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(Deter)ring Deforestation in the Brazilian Amazon: Environmental Monitoring and Law Enforcement

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Abstract

This paper evaluates the impact of environmental police presence on Amazon deforestation using data from DETER, a remote sensing-based system for the detection of deforestation that serves as a key tool for the targeting of law enforcement activities. DETER cloud coverage is shown to be systematically correlated with the number of fines applied by the environmental authority. DETER cloud coverage is therefore used as a source of exogenous variation in monitoring at the municipality level, serving as an instrument for the number of fines to evaluate the effect of monitoring on deforestation. Results show that the observed deforestation in the Amazon in the 2007 through 2011 period was 73% smaller than would have been in the absence of fines. There is no evidence of an adverse effect on agricultural production.

Keywords: deforestation, conservation policies, enforcement, command and control
JEL codes: K42, Q18, Q23, Q58

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1. Introduction

The Amazon is the world's largest rainforest, stretching over an area of over 5 million square kilometers, or almost half of continental Europe. It holds unique biodiversity, 20% of the planet's fresh water, and substantial carbon stock (Ministério do Meio Ambiente, MMA (2012)). Protecting the Amazon from illegal deforestation and enforcing environmental regulation in the region is a challenge as immense as the forest itself. Evidence suggests that recent Brazilian conservation policies helped address this challenge. Amazon deforestation rates escalated in the early 2000s, but after peaking at over 27,000 square kilometers in 2004, decreased sharply to about 5,000 square kilometers in 2011 (INPE (2012)). Conservation policies introduced in the second half of the decade significantly contributed to this deforestation slowdown, avoiding substantial amounts of forest clearings and curbing deforestation during periods of rising agricultural commodity prices (Assunção et al. (2011)).

This paper evaluates the contribution of command and control policies to the 2000s Amazon deforestation slowdown. The Action Plan for the Prevention and Control of Deforestation in the Legal Amazon (*Plano de Ação para a Prevenção e o Controle do Desmatamento na Amazônia Legal*, PPCDAm) was the pivotal conservation policy effort of the mid-2000s. Launched in 2004, this tactical-operational plan integrated actions across different government institutions and introduced new procedures for monitoring, environmental control, and territorial management (Ipea et al. (2011), IPAM (2009), Assunção et al. (2011)).

One of the key changes introduced by the PPCDAm was the use of the Real Time System for Detection of Deforestation (*Detecção de Desmatamento em Tempo Real*, DETER). Developed by the National Institute for Space Research (*Instituto Nacional de Pesquisas Espaciais*, INPE), DETER is a satellite-based system that captures and processes georeferenced imagery on forest cover in 15-day intervals. These images are used to identify deforestation hot spots and issue alerts signaling areas in need of immediate attention. Law enforcement activities are then targeted based on these alerts. Prior to the activation of DETER, Amazon monitoring relied strictly on denouncements of threatened areas. With the adoption of the new remote sensing system, however, the Brazilian Institute for the Environment and Renewable Natural Resources (*Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis*, Ibama), which acts as the national environmental police and law enforcement authority, was able to better identify, more closely monitor, and more quickly act upon areas with illegal deforestation activity.

In addition to the use of DETER satellite data, the PPCDAm also promoted institutional changes that enhanced command and control capabilities in the Amazon. These changes resulted in an increase in the number and qualification of law enforcement personnel, brought greater regulatory stability to the investigation of environmental crimes

and application of sanctions, and established the legal basis for singling out municipalities with very high deforestation rates and taking differentiated action towards them. The new command and control framework introduced by the PPCDAm, which relied heavily on satellite data, therefore represents both an improvement in the targeting and an increase in the intensity of monitoring and law enforcement activities in the Amazon.

Were these policy efforts effective in containing forest clearings in the Amazon? How did they alter deforestation paths? Did they affect agricultural production? To answer these questions, we must first deal with a well-known endogeneity problem (Cameron (1988)). Although monitoring and law enforcement can determine the occurrence of illegal activities, the opposite can also be true. After all, it is rational to allocate law enforcers in areas where illegal activities are more prevalent. The literature has documented different methods for disentangling these two effects, particularly in a context of police force and crime. Examples include, but are not limited to, Levitt (1997), who identifies the causal effect of police on crime by using electoral cycles as an instrument for police presence, and Di Tella and Schargrodsky (2004) and Draca et al. (2011), who explore specific and sporadic events (such as a terrorism attack) as exogenous sources of variation in police presence.

Our analysis draws on this literature, using an exogenous source of variation for the allocation of Ibama resources and personnel to capture the impact of stricter monitoring and law enforcement on deforestation. As the satellite used in DETER is incapable of detecting land cover patterns in areas covered by clouds, no deforestation activity is identified in these areas and, thus, no alerts are issued. Monitoring personnel therefore have a lower probability of being allocated to such areas. Based on this, we derive an empirical strategy that uses average DETER cloud coverage for a municipality in a given period as an instrument for the intensity of law enforcement activity in that municipality, which is proxied by the total number of fines applied in the municipality.

The inclusion restriction for our instrument is validated by the finding that the number of fines varies systematically with cloud coverage, even after controlling for observables and fixed-effects. Yet, the fact that deforestation could be affected by rain - either positively or negatively - raises a concern about our exclusion restriction. Since rainfall is correlated with clouds, we use additional data on observed precipitation to control for rainfall, and thereby only consider cloud coverage that is orthogonal to rain in our estimation.

Another potential cause of concern is that PRODES, the satellite used to measure annual deforestation rates in the Amazon, is also sensitive to cloud coverage. This could be an issue for our empirical strategy, should PRODES cloud coverage be correlated with DETER cloud coverage. As we have cloud coverage data for both PRODES and DETER, we are able to tackle this issue. By controlling for PRODES cloud coverage, we estimate

results considering only DETER cloud coverage that is orthogonal to PRODES cloud coverage.

Typically, the police force and crime literature suffers from a tradeoff between identification and relevance, as circumstances that offer an empirical opportunity to explore the causal relationship are often very context-specific. This tends to force authors to resort to additional assumptions for the extrapolation of their results (Di Tella and Schargrodsky (2004), Draca et al. (2011)). Our novel strategy, however, allows us to identify a causal effect of environmental police (Ibama) presence on environmental crimes within an unrestricted empirical context. Indeed, by construction, the strategy uses information from all of the Amazon, ensuring that our estimates are computed based on data from the areas where the problem is actually relevant.

