 2007), and in time dimension (Ewers et al. 2008, Barreto et al. 2008). This relationship has received major attention with the national and international press, NGOs, as well as the academic community (see e.g., The Economist 2008, Kaimowitz et al. 2004, Nepstad et al. 2006b).[3] Several studies documented that the expansion of cattle ranching basically coincides with the *deforestation arch*, and that deforestation is highly correlated with it (e.g. Andersen and Reis 1997, Margulis 2003).

A large part of the earlier economic literature on deforestation of the Brazilian Amazon explains deforestation during its first, predominantly state driven period; it uses mainly state- or municipality-level data derived from agricultural censuses (e.g. Pfaff 1999, Andersen 1996, Andersen et al. 2002). These studies emphasize among others, the role of population pressure, roads (see e.g., Andersen 1996, Pfaff 1999), and cattle herd (Reis and Guzman 1992, Andersen and Reis 1997).[4] Newer literature addresses determinants of deforestation often at a much finer scale (involving census-tract or satellite pixel data), but incorporates mostly only cross-sectional aspects of it (e.g. Arima et al. 2007 and Pfaff et al. 2007), leaving the recent time patterns of deforestation unexplored.[5]

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[3] Soybean cropping and cattle ranching have expanded significantly in the region during the last 15 years. The region's cattle herd, for example, almost tripled from 26 million in 1995 to 73 million in 2006 (Barreto et al. 2008).

[4] Kaimowitz and Angelsen (1998) provide a thorough review of earlier deforestation studies and their methodologies.

[5] Prates (2008) who uses a short panel from 2000 to 2004 is an exception; he finds that product prices and credit availability fuel deforestation.

Our study deviates from the existing literature by investigating municipal level determinants of yearly fluctuations in deforestation of the Brazilian Amazon from 2002 to 2007. We focus hereby on economic and policy drivers that influence the expected profitability of different land use methods and therefore affect agents' decisions concerning land use choices. In particular, we explore the effects of meat and soybean price variations, the role of local availability of subsidized rural credit, and of the local presence of the environmental police (IBAMA).

During this period deforestation rates have been above historical levels (cf. Figure 1). More important than that however, is the fact that within this relatively short period, deforestation rates have fluctuated significantly. Deforestation peaked in 2004 with a forest loss of almost 32,000 square kilometers, and decreased sharply after that. This time-pattern closely resembles the fluctuations in meat and soybean prices (cf. Figure 1), which have been made responsible for the fluctuations in deforestation rates (see above). However, econometric evidence on this hypothesis is scarce.[6] A second, not yet empirically tested, claim is that the dramatic increase in the monitoring and fining activity of the environmental police (IBAMA), which is the enforcement agency of the Brazilian Ministry of the Environment, has effectively contributed to the decrease in deforestation over the period.[7] The econometric analysis of these issues constitutes the main contribution of our study.

We analyze the determinants of this most recent period of deforestation by estimating panel data models with municipality fixed effects. We use the large within-municipality variation of economic and policy variables to identify their effects on deforestation, while controlling for the time invariant differences between municipalities (like climate,

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[6] State-level analyses of deforestation dynamics for earlier periods do not find an effect of agricultural prices on deforestation (see Araujo et al. 2009 for cattle prices over 1988-2000, and Ferraz 2001, for agricultural product prices over 1980-1998).

[7] Barreto et al. (2009) make a first attempt to assess the role of the environmental police by outlining how high deforestation rates could have been in 2008 without the measures taken by IBAMA.

remoteness, economic structure, etc.). By including state specific time effects we also allow for general deforestation dynamics to vary differently across states with time. Since we are concerned about the endogeneity of two policy measures, credit availability, and the presence of environmental police, we also estimate difference GMM models, where credit availability and the intensity of environmental fines are treated as endogenous and instrumented within the model.

The main results show that deforestation rates, during this period, were strongly affected by the evolution of the main economic and policy variables studied. Increases in meat and soybean prices, and in the availability of official rural credit are associated with increases in the deforestation rates in the Brazilian Amazon. This supports the claims made by media and many non-econometric studies (see above). The biggest novelty brought by this study is the empirical evidence showing that the environmental fines at the municipality level had a statistically significant effect in decreasing the deforestation rates during the studied period. We also find evidence on spatial spillover effects of both fines and credit availability on the deforestation of neighboring municipalities.

The remaining of this paper is organized as follows. The next section presents some theoretical concepts underlying our empirical study and our main hypotheses. Section 3 describes the data and the empirical models. Section 4 presents the results, while the last section concludes with policy implications and scope for future research.