Our results show that a higher number of fines applied in a current year significantly reduces forest clearings the following year. In a counterfactual exercise, we estimate that the increased presence of Ibama in the Amazon helped avoid approximately 53,000 square kilometers of forest clearings from 2007 through 2011. Considering that observed deforestation in this period totaled 40,500 square kilometers, our estimates indicate that deforestation was 57% smaller than would have been in case policy did not change. In an analogous exercise, we estimate that in the complete absence of Ibama (as captured by the complete absence of fines), 109,000 square kilometers more forest would have been cleared from 2007 through 2011. The observed pattern was 73% smaller than the estimated counterfactual in the period. These results indicate that monitoring and law enforcement activities have a substantial deterrent effect on deforestation activity.

We perform a simple cost-benefit analysis, comparing Ibama's budget with the estimated monetary benefits of preserving forest areas and thereby avoiding carbon dioxide emissions. We calculate that, from 2007 through 2011, the avoided deforestation associated with increased Ibama presence is valued at an average of 4.02 billion USD per year. Compared with Ibama's average budget of 513 million USD per year during the same period, our estimation suggests that more stringent command and control policy yields significant gains – monetary benefits from increased preservation are over seven times greater than Ibama's cost of operation. These findings highlight the value of strategically using available information and technology, which allowed Ibama to achieve such impressive results having only 3,000 agents to cover an immense area.

Our first stage results, which show that DETER cloud coverage systematically affects the application of fines as punishment for environmental crimes, also yield important policy implications, underlining the importance of overcoming DETER's inability to see through clouds as a means to further strengthen the combating of deforestation.

We also investigate potential adverse effects of the command and control policies on agricultural production. Estimated coefficients suggest that more stringent monitoring

and law enforcement had no significant impact on regional agricultural GDP. Combined, our results show that command and control has played a crucial role in the the curbing of Amazon deforestation and containment of carbon dioxide emissions without adversely affecting agricultural production. This corroborates the argument that it is possible to protect the native forest without significantly interfering with local agricultural production.

Other studies have explored the relationship between income and forest preservation, but no consensus has been established in the literature. Cropper and Griffiths (1994) and Panayotou (1995) find no evidence of a significant relationship between the two, while Antle and Heidebrink (1995) documents a positive relationship between afforestation and income, but only when income is above a certain threshold. Foster and Rosenzweig (2003) finds no relationship between forest and economic growth in open economies, but a positive relationship in closed ones. From a more general perspective, our results contribute to the debate about economic growth and environment (Grossman and Krueger (1995), Arrow et al. (1996)).

This paper also speaks to the literature that evaluates effectiveness of environmental monitoring and law enforcement. Gray and Shimshack (2011) provides a recent survey of this literature. Most studies refer to plant-level environmental performance, as captured by standard emissions or accidental discharges (Earnhart and Segerson (2012), Gray and Shadbegian (2005), Shimshack and Ward (2005), Magat and Viscusi (1990), Epple and Visscher (1984), Anderson and Talley (1995), Eckert (2004)). Our paper addresses a different dimension of environmental monitoring and law enforcement, focusing on the impact of command and control policies on deforestation.

Finally, our results provide a better understanding of the determinants of the recent Brazilian Amazon deforestation slowdown. There is a substantial stream of literature documenting the impact of long-run socioeconomic drivers of deforestation activity in the Amazon. Examples include, but are no limited to, the effect of population, road density, and agroclimatic characteristics on deforestation (see Pfaff (1999), Chomitz and Thomas (2003), Reis and Guzmán (1994), Reis and Margulis (1991)). However, there is scarce empirical evidence on the immediate drivers of the recent Amazon deforestation slowdown. Hargrave and Kis-Katos (2010) find a negative relationship between fine intensity and deforestation in the Amazon, but do not adequately address endogeneity issues in their work. This paper complements the findings of Assunção et al. (2011). The authors show that, even when controlling for commodity prices and relevant fixed effects, conservation policies introduced in the second half of the 2000s helped avoid 60,000 square kilometers of forest clearings. In this study, we isolate the command and control policy channel, and find that monitoring and law enforcement have been particularly effective in curbing deforestation compared to other recent Amazon conservation efforts adopted

in Brazil.

The rest of the paper is organized as follows. Section 2 describes the institutional context, as well as Amazon monitoring and law enforcement policies implemented starting in the mid-2000s. Section 3 introduces the data and descriptive statistics. Section 4 details our empirical strategy used to identify the causal effect of police presence on deforestation. Section 5 discusses results for the impact of cloud coverage on the number of fines, the effect of the number of fines on deforestation, and the potential relationship between conservation policies on agricultural production. It also presents some robustness checks. Finally, Section 6 concludes with final remarks.

2. Institutional Context

Since its creation in February 1989, Ibama has been responsible for environmental monitoring and law enforcement in Brazil. It both operates as an environmental police force, investigating environmental infractions and applying administrative sanctions, and executes environmental policy actions concerning environmental licensing, environmental quality control, environmental impact, and generation and spread of environmental information. As the country's leading figure in environmental monitoring, Ibama plays a particularly active role in the prevention and control of deforestation and forest fires.

The strengthening of command and control has been a key policy effort of the Brazilian Ministry of the Environment (*Ministério do Meio Ambiente*, MMA) since the mid-2000s. Launched in 2004, the PPCDAm marked the beginning of a novel approach towards combating deforestation in the Brazilian Amazon, integrating actions across different government institutions and introducing new procedures for monitoring, environmental control, and territorial management (Ipea et al. (2011), IPAM (2009), Assunção et al. (2011)). Changes to command and control constituted an important part of the PPCDAm's tactical-operational strategy. One such change was the major leap forward in Legal Amazon remote sensing-based monitoring capacity brought about by the implementation of DETER. Developed by INPE, DETER is a satellite-based system that captures and processes georeferenced imagery on forest cover in 15-day intervals. Figure 1 shows how deforestation is captured by DETER – deforested areas appear in the satellite imagery in a different color to forest areas. Thus, for any given Amazon region, recent images are compared with older ones to identify changes in forest cover. The imagery is prepared and distributed in the form of georeferenced digital maps by Ibama's Center for Environmental Monitoring (*Centro de Monitoramento Ambiental*, CEMAM). These maps are then used to locate deforestation hot spots and issue alerts signaling areas in need of immediate attention.

[Figure 1 about here.]

Since its implementation in 2004, DETER has been heavily used to target law enforcement activities in the Amazon. Prior to the activation of DETER, Amazon monitoring relied strictly on denouncements of threatened areas. With the adoption of the new remote sensing system, however, Ibama was given speedier access to recent georeferenced data and was thus able to better identify, more closely monitor, and more quickly act upon areas with illegal deforestation activity.

The PPCDAm also promoted institutional changes that enhanced command and control capabilities in the Amazon. Ibama sought to improve the qualification of its personnel through the establishment of stricter requirements in its recruitment process. This led to an increase in both the number and quality of monitoring personnel. Additionally, Ibama's law enforcement efforts gained greater legal support with the passing of Presidential Decree 6.514 in July 2008, which reestablished the directives for the investigation of environmental infractions and application of sanctions. The decree determined, in more detail than had been previously incorporated in legislation, the administrative processes for sanctioning environmental crimes. This increased both the clarity and the speed of such processes. It also introduced new instruments for use in law enforcement (such as loss and destruction of goods, donation, seizure of animals and crop production, among others), and established that a list identifying landowners of areas under embargo was to be made public. These measures not only increased the robustness of sanctions and the safety of law enforcement agents, but also brought greater regulatory stability to the administrative processes for the investigation and punishment of environmental crimes.

Another relevant command and control effort of the late 2000s was the signing of Presidential Decree 6.321 in December 2007, which established the legal basis for singling out municipalities with intense deforestation activity and taking differentiated action towards them. These municipalities, selected based on their deforestation history, were classified as in need of priority action to prevent, monitor, and combat illegal deforestation. Exiting the list of priority municipality was conditioned upon significantly reducing deforestation activity. In addition to concentrating a large share of Ibama's attention and monitoring efforts, priority municipalities became subject to a series of other administrative measures that did not necessarily relate to command and control policy. Examples of such measures include, but are not limited to harsher licensing and georeferencing requirements, revision of private land titles, compromised political reputation for mayors of priority municipalities, and economic sanctions applied by agents of the commodity industry. In light of this, the impact of being added to the list of priority municipalities could be broader than that of increased monitoring and law enforcement. Our empirical analysis takes this potentially broader impact into consideration.

Overall, the policy efforts adopted starting in the mid-2000s represented both an increase in the intensity and an improvement in the targeting of command and control

activity in the Brazilian Amazon.

3. Data

Our empirical analysis is based on a 2007 through 2011 municipality-by-year panel data set. The sample includes all municipalities located entirely within the Amazon Biome, and excludes those crossed by the biome frontier. As variation in forest cover during the sample period is required to calculate our main dependent variable (annual deforestation increment), the sample is further restricted to municipalities that portrayed such variation. The final sample comprises 433 municipalities.

The following sections describe our variables of interest and present some descriptive statistics.

3.1. Deforestation

We define deforestation as the annual deforestation increment, which is the area of forest cleared over the twelve months leading up to August of a given year.[1] The annual deforestation increment of year t measures the area, in square kilometers, deforested between the 1st of August of $t-1$ and the 31st of July of t. Deforestation data is built from satellite-based images that are processed and publicly released by INPE's Project for Monitoring Deforestation in the Legal Amazon (*Projeto de Monitoramento do Desflorestamento na Amazônia Legal*, PRODES). The data captures the total area of forest cleared in a twelve-month period at the municipality level.

Sample municipalities exhibit a significant amount of cross-sectional variation in deforestation due to heterogeneity in municipality size. We address this by using a normalized measure of the annual deforestation increment, which ensures that our analysis considers relative variations in deforestation increments within municipalities. The variable is constructed according to the following expression:

$$D_{it} = \frac{ADI_{it} - \overline{ADI}_{it}}{sd\left(ADI_{it}\right)} \tag{1}$$

where D_{it} is the normalized annual deforestation increment for municipality i and year t; ADI_{it} is the annual deforestation increment measured in municipality i between the 1st of August of $t-1$ and the 31st of July of t; and $\overline{ADI}_{it}$ and $sd\left(ADI_{it}\right)$ are, respectively, the mean and the standard deviation of the annual deforestation increment calculated for each i over the 2002 through 2009 period. The variable ADI_{it} replaces D_{it} in some alternative specifications.

[1] We use deforestation increments, as opposed to deforestation rates, because information on municipality-level deforestation rates is not available from PRODES/INPE for the period of interest.

For any given municipality, cloud coverage during the period of remote sensing may prevent the PRODES satellite from capturing land cover imagery. Forest areas that were cleared in a given year, but were blocked from view by clouds during remote sensing, are not incorporated into that year's deforestation increment figure. These areas are only accounted for when they show up on PRODES imagery. Variables indicating PRODES cloud coverage and other unobservable areas, both of which are made publicly available by PRODES/INPE, are included in all regressions to control for measurement error.

3.2. Law Enforcement

We use the total number of fines applied as sanctions for environmental crimes in each municipality as a measure of the intensity of monitoring and law enforcement at the municipality level. The data are publicly available from Ibama.

It is worth highlighting that although collection rates for environmental fines applied in Amazon municipalities are knowingly low (Barreto et al. (2008), Brito (2009), Brito and Barreto (2008), Hirakuri (2003)), this does not interfere with our analysis. These fines are often accompanied by other sanctioning instruments that are more binding, such as loss and destruction of goods, seizure of animals and crop production, and embargoes. Because data about these instruments are not available, we use the number of fines as a proxy for command and control efforts as a whole. Essentially, we are interested in exploring fines as a means of capturing the effect of police (Ibama) presence – not of the sanctioning instrument itself – on deforestation.

To maintain consistency across our panel data, we consider the PRODES year - the period from the 1^{st} of August of $t-1$ through the 31^{st} of July of t - as the relevant unit of time. Thus, for each municipality, the total number of fines in a given year captures all fines applied in that municipality in the twelve months leading up to August of that year.

3.3. Cloud Coverage

As explained in Section 2, the DETER system produces georeferenced data on deforestation activity in 15-day intervals. These data are used to identify deforestation hot spots and issue alerts, which then serve to target law enforcement activity. However, DETER suffers from one important limitation. As the satellite used in DETER is incapable of detecting land cover patterns in areas covered by clouds, no deforestation activity is captured and no deforestation alerts are issued in these areas. Ultimately, this reduces the probability of monitoring personnel being allocated to such areas (see Figure 2 for DETER maps illustrating cloud coverage and alerts). It is therefore likely that monitoring and law enforcement in the Amazon are directly affected by DETER cloud coverage.

[Figure 2 about here.]