2. Main hypotheses

Because of incomplete property rights regulation, large parts of the Brazilian Amazon forest can be still considered as open access. The land statute of 1964 (which served as a basis for land reform) allows settlers to use undeveloped public land which can become private property after five years of continuous use (cf. Araujo 2009). For a small open economy with open access, the theoretical model of Angelsen (1999) predicts that deforestation size depends positively on the expected difference between profits of unsustainable land uses (logging followed by deforestation and agriculture or cattle ranching) and sustainable land uses. The larger the differential, the larger deforestation is expected to be.

Although we recognize that what matters for clearing is the difference between the rents from sustainable and unsustainable land use, the former would be hard to quantify due to its complex and still incipient role in the region. We thus make the reasonable assumption that rents from sustainable land use are time invariant and therefore can be captured within the time-constant municipality-fixed effects. Instead, we focus on the determinants of profitability of unsustainable land use.[8]

Expected revenues of unsustainable land use are directly determined by market prices of agricultural goods, agents' market access and other municipality specific conditions. Its costs are determined by the direct costs of clearing, the expected agricultural and cattle ranching costs, credit availability and the risk of being fined by the environmental police. Agents maximize the expected profits from land use by choosing a level of clearing activity that will be implemented in the next period, taking into consideration prices and other constraints. The drivers of expected profits can thus be divided into three groups: market conditions, policy influence and natural or initial conditions.

We hypothesize that market conditions in the Amazon should be well captured by local meat and soybean prices. If prices of meat and soybean increase, there should be an upward pressure on deforestation. Better market access and thus lower transport costs result in higher prices paid at a farm-gate level which lead to higher expected profitability and should increase deforestation as well.

Concerning the economic policies, larger availability of official subsidized credit should fuel deforestation, by making the clearing plans resulting from increasing expected profits possible. Environmental fines constitute a risk factor for clearing. IBAMA administers a law

[8] Another reason to exclude sustainable use is that most of the services provided by forests have public goods' characteristics and therefore are mostly ignored by individual deciding on land clearing (Angelsen 1999).

prescribing that properties in the Amazon retain 80% of their area in forest, violation of which policy might result in environmental fines. Given any expected profitability, a positive chance that an agent could be fined for illegal clearing has a negative effect on his expected profitability. As a result higher fines intensity should lead to lower deforestation rates. The effect of expected environmental fines might be partly mitigated if forest conservation and hence "nonproductive use" also increases the likelihood of expropriation (which is the case according to INCRA's policies, see Alston, Libecap and Mueller 2000). Lastly, protected areas should work as a barrier to deforestation whereas the existence of agrarian rural reform settlements in one municipality is hypothesized to fuel clearing.

Deforestation should also be influenced by geoclimatic factors, especially rainfall. There are two possible theoretical links between rainfall and profitability. First, the higher rainfall rates, the more difficult it is to construct and conserve roads, which increases transport costs. More indirectly, higher precipitation (after a certain threshold) leads to lower productivity for both cattle ranching and soybean cropping (Arima et al. 2007). Finally, we also expect to see scale effects, deforestation increasing in absolute terms with forest size.

3. Data and empirical approach

3.1. Data and controls

Our data set consists of yearly observations for 368 municipalities in the Brazilian Amazon for the time period of 2002 to 2007. The data on municipal deforestation comes from satellite based information of the Prodes project of the Brazilian Space Research Institute (INPE); it measures forest cover as well as newly deforested areas in square kilometers over a given year Deforestation is reported from September of the previous year to August of the current year; hence we measure all economic variables (prices, credit) within the same time window. All economic variables were deflated by IPCA – the official Brazilian consumer price index.[9] Summary statistics are presented in Table 1.

Local meat prices are constructed by interacting the national average of beef prices received by cattle ranchers in Brazil (from Anualpec 2009)[10] with a meat price index based on Arima et al. (2007), who captured spatial variability of meat prices in 2001.[11] This variable thus should essentially reflect yearly fluctuations in beef prices as well as the difference in transport costs from each municipality to the main consumer markets, and also local market conditions.

For soybeans we use Fundação Getúlio Varga's (FGV) monthly average prices received by farmers for the 60kg bag. Soy prices are only reported where soybean production actually takes place (in the Southern and South Eastern parts of the Brazilian Amazon). Thus, we use two different measures of soybean prices. First, we include yearly national average soybean prices; they capture the average effects of soybean price fluctuations, not only in producing regions but also the indirect effects of expanding soybean production on the deforestation frontier. Second, in some of the regressions we additionally include regional soybean prices after imputing zero prices for all regions where production of soybean is not possible due to climatic factors. This second variable measures the additional direct effect of soybean prices on deforestation of soybean producing regions only.