We are interested in exploring how DETER cloud coverage affects police presence in the Amazon. To do this, we use georeferenced data from DETER/INPE that maps cloud coverage over the Amazon throughout the year. When visibility is at least partial, these maps show exactly which areas were covered by clouds. When visibility is too precarious to derive information about land cover, however, no map is produced. In this case, we assume DETER cloud coverage to be complete. Based on this, we calculate, for each sample municipality and year, the average area in square kilometers covered by clouds in that year. We use this as an instrument for the intensity of law enforcement activity in each Amazon municipality. Again, the relevant unit of time is the PRODES year.

It is important to stress that PRODES and DETER cloud coverage are two separate variables. A potential cause of concern in our empirical exercise is that the PRODES satellite, used to measure annual deforestation increments in the Amazon, is also sensitive to cloud coverage. This could be an issue for our empirical strategy, should PRODES cloud coverage be correlated with DETER cloud coverage. As we have cloud coverage data for both PRODES and DETER, we are able to tackle this issue. By controlling for PRODES cloud coverage, we estimate results considering only DETER cloud coverage that is orthogonal to PRODES cloud coverage.

Finally, we note that although DETER was implemented in 2004, the first georeferenced DETER maps to be made publicly available refer to 2006. This determines that 2007 must be our first sample year.

3.4. Additional Controls

We include a series of variables to control for other potentially relevant determinants of deforestation. First, there is no consensus in the literature as to how deforestation and precipitation are related. On the one hand, forest clearings are often concentrated in dry seasons, when it is easier to penetrate and burn the forest. On the other hand, the cutting down of forests may affect the region's microclimate and ultimately its precipitation patterns (Saad et al. (2010), Negri et al. (2004), Aragão et al. (2008)). Understanding this relationship in detail is out of the scope of this paper, but we include an estimate of total precipitation in each sample municipality to account for the effect of rainfall on forest clearing activities.

We use annual precipitation data compiled by Matsuura and Willmott (2012). The authors draw on worldwide climate data to calculate a regular georeferenced world grid of estimated precipitation. Their estimations are based on geographic extrapolations of data collected at weather stations from a variety of sources. Using this georeferenced grid, we estimate total precipitation in each municipality according to the following rule: (i) for municipalities that overlap with only one grid node, we use the precipitation value

for that grid node as municipality precipitation; (ii) for municipalities that overlap with two or more grid nodes, we consider all node values and use their average precipitation as municipality precipitation; and (iii) for municipalities that have no overlap with any grid nodes, we take the area of a 28-kilometer buffer around the municipality and consider the average precipitation of all grid nodes that fall within this area as municipality precipitation.

For the second set of controls, we consider agricultural commodity prices, which have been shown to be drivers of deforestation (Assunção et al. (2011), Angelsen and Kaimowitz (1999), Barbier and Burgess (1996), Panayotou and Sungsuwan (1994)). As agricultural prices are endogenous to local agricultural production and thereby deforestation, we must construct output price series that capture exogenous variations in the demand for agricultural commodities produced locally. As argued in Assunção et al. (2011), agricultural commodity prices recorded in the southern Brazilian state of Paraná are highly correlated with average local crop prices calculated for Amazon municipalities. We follow the authors and collect prices at the Agriculture and Supply Secretariat of the State of Paraná (*Secretaria de Agricultura e do Abastecimento do Estado do Paraná*, SEAB-PR). The set of commodity prices includes prices for beef cattle, soybean, cassava, rice, corn, and sugarcane.[2]

The Paraná price series are used to build two variables of interest. The first of these variables, an annual index of crop prices, is constructed in three steps. In step one, we calculate nominal annual prices by averaging nominal monthly prices for each calendar year and culture. Annual prices are deflated to year 2000 Brazilian reais and are expressed as an index with base year 2000.

In step two, we calculate a weighted real price for each of the crops according to the following expression:

$$PPA_{itc} = PP_{tc} * A_{ic,2000-2001} \tag{2}$$

where PPA_{itc} is the weighted real price of crop c in municipality i and year t; PP_{tc} is the Paraná-based real price of crop c in year t expressed as the index with base year 2000; and $A_{ic,2000-2001}$ is the share of municipal area used as farmland for crop c in municipality i averaged over the 2000 through 2001 period.[3] This latter term captures the relative importance of crop c within municipality i's agricultural production in the

[2]Soybean, cassava, rice, and corn are predominant crops in terms of harvested area in the Legal Amazon. Although not a predominant crop in the region, sugarcane is also included to account for concerns about the recent expansion of Brazilian ethanol biofuel production. Together, the five crops account for approximately 70% of total harvested area averaged across sample years.

[3]Variables on annual municipality crop production (harvested area, *quantum*, or value in current prices) are constructed based on data from the Municipal Crop Survey of the Brazilian Institute for Geography and Statistics (*Pesquisa Agrícola Municipal do Instituto Brasileiro de Geografia e Estatística*, PAM/IBGE)

years immediately preceding the sample periods. It thus serves as a municipality-specific weight that introduces cross-sectional variation in the commodity price series.

In the third and final step, we use principal component analysis on the weighted real crop prices to derive our first variable of interest, the annual index of crop prices. This technique allows the price variations that are common to the five selected crops to be represented in one single measure. The resulting index of crop prices captures the first principal component of the five weighted real prices. As the index maximizes the price variance, it represents a more comprehensive measure of the agricultural output price scenario for this analysis than the individual prices themselves.

The second variable of interest is an annual index of cattle prices, which is derived analogously to PPA_{itc} in equation 2. However, as land pasture is not observable, in this case $A_{ci,2000-2001}$ is the ratio of heads of cattle to municipal area in municipality i averaged over the 2000 through 2001 period.

Finally, we include controls for other relevant conservation policies introduced during the sample period. In particular, we consider total protected area, including both conservation units and indigenous lands, in each municipality, and priority municipalities. As discussed in Section 2, priority municipalities were subject not only to stricter command and control, but also to other administrative measures with a potentially deterrent effect on deforestation. By including controls for these municipalities in our estimations, we ensure that the effect of increased Ibama presence (captured via the number of fines) is isolated from the effect of the other administrative measures in priority municipalities.

3.5. Trends and Descriptive Statistics

Figure 3, which shows trends for total number of fines applied in the Amazon and total deforestation from 2002 through 2011, indicates Ibama's efforts to enforce environmental law with greater stringency. While the average number of fines applied by municipality grew nearly 200% from 2002 through 2008, average deforested area by municipality declined by almost 50% in the same period. In the following years, the number of fines decreases alongside deforestation. The endogeneity problem discussed in Section 1 accounts for this trend.

[Figure 3 about here.]