Availability of official subsidized rural credit was obtained from the Rural Credit Annual Report of the Brazilian Central Bank. We measure relative credit density by the natural logarithm of credit value (in 1000 $R) per square kilometer of municipality area. The

[9]The non-existence of regional price deflators for the Amazon region forced us to use the national CPI. Results are robust to different choices of the price deflator (e.g. wholesale price index or even the use of nominal data).

[10]Beef prices refer to 15kg of Boi Gordo, and are adjusted to the August-September time window.

[11]The original measure of Arima et al. (2007) was calculated based on field interviews that assessed prices paid at slaughterhouses all over the region. These prices were then recalculated net of the pixel-wise estimated average transport costs which resulted in farm-gate level meat prices. We readjusted their pixel based measure to municipal base, and use it to proxy the variability of prices paid across Amazonian municipalities, assuming constancy of relative differences in transport costs over the study period. Thus, we are unable to assess the differential effect of road building that would change regional beef price differences.

figures reflect the annual flow of agricultural credit granted to rural properties in each municipality within the official rural credit system. These credits are highly subsidized and target agricultural activities (Fearnside 2005), which might also include (direct or indirect) conversion of forest into pasture or cropland. Thus, credit availability results from the interactions of credit supply and demand and hence might partly reflect planned deforestation activities.

Data on environmental fines were obtained from the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA). We calculate the intensity of the activity of the environmental police by dividing the number of fines issued within a municipality by deforestation observed in the period. As only a minor part of the fines are actually paid (around 5% according to Barreto et al. 2008), we believe this measure proxies better the intensity of IBAMA presence in each municipality. We impute zero fines in 25% of cases as no fines were reported in those municipalities.[12] Due to the potential underreporting involved in this procedure, we might underestimate the effects of the activity of environmental police in these villages; nonetheless, we believe that this is a meaningful assumption as these villages have on average around 5.5 times lower levels of deforestation than those reporting fines. The inclusion of average neighboring fines intensity might partly correct for these measurement errors.

The percentage of the municipality area under official environmental protection such as National Parks or Indigenous Areas was obtained from IMAZON (Amazon Institute of People and the Environment). Official protection encompasses different types of legal protection, notably integral protection, sustainable use and indigenous areas, which have been argued to significantly inhibit deforestation (see e.g. Nepstad et al 2006a). A similar proxy is made for settlement areas, the share of municipality area that is under an agrarian reform project by INCRA, the Brazilian Agency of Agrarian Reform. This latter variable is

[12] Complete lack of data on fines makes us to exclude all municipalities in the state of Maranhao. As we measure fines intensity in natural logarithms, we transform fines intensity f to take the form of $ln(1+f)$.

time-invariant and measures the area of agrarian reform settlement projects by municipality for 2008 (Source: IMAZON).

As deforestation is a spatially strongly correlated process, in some specifications we try to capture this spatial dimension by including neighborhood controls. Specifically, we control for the deforestation rates across neighboring regions which is measured as the share of overall forest cover deforested within the same period within the neighboring municipalities. Due to their geographic/climatic proximity and the relative similarity in their economic structure, neighborhood deforestation rates are also likely to capture some of the time-variant unobservable effects driving local deforestation. Additionally, we include measures of neighborhood credit availability and neighborhood presence of the environmental polices (both defined the same way as the variables for the municipality itself). These latter two neighborhood variables might serve two purposes: first, they can partly capture the effects of credit and environmental fines within the own municipality if these variables are measured with error and spatially correlated; second, they can capture genuine spillover effects. For instance, if the financial infrastructure is less developed at the deforestation frontier, credit from neighboring municipalities will be used to finance deforestation at the frontier. Similarly, if higher presence of the environmental police in the neighborhood is perceived as increasing the risk of getting fined in the given municipality, we should find deforestation to be decreasing not only with fining activity not only within the own municipality but also within the neighborhood.

Further geoclimatic factors can also be expected to affect the probability of fire and hence deforestation (see e.g., Kirby et al 2006, Arima et al. 2007, Aguiar et al. 2007), thus, we construct a proxy for rainfall variation across space and time by building a rainfall index. The index measures spatial variation in rainfall across the different municipalities based on data from 2005-2006, we standardize it and interact with the annual fluctuations from

2002 to 2007 that affected the region as a whole.[13] This rainfall index offers a rather crude proxy of rainfall variation and we hope to be able to improve its precision in the future.