Table 1 presents the means and standard deviations of the variables used in our empirical analysis. The figures show that agricultural prices and production were rising during the period of interest, which could have pushed for greater deforestation. We note that average DETER cloud coverage is very high, highlighting the monitoring system's limitation. Finally, the extent of protected areas during the period show only minor variation from year to year.

[Table 1 about here.]

4. Empirical Strategy

This section describes the empirical strategy we use to identify the causal effect of Ibama's presence on deforestation activity. We follow the literature on the effect of police presence on crime in aiming to address problems of endogeneity. As we only observe an equilibrium situation – the number and value of fines applied by Ibama once the crime has already been committed –, we face a serious problem of simultaneity (deforestation affecting the application of fines) in addition to the usual problems of omitted variables.

As is done in the majority of studies concerning the environment and law enforcement (Magat and Viscusi (1990), Shimshack and Ward (2005), Shimshack and Ward (2008)), a first attempt to solve the endogeneity problem could entail taking the lag of the number of fines. This captures the effect of the number of fines applied by Ibama in year $t-1$ on deforestation recorded in year t. However, it does not fully solve the problem, since it does not address a possible persistence of deforestation activity.

We propose a novel strategy to tackle the endogeneity issue. As explained in Section 2, Ibama bases the allocation of its monitoring personnel on alerts issued by the DETER system. Yet, due to DETER's inability to detect land cover patterns beneath clouds, monitoring personnel have a lower chance of being allocated to areas that are covered by clouds during remote sensing, even if deforestation activity is occurring in these areas. We use this source of exogenous variation - average annual DETER cloud coverage for each municipality - as an instrument for the number of fines applied by Ibama.

Why is this instrument exogenous? To be exogenous, it must be uncorrelated with the error in the deforestation equation, conditional on the observable variables. There are two obvious cases in which this condition would be violated in our empirical setup: (i) correlation between cloud coverage and rainfall, which, in turn, is correlated with deforestation; and (ii) correlation between DETER cloud coverage and PRODES cloud coverage, which, in turn, is correlated with observed deforestation. The availability of relevant observable variables guarantees the exogeneity of our instrument.

We address the first case by using rainfall data compiled by Matsuura and Willmott (2012) to control for precipitation at the municipality level. The second case merits a more detailed discussion. The cause of concern here is that PRODES, the satellite used to measure annual deforestation rates in the Amazon, is also sensitive to cloud coverage. This could be an issue for our empirical strategy, should PRODES cloud coverage be correlated with DETER cloud coverage. We use two complementary approaches to tackle this issue. First, we control for PRODES cloud coverage, leading our coefficients to be estimated considering only DETER cloud coverage that is orthogonal to PRODES cloud coverage. Second, we conduct a robustness check by replacing our original instrument by a measure of average DETER cloud coverage strictly for the period when the PRODES satellite is not collecting imagery to be used in the calculation of Amazon deforestation

rates. PRODES collects such imagery between the 1st of June and the 29th of August of a given year. DETER imagery, on the other hand, is collected every 15 days. Thus, we calculate average DETER cloud coverage excluding data from PRODES' period of remote sensing. Specifications that use this alternative instrument also include PRODES cloud coverage as a control.

Having controlled for precipitation and potential measurement error, we argue that the only remaining channel through which DETER cloud coverage could be correlated with deforestation is the allocation of Ibama monitoring personnel. In Section **??**, we show that DETER cloud coverage is, in fact, systematically correlated with the number of fines applied by Ibama at the municipality level. This indicates that our instrument is not weak.

Our strategy also addresses other potential causes of concern. First, deforestation has been shown to be strongly correlated with agricultural commodity prices (Assunção et al. (2011)). We therefore control for both crop and cattle prices, following Assunção et al. (2011). Second, other conservation policies were introduced during our period of interest. We account for them by controlling for the three main conservation efforts of the second half of the 2000s: priority municipalities, protected areas, and rural credit policies. Finally, there are important fixed effects that could be related with both deforestation and monitoring and law enforcement. We take advantage of the panel structure of our data to control for municipality fixed effects.

As mentioned in Section 3, our variables are constructed to fit the PRODES year time frame. Agricultural price series are the sole exception. For these series, we follow Assunção et al. (2011) and calculate average prices for both the previous year and the first semester of each current year.

For the first stage, our estimation equation is given by:

$$Fines_{it} = \alpha_i + \phi_t + \beta_1 DeterClouds_{it} + \beta_2 rain_{it} + \beta_3 ProdesClouds_{it} + \sum_k \beta_k X_{itk} + \epsilon_{it} \quad (3)$$

where $Fines_{it}$ is the number of fines applied by Ibama in municipality i and year t; αi is the municipality fixed effect; ϕ_t is the year fixed effect; $DeterClouds_{it}$ is the average annual DETER cloud coverage for municipality i and year t; $rain_{it}$ is precipitation for municipality i and year t; $ProdesClouds_{it}$ is PRODES cloud coverage for municipality i and year t, as measured during the period of PRODES remote sensing; X_{it} is a vector of controls including other conservation policies and agricultural commodity prices; and ϵ_{it} is the idiosyncratic error.

For the second stage, we include the lagged number of fines and, thus, lagged values for both DETER cloud coverage and precipitation. As we intend to capture DETER cloud coverage that is correlated with the allocation of Ibama's monitoring personnel,

but uncorrelated with deforestation through any other channels, we must also control for precipitation in year $t-1$. No lags are included for the other variables. Our estimation equation is given by:

$$Deforest_{it} = \alpha_i + \phi_t + \beta_1 Fines_{i,t-1} + \beta_2 rain_{i,t-1} + \beta_3 ProdesClouds_{it} + \sum_k \beta_k X_{itk} + \epsilon_{it} \quad (4)$$

where $Fines_{i,t-1}$ is instrumented by $DeterClouds_{i,t-1}$; and $Deforestation_{it}$ is the normalized deforested increment in municipality i and year t. All other variables are the same as in equation 3.

Standard errors in all specifications are clustered at the municipality level, making them robust to heteroscedasticity and serial correlation (Bertrand et al. (2004)).

5. Results

This section presents results for both first and second stage estimations, counterfactual exercises, and robustness checks.