3.2. Empirical strategy

3.2.1. Linear panel data models

Our analysis of deforestation concentrates on the Brazilian Amazon rainforest and thus, unlike many other studies on the Brazilian Legal Amazon, it excludes some areas with little forest cover remaining as well as tropical savanna (cerrado).[14] In studies including areas with extremely low levels of forest, low deforestation can occur due to two reasons: first there are factors that keep the forest standing; second, there is no (or almost no) forest to be cleared. To reduce this latter problem we analyze only areas with at least 10% of forest cover in 2002. Thus, we explain deforestation dynamics where there is actually forest,[15] eliminating a large part of not forested municipalities that follow a different environmental, economic and social dynamic.[16]

Identification of the effects of economic and policy variables on deforestation comes from the municipality panel structure of the data, and in particular from the large variation of the explanatory variables over time and over space. Municipality fixed effects (α_i) control for the regional variation and capture the presence of time-constant municipality specific unobservables. The inclusion of state specific time variables (λ_{st}) controls for aggregate

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[13] The fluctuations across space were estimated based on year rainfall observed in each municipality from 2005 to 2007 (Source: IMAZON). The yearly variation is based on data provided by INMET, and measures the average yearly rainfall of 10 of stations distributed all over the region.

[14] Cerrado areas were never forested by Amazon forest, and their deforestation is not reported by INPE.

[15]This corresponds to 484 municipalities out of the 783 cities of the Legal Amazon; availability of control variables (notably environmental fines) further restricts the sample to 368 municipalities. Results are robust to the selection of the threshold, although the inclusion of regions with almost no forest considerably worsens the fit of the data.

[16] With the 10% filter, for example, we eliminate a large part of the municipalities of the States of Mato Grosso (45%), Maranhao (48%), and Tocantins (78%), but only a small part of Acre and Amapá (0%), Amazonas (2%), Roraima (13%), Rondônia (2%), Pará (38%). Maranhao is excluded from the final analysis since data for environmental fines are completely unavailable.

time trends in deforestation dynamics which are allowed to differ across the eight states (Acre, Amapa, Amazonas, Mato Grosso, Para, Rondonia, Roraima, and Tocantis). These state specific time effects take the form of either a distinct time trend for each state or state-time fixed effects.

The main specification of the municipal panel takes the following form:

$$lnD_{it} = X_{it,t-1}'\beta + \lambda_{st} + \alpha_i + \varepsilon_{it} \quad (1)$$

where the dependent variable, lnD_{it}, denotes the natural logarithm of the yearly level of deforestation at the end of year t in municipality i.[17] The vector of controls $X_{it,t-1}$ includes lagged forest size, lagged meat prices, national soybean prices and regional soybean prices for producing regions, the log of credit value per area (1000km), the log of fines intensity (number of fines per deforested area), the log of the size of protected and settlement areas (sq kms), neighborhood variables (deforestation rates, credit and fines), and a rainfall index. Standard errors are clustered at the municipality level and are robust to autocorrelation and heteroskedasticity.

We estimate equation (1) using fixed effect panel data models, which identify the effects of explanatory variables based on within-municipality variation. Thus, they do not capture the total effects of specific policies or economic variables, only the effects of within district variation of these variables over time.[18] One reason for concern remains if municipality specific differences in deforestation dynamics are driven by unobservables that also affect some of the explanatory factors.

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[17] Alternative specifications treating the rate of deforestation as dependent variable yielded comparable results, and are not reported.

[18] As a comparison, we also present random effects (RE) estimates, which assume that the overall effect of omitted variables ($\alpha_i + \varepsilon_{it}$) is randomly distributed over time and municipalities and therefore uncorrelated with other explanatory variables. Hausman tests indicate that coefficient estimates are statistically different under the random and fixed effects assumptions, which leads us to prefer the consistent though less efficient FE estimates.

3.2.2. Endogeneity concerns and estimation by the General Method of Moments

We are concerned about the fact that some of the policy variables, especially credit availability and fines intensity, might endogenously respond to deforestation, which could bias our estimated coefficients. The value of subsidized agricultural credit granted to producers in a municipality does not only reflect the volume of official credit supply, arising from the regional development policy; instead, it results from the interplay of the supply of and the demand for subsidized credit. If demand for subsidized credit increases with prospective deforestation activities, this would bias the coefficients on credit availability upwards and lead us to overestimating the increase in deforestation that is due to credit availability.

Similar rational could be applied for the strictness of the environmental police (in giving out fines) responding to current deforestation activities. The activities of IBAMA should be ideally concentrated in municipalities where deforestation is the highest, which would lead to a positive correlation between environmental fines and deforestation. But the intensity of fining activity (and hence the chances of getting fined) per deforested area could also be lower in high-deforestation areas if the environmental police strives for a wide geographic coverage, but operates under resource constraints.

Ideally, we would like to find exogenous instruments for both local financial depth and the presence of the environmental police; this is left for future versions of this paper. In order to assess the potential endogeneity biases, we re-estimate a slightly leaner model than the baseline specification by applying an Arellano-Bond (1991) difference GMM estimator, with a two-step Windmeijer (2005) correction. This allows us to consider both local rural credit and environmental fines as endogenous within the model, and instrument their first differences with past levels of all variables in a GMM style.

Thus we estimate the following equation:

$$\Delta lnD_{it} = \Delta X'_{it}\beta + \Delta \lambda_{st} + \Delta \varepsilon_{it}, \quad (2)$$

where the growth rate of deforestation $lnD_{it} - lnD_{it-1}$ is explained by changes in the vector of control variables.

We treat local rural credit, environmental fines, but also protected areas as endogenous, past forest size and lagged meat prices as predetermined with respect to deforestation (and hence not influenced by current deforestation), and the state year effects, national soy prices and rainfall as exogenous, these latter three are thus used as instruments for all endogenous variables.

4. Results

Results from random and fixed effect models are presented in Table2; columns 4 to 6 present our preferred specifications with municipality fixed effects. The reported specifications differ with respect to the functional form of the state-wise time effects (with stat-specific trends included in columns 2 and 5 and state-year fixed effects in columns 3 and 6).

The overall results confirm most of our expectations. As the main driver of the expected profitability of unsustainable land use, increases in meat price in one year are associated with increases in deforestation rates in the following year, 10R$ increase in meat prices leading up to 0.9% more deforestation. A 10R$ increase in soybean prices is associated with around 0.25% increase in deforestation rates in the same year over all municipalities, these price effects turning out somewhat larger in soybean producing areas. Also not surprisingly, coefficients on soy are considerably less than those on meat price, which reflects the relatively larger role of cattle ranching across the whole area. For credit, larger credit volumes are associated with higher deforestation rates, with an elasticity of around 0.2-0.3%. Fines are robustly related to deforestation; increases in fines intensity are associated with decreases in deforestation rates with an elasticity of about -0.5%.

Exchanging the state specific trends to state-year fixed effects makes the price variables insignificant in fixed effects specifications (column 6) although not in random effects specifications (column 3). The reason for this is that fixed effect specifications measure the effects of price variations mainly along the time dimension; including state-specific year fixed effects gauges exactly this type of variation. By contrast, credit availability and fines intensity are less sensitive to the specification of state-year effects.

Deforestation is also increasing with forest size; protected areas seem to represent a barrier to deforestation, while the existence of agrarian reform settlement areas is linked to higher deforestation rates (only in random effects models). We do not find robust evidence on the association of rainfall with deforestation rates over time. Rain is only significantly reducing deforestation in random effects specifications, which shows that the effects of rainfall reducing deforestation might be much more pronounced across space then time. However, this result might also be due to data quality as our rain index offers only a crude proxy for precipitation at the local level.

Table 3 presents the specifications including neighborhood effects which confirm the presence of strong spatial effects in deforestation. An increase of neighboring deforestation rates by 1 percentage point is associated with an increase in own deforestation rates by around 0.1%. Including these neighborhood effects reduces all other coefficient estimates; as neighboring municipalities most likely underlie to similar economic and political dynamics, this is to be expected since neighboring deforestation is induced by the same fluctuations in market prices and policies. The effects of neighboring credit turn out even more significant than those from local credit. This is not surprising as municipalities at the deforestation frontier are often less developed, and subsidized credit might be thus originating from the nearest source. Finally, neighboring fines intensity has also an additional negative effect on deforestation. As discussed before, this might partly correct for measurement errors in police presence but it might also capture spatial spillovers in deterrence intensity on the perceived risk of getting fined.

Table 4 presents difference GMM results, which mostly support our previous findings. Both presented models include state-year fixed effects, with column (1) presenting a lean baseline specification while column (2) also including neighborhood controls, all of which are also treated as endogenous and instrumented within the model. The effects of meat prices stay very similar to those before, while soy prices lose significance [and even turn sign]. The two policy variables we were concerned about, the measure of credit availability and of fines intensity both remain highly significant and do not change in magnitude. Municipalities that were experiencing larger increases in credit, experience larger increases in deforestation; the converse holds through to the role of environmental fines. The effects of neighboring deforestation rates also remain relatively stable, but neighboring credit and fines intensity lose significance when instrumented. This might point to the fact that these two neighborhood variables were actually more strongly proxying for mismeasured local effects, and make us more cautious to interpret these as neighborhood spillover effects of the policies themselves.

6. Discussion

This study analyzed the current determinants of deforestation of the Brazilian Amazon. Using a panel data of 368 municipalities of the Brazilian Legal Amazon from 2002 to 2007 it investigated how changes in major economic and policy variables affected the observed fluctuations in deforestation rates during the period.