5.1. Cloud Coverage and Monitoring

We start by assessing the impact of average DETER cloud coverage during the year on the presence of Ibama monitoring personnel in each municipality. We use the number of fines applied by Ibama in each municipality as a proxy for Ibama presence in that municipality. Table 2 results indicate that an increase in DETER cloud coverage significantly reduces the number of fines applied by Ibama. Column (1) presents coefficients estimated in specifications using no controls. In columns (2) through (4), the following controls are gradually added: precipitation and PRODES cloud coverage; time and municipality fixed effects; agricultural commodity prices and other environmental policies. Coefficients remain negative and significant at a 5% significance level in all specifications. Quantitatively, a 10 percentage point increase in DETER cloud coverage represents an average reduction of 1.43 in fines – a decrease of 18% in the total number of fines for our period of interest.

[Table 2 about here.]

Results therefore suggest that DETER cloud coverage is strongly correlated with the number of fines applied by Ibama. This finding validates the first stage of our empirical strategy.

5.2. Monitoring and deforestation

Having shown that DETER cloud coverage and Ibama presence in Amazon municipalities are indeed correlated, we move on to evaluate the impact of command and control

efforts on deforestation. Coefficients shows in Table 3 capture the effect of the number of fines applied by Ibama on deforestation at the municipality level. Results indicate that a higher number of fines in a given year will significantly reduce deforestation the following year, suggesting that monitoring and law enforcement efforts effectively curb deforestation. Results are consistent throughout specifications using different dependent variables (normalized or absolute annual deforestation increments). The inclusion of controls for other relevant conservation policies during the period of interest does not substantially alter results.

[Table 3 about here.]

To better understand the magnitude of this effect, we conduct two counterfactual simulations. First, we assume that the annual number of fines has remained fixed at levels observed in 2003, the year immediately preceding the launch of PPCDAm. Second, we assume that Ibama was entirely absent from the Amazon, having applied no fines at all during our period of interest. Results for both exercises are shown in Table 4. Estimated figures indicate that, in the counterfactual scenario where no policy change occurred and the annual number of fines from 2007 through 2011 was kept fixed at its 2003 levels, deforestation in the Amazon would have been 53,000 square kilometers greater than was actually observed during the 2007 through 2011 period. Considering that total deforestation observed for the Amazon Biome in this period was approximately 40,500 square kilometers, forest clearings would have been more than twofold greater in the absence of the command and control policy change. Analogously, in the counterfactual scenario where Ibama applied no fines at all from 2007 through 2011, deforestation in the Amazon would have been 109,000 square kilometers greater, or more than threefold what was observed in the period.

[Table 4 about here.]

This is a very impressive effect in both absolute and relative terms. Moreover, the empirical evidence has substantial policy value. Unlike several other empirical exercises in the police force and crime literature that explore context-specific circumstances and require additional assumptions for the extrapolations of their results, our strategy analyzes policies that have actually been put into practice in the full extent of our area of interest. It allows us to identify a causal effect of environmental police presence on environmental crimes within an unrestricted empirical context.

We also perform a simple cost-benefit analysis, comparing Ibama's budget with the estimated monetary benefits of preserving forest areas and, thus, avoiding carbon dioxide emissions. We estimate that, from 2007 through 2011, avoided deforestation associated

with increased Ibama presence is valued at an average of 4.02 billion USD per year.[4] Compared with Ibama's average budget of 513 million USD per year during the same period, our estimation suggests that more stringent command and control policy yields significant gains. Indeed, monetary benefits from increased preservation are over seven times greater than Ibama's cost of operation. These findings highlight the value of strategically using available information and technology, which allowed Ibama to achieve such impressive results having only 3,000 agents to cover the vast area of the Amazon Biome.

5.2.1. Timing

In addition to showing that monitoring and law enforcement affect deforestation, we are interested in investigating the timing of this effect. Table 5 reproduces the specifications of Table 3 using double and triple lags for the number of fines to test the persistence of the deterrent effect. Results show that the impact of fines applied in $t-2$ is is weaker than that of fines applied in $t-1$. Although coefficients are negative and significant in column (1), the inclusion of controls for other relevant environmental policies extinguish this significance. The number of fines applied in $t-3$ is not significant in any specification.

[Table 5 about here.]

These results suggest that the effect of Ibama's presence in a given municipality dissipates over time. Moreover, they reinforce the need to sustain continuous command and control efforts in the Amazon.

5.3. Monitoring and Agricultural Production

In the previous section, we showed that increased Ibama presence has a deterrent effect on deforestation. We now investigate whether it also has an impact on local agricultural production. There is an ongoing debate about whether conservation policies affect economic outputs. Should this be the case, there would be a dichotomy between preservation and economic growth – it is not obvious which of these paths society would choose to follow. However, should it be possible to sustain economic growth whilst preserving natural resources, this dichotomy would cease to exist (Cropper and Griffiths (1994), Panayotou (1995), Antle and Heidebrink (1995), Foster and Rosenzweig (2003), Grossman and Krueger (1995), Arrow et al. (1996)). With increasing conservation efforts, farmers could start to operate at the intensive margin of agricultural production, pursuing growth via increased agricultural productivity. Such growth efforts could more than compensate conservation efforts.

[4]Estimations are based using conversion factors established in Ministério do Meio Ambiente, Departamento de Políticas para o Combate ao Desmatamento - MMA/DPCD (2011).

In this section, we investigate whether command and control policies in the Amazon had an adverse effect on local agricultural production. We use two different measures of agricultural production: (i) agricultural GDP from Brazilian national accounts, and (ii) agricultural revenues from the Municipal Agricultural Survey (*Pesquisa Agrícola Municipal, PAM*). Results presented in Table 6 provide no evidence to support the tradeoff between conservation and agricultural production. Specifications with both measures of agricultural production yield insignificant coefficients, suggesting that it is possible to expand agricultural production without increasing deforestation.

[Table 6 about here.]

So far, our results indicate that command and control policies play a very important role in the containment of carbon dioxide emissions from deforestation, at no apparent cost to agricultural production. Perhaps subsistence agriculture may have been affected by conservation efforts, but this effect cannot be perceived in total agricultural production. This suggests that it is possible to protect the rainforest without significantly affecting agricultural production.

5.4. Robustness checks

Although our results are generally consistent with the institutional context, we run a series of tests to check their robustness. We focus on three sources of potential concern. First, it could be that our regressions capture a spurious effect due to the correlation between PRODES cloud coverage and DETER cloud coverage. Second, our identification strategy relies on the fact that, after controlling for observable characteristics and municipality and time fixed effects, municipalities are comparable. However, initial forest cover varies significantly across Amazon municipalities. This could potentially have driven our results. Third, initial deforestation rates, as well as initial forest cover, could be determinants of the deforestation pattern at the municipality level.