This study advances beyond previous studies in several aspects for the discussion about today's determinants of deforestation. Firstly, in terms of data, it uses recently launched panel data of deforestation of the 2000s at municipal level. It also uses some data that has not been deeply or properly analyzed in econometric papers, such as municipal credit or commodity prices, and even some that has never been used, such as municipal environmental fines. Secondly, it focuses on the economic and policy decision parameters that affect agents' deforestation decisions rather than on direct causes of clearing. Therefore it studies how the incentive structure for deforestation works. A third aspect is that this study innovates by excluding from the analysis areas that were never forest or that are almost completely deforested in order to better assess the recent deforestation drivers.

Our major empirical finding is the significance of all of the most important economic variables (meat and soybean prices) and policy variables (rural credit and environmental fines) studied as drivers of the fluctuations of deforestation rates during the period analyzed. Changes in these variables are responsible for changes in the expected profitability of future land use and therefore in the incentives for deforestation. By showing empirically that the fluctuation of these variables drive the ups and downs of deforestation rates, we see that deforestation decisions are taken rationally by agents who are comparing expected profitability of different land use methods. More specifically, higher meat and soybean prices, as well as higher availability of official subsidized rural credit, are associated with higher deforestation rates. Higher issuing of environmental fines is associated with lower deforestation rates. The existence of rural reform settlement areas is related to larger deforestation, whereas the presence of protected areas represents a barrier to deforestation. Additionally, larger forest size and neighborhood deforestation are associated with higher deforestation rates.

There are a wide range of policy implications related to this study's findings. The most important of them is that the deforestation of the region is now an endogenous economic process driven by rational economic decisions made by agents that live in the region. Therefore the focus of new policies should be to modify the economic incentive structure that agents face by changing the expected profits of different land use methods (sustainable versus unsustainable).

One more specific implication is that commodity prices, and also commodity future prices, should be taken seriously in consideration for policy design, for deforestation forecasts and also for evaluation of implemented policies. For example, the Brazilian government has openly claimed that the new plan to combat illegal deforestation has alone driven the decrease of deforestation rates from 2005 to 2007. This study shows that although the greater issuing of fines played an important role, the decrease in meat and soybean prices also contributed toward it.

The evidence about the effectiveness of the environmental fines is probably the most innovative result of this study. Being aware of it, policy makers should intensify the combat against illegal deforestation. More studies are, however, necessary in order to understand in detail where, when and under which conditions this combat is more effective and, therefore, how it should be focused.

Another major implication is that the credit granting rules and practices for farmers should be reviewed so that credit is only granted to those agents who respect the environmental legislation. Additionally the Brazilian government should re-think its strategy of establishing rural settlements in forested areas, and also consider the possibility of using already deforested areas.[19]

The next natural extension of this study involves dealing better with the potential endogeneity of credit size and fines by searching for suitable instruments for credit supply and the spatial distribution of the activity of the environmental police. Furthermore, we are planning to perform more extensive tests to assess the sensitivity of these results to some of our variable encoding procedures.

Combining econometrics and field research is also needed. Interviews with deforestation agents could contribute to the understanding of what kind of information do agents have access to and what part of this information is more important to them for their clearing decisions. This could also improve the understanding of the timing of the decision of clearing, its execution, and the beginning of an economic activity (such as cattle ranching). Ultimately the goal is to find out when the deforestation decision is made and which variables are most important in an agents' decision making process. After knowing that, new policies can be more efficiently designed to change the economic incentive structure to foster a more sustainable use of the Amazon region.

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[19] In line with this but not as a direct implication of our results, there is an urgent need for the implementation of "Zonemento ecológilo econômico" (Economic Ecological Land Use Planning) to promote a more sustainable and rational use of the forest.

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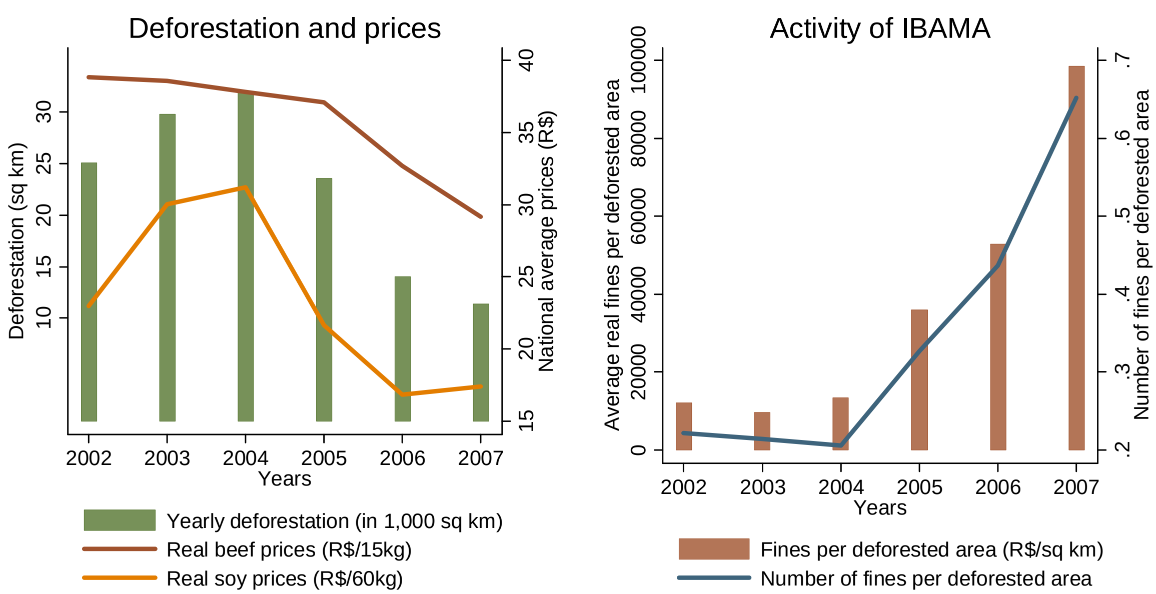
Appendix A. Figures

Figure 1. Deforestation of the Brazilian Amazon, average price movements and the activities of the environmental police (IBAMA) (2002—2007)



Source: Own calculations based on data from INPE, Anualpec, FGV and IBAMA.

Appendix B. Tables

Table 1: Summary statistics

	Mean	St. dev	Min.	Max.
ln Deforestation	2.864	1.617	0	7.248
ln Forest *(t-1)*	7.506	1.799	3.153	11.92
Meat price *(t-1)*	33.71	6.881	2.480	44.98
National soy price	23.30	6.108	16.86	31.22
Regional soy price	5.086	8.642	0	55.47
ln Credit per area	0.594	0.583	$3X10^{-5}$	3.360
ln Fines intensity	0.430	0.674	0	6.330
ln Protected areas	4.752	3.687	0	11.66
ln Settlement areas	4.436	2.736	0	9.291
Neighboring deforestation rates	1.872	2.321	0	20.62
ln Neighboring credit per area	0.567	0.499	0	2.788
ln Neighboring fines intensity	0.465	0.582	0	5.248
Rainfall index	0.177	1.138	-0.516	12.02

Note: Statistics refer to N=1744 observations (on 368 municipalities).

Table 2: Determinants of deforestation: Main panel data results

	Dependent: *ln* Deforestation					
	(1)	(2)	(3)	(4)	(5)	(6)
	RE	RE	RE	FE	FE	FE
ln Forest *(t-1)*	0.6074**	0.7307**	0.7091**	1.8965**	2.5282**	2.5616**
	(0.0392)	(0.0453)	(0.0458)	(0.3475)	(0.3497)	(0.3783)
Meat price *(t-1)*	0.0534**	0.0646**	0.0407**	0.0510**	0.0985**	0.0386
	(0.0052)	(0.0076)	(0.0088)	(0.0065)	(0.0120)	(0.0277)
National soy price	0.0122**	0.0216**	0.0123**	0.0053	0.0253**	0.0275
	(0.0033)	(0.0055)	(0.0086)	(0.0039)	(0.0057)	(0.0153)
Regional soy price	0.0163**	0.0145**	0.0027	0.0156**	0.0064*	0.0043
	(0.0033)	(0.0032)	(0.0031)	(0.0035)	(0.0032)	(0.0032)
ln Credit per area	0.3093**	0.3053**	0.1762†	0.3467**	0.2750**	0.2939**
	(0.0724)	(0.0745)	(0.0707)	(0.0840)	(0.0779)	(0.0742)
ln Fines intensity	-0.5896**	-0.5943**	-0.4652**	-0.5800**	-0.5717**	-0.4542**
	(0.0389)	(0.0381)	(0.0365)	(0.0424)	(0.0421)	(0.0421)
ln Protected areas	-0.0585**	-0.0699**	-0.0566**	-0.0626**	-0.0738**	-0.0471†
	(0.0143)	(0.0151)	(0.0145)	(0.0230)	(0.0244)	(0.0275)
ln Settlement areas	0.2411**	0.2275**	0.2018**			
	(0.0196)	(0.0210)	(0.0202)			
Rainfall index	-0.0232	-0.0455	-0.0857*	0.0831†	0.0576	-0.0195
	(0.0371)	(0.0362)	(0.0394)	(0.0433)	(0.0587)	(0.0470)
State-specific linear time trend	No	Yes	No	No	Yes	No
State-year fixed effects	No	No	Yes	No	No	Yes
R-squared	0.598	0.620	0.694	0.480	0.528	0.597

Note: †significant at 10%, *significant at 5%, **significant at 1%. Number of observations is 1744, number of municipalities is 368. Robust standard errors, clustered at municipality level, are reported in parentheses.