We tackle these issues in three sets of robustness checks. First, we re-calculate average DETER cloud coverage using strictly the period for which there is no PRODES remote sensing, as explained in Section 4.

Second, we restrict our sample to municipalities that had deforested less than 50% of their territory at the beginning of our period of interest. In municipalities where comparatively less forest remains, the dynamics of deforestation is very different from that in municipalities where forest cover is still high. We also test this by controlling for a trend depending on initial percentage of deforested area in the municipality (an interaction between a linear trend and initial deforested area). Should our results have been driven by a natural convergence in deforestation rates between municipalities with greater and smaller deforested areas, this test would yield insignificant coefficients.

Finally, we run a similar test, but instead of using the initial value of deforested territory, we use the initial value of deforestation rates. The economic dynamics of municipalities with higher deforestation rates could be very different from the dynamics of those with smaller deforestation rates. Note that, in this case, we are analyzing initial annual deforested increments; in the previous case, we were assessing initial cumulated share of deforested area in each municipality. Differences in economic dynamics could imply very different trends in deforestation rates and potentially have driven our results. We therefore also control for a trend that depends on initial deforestation rates (an interaction between a linear trend and initial deforestation rates).

Table 7 presents the results of all robustness tests. The coefficient for the number of fines remains negative and significant in all the specifications. Overall, the robustness of our results support the specifications chosen for our main regressions, as well as the interpretation of our results.

[Table 7 about here.]

6. Final Comments

Climate change and biodiversity concerns have made tropical deforestation one of the most relevant topics in the global policy debate today. Understanding deforestation in the Brazilian Amazon and how to most efficiently prevent it is therefore a matter of first-order importance not only for Brazil, but for the global community.

This paper investigates the effect of a series of command and control policy changes promoted by the Brazilian federal government on Amazon deforestation. We show that the strategic use of advanced satellite technology and the intensification of monitoring, alongside improvements in the qualification of monitoring personnel significantly contributed to the 2000s Amazon deforestation slowdown. We find that monitoring and law enforcement efforts have been particularly effective in curbing deforestation compared to other recent Amazon conservation efforts. Increased presence of police force in the Amazon accounts for the preservation of 50,000 square kilometers of forest area from 2007 through 2011.

Our results also shed light on the potentially adverse effects of conservation policies, and particularly on the supposed tradeoff between economic growth and preservation of natural resources. We show that command and control policies adopted in the second half of the 2000s had no significant impact on agricultural production. Overall, command and control appears to play a crucial role in the curbing of Amazon deforestation and containment of carbon dioxide emissions, at no apparent cost to agricultural production.

Finally, a simple cost-benefit analysis suggests that the gains derived from the reduced deforestation more than compensate monitoring and law enforcement costs. This

reinforces the case for promoting preservation of the forest via command and control efforts.

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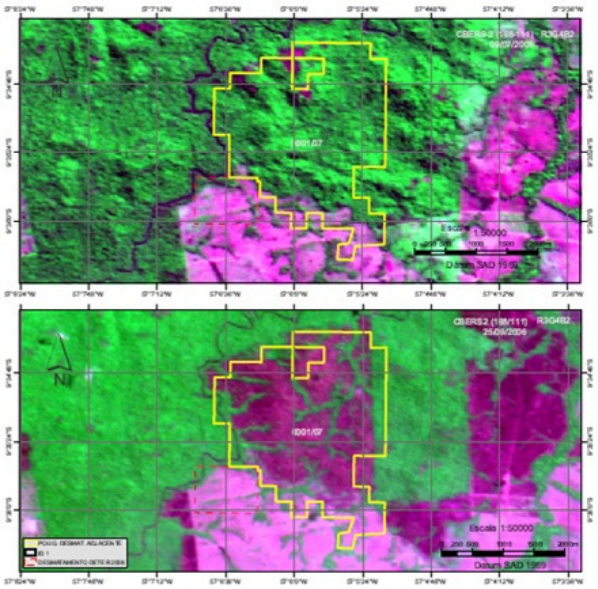
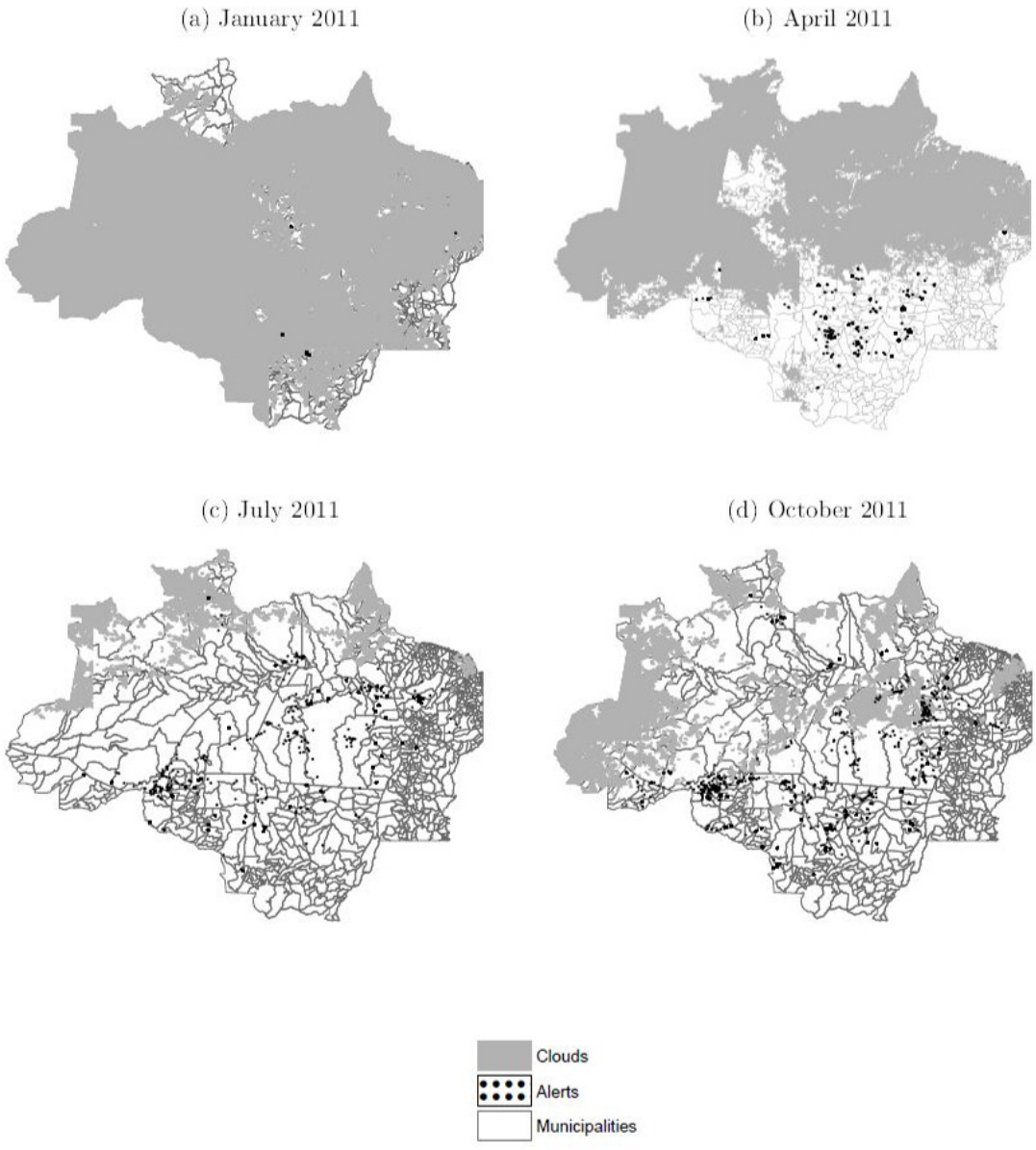
Figure 1
Deforestation Captured in DETER Satellite Imagery