Table 3: Determinants of deforestation: Panel data results with neighborhood effects

	Dependent: *ln* Deforestation					
	(1)	(2)	(3)	(4)	(5)	(6)
	RE	RE	RE	FE	FE	FE
ln Forest *(t-1)*	0.6709**	0.7723**	0.7117**	1.1745**	1.7642**	1.8564**
	(0.0382)	(0.0418)	(0.0435)	(0.3664)	(0.3687)	(0.3936)
Meat price *(t-1)*	0.0283**	0.0358**	0.0347**	0.0232**	0.0406**	0.0222
	(0.0050)	(0.0070)	(0.0085)	(0.0060)	(0.0118)	(0.0258)
National soy price	0.0076**	0.0110*	0.0105**	0.0069†	0.0124*	0.0110
	(0.0031)	(0.0052)	(0.0085)	(0.0037)	(0.0056)	(0.0150)
Regional soy price	0.0097**	0.0088**	0.0035	0.0090**	0.0034	0.0042
	(0.0029)	(0.0028)	(0.0028)	(0.0031)	(0.0030)	(0.0029)
ln Credit per area	0.1643*	0.1845	0.1127†	0.1921**	0.2149**	0.2047**
	(0.0714)	(0.0695)	(0.0679)	(0.0807)	(0.0735)	(0.0710)
ln Fines intensity	-0.4671**	-0.4666**	-0.4157**	-0.4718**	-0.4679**	-0.4166**
	(0.0369)	(0.0355)	(0.0358)	(0.0396)	(0.0386)	(0.0396)
ln Protected areas	-0.0502**	-0.0591**	-0.0447**	-0.0597**	-0.0566**	-0.0396
	(0.0130)	(0.0138)	(0.0136)	(0.0201)	(0.0216)	(0.0235)
ln Settlement areas	0.2108**	0.1904**	0.1749**			
	(0.0183)	(0.0191)	(0.0189)			
Neighboring deforestation rates	0.1305**	0.1281**	0.1415**	0.1217**	0.1124**	0.1240**
	(0.0141)	(0.0145)	(0.0151)	(0.0145)	(0.0145)	(0.0159)
ln Neighboring credit per area	0.3801*	0.3220*	0.0262	0.5772**	0.4252*	0.3306†
	(0.1294)	(0.1257)	(0.1149)	(0.1913)	(0.1765)	(0.1740)
ln Neighboring fines intensity	-0.2975**	-0.3104**	-0.2147**	-0.3068**	-0.3387**	-0.2297**
	(0.0443)	(0.0440)	(0.0481)	(0.0471)	(0.0443)	(0.0509)
Rainfall index	-0.0882*	-0.0964**	-0.0857*	0.0122	0.0318	0.0364
	(0.0375)	(0.0361)	(0.0394)	(0.0397)	(0.0587)	(0.0453)
State-specific linear time trend	No	Yes	No	No	Yes	No
State-year fixed effects	No	No	Yes	No	No	Yes
R-squared	0.647	0.667	0.715	0.582	0.611	0.648

Note: †significant at 10%, *significant at 5%, **significant at 1%. Number of observations is 1744, number of municipalities is 368. Robust standard errors, clustered at municipality level, are reported in parentheses.

Table 4: Determinants of deforestation: GMM results

	Dependent: ln Deforestation	
	(1)	(2)
	GMM	GMM
Forest *(t-1)*	0.3511†	0.2168
	(0.1912)	(0.1507)
Meat price *(t-1)*	0.0850**	0.0516†
	(0.0296)	(0.0292)
National soy price	-0.8563	-0.1300
	(0.5276)	(0.4967)
ln Credit per area	0.7815**	0.4366**
	(0.2312)	(0.1986)
ln Fines intensity	-0.3046*	-0.3901**
	(0.1372)	(0.0876)
Neighboring deforestation rates		0.1470**
		(0.0228)
ln Neighboring credit per area		0.4890
		(0.3111)
ln Neighboring fines intensity		-0.1826
		(0.1438)
Rainfall index	0.0908	0.0189
	(0.0709)	(0.0561)
State-year fixed effects	Yes	Yes
Sargan test on overid. restrictions (p-value)	0.235	0.500
Hansen test on overid. restrictions (p-value)	0.321	0.705
R-squared	0.620	0.667

Note: †significant at 10%, *significant at 5%, **significant at 1%. Number of observations is 1360, number of municipalities is 355. The GMM model is estimated in first differences. Robust standard errors, clustered at municipality level, are reported in parentheses.