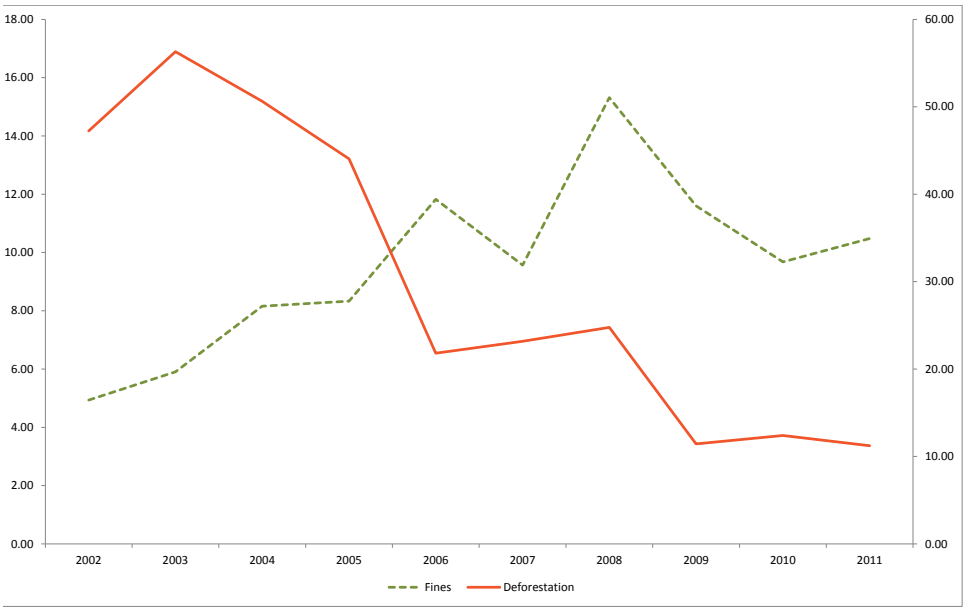
Notes: Green indicates forest areas and purple deforested areas. Both top and bottom panels are satellite images of the same area – the top one was taken before the forest was cleared, and the bottom one after it.
Source: Ibama/MMA.

Figure 2
Examples of DETER Cloud Coverage and Alerts



Source: DETER/INPE.

Figure 3
Number of Fines and Deforestation in the Amazon



Source: Deforestation data - PRODES/INPE. Fines - Ibama.

Table 1
Descriptive Statistics

	(1)					
	2006	2007	2008	2009	2010	2011
Deforested Area	20.13	21.18	24.07	10.53	11.22	10.39
	(54.45)	(59.20)	(57.67)	(34.56)	(27.85)	(27.72)
GDP - Agriculture	16851.1	18686.7	21421.0	20691.1	.	.
	(17123.0)	(23737.7)	(29902.6)	(26607.8)	(.)	(.)
Crop Production	8411.2	9685.1	12605.6	11520.0	10368.3	13832.6
	(21792.2)	(29473.5)	(44281.7)	(39226.5)	(27986.2)	(46765.8)
Number of Fines	10.64	8.935	14.21	10.68	9.040	9.721
	(23.82)	(19.50)	(33.64)	(30.91)	(21.75)	(24.74)
Cloud Deter	0.383	0.713	0.612	0.685	0.619	0.546
	(0.0714)	(0.172)	(0.201)	(0.215)	(0.221)	(0.197)
Rain	5469.5	5631.7	5500.2	5633.9	5229.5	.
	(1484.5)	(1487.2)	(1339.4)	(1085.8)	(1068.9)	(.)
Protected Areas	24.85	26.15	26.46	26.78	27.27	27.40
	(31.33)	(32.20)	(32.34)	(32.51)	(32.62)	(32.69)
Cloud Prodes	374.1	565.3	439.1	430.6	822.3	554.1
	(1443.5)	(2397.2)	(1799.2)	(1389.9)	(3303.2)	(2871.6)
Non-Observed Prodes	44.39	45.18	19.57	12.62	11.01	10.96
	(255.3)	(255.8)	(223.8)	(71.10)	(70.13)	(70.04)
Crop Prices 1st Semester	-0.586	-0.557	-0.542	-0.563	-0.542	-0.535
	(0.142)	(0.180)	(0.219)	(0.198)	(0.207)	(0.215)
Crop Prices in t-1	-0.564	-0.581	-0.551	-0.551	-0.560	-0.541
	(0.171)	(0.146)	(0.189)	(0.203)	(0.196)	(0.207)
Cattle Prices 1st Semester	14.41	16.03	19.91	19.30	18.89	21.67
	(17.45)	(19.41)	(24.11)	(23.37)	(22.87)	(26.24)
Cattle Prices in t-1	16.80	16.03	17.71	21.43	20.22	20.97
	(20.34)	(19.41)	(21.45)	(25.95)	(24.49)	(25.39)

Data sources: Deter-INPE, Prodes-INPE, Paraná Secretariat, Matsura and Willmott (2007), Ibama, and PAM-IBGE.

Table 2
First Stage Regressions

VARIABLES	(1) Number of Fines	(2) Number of Fines	(3) Number of Fines	(4) Number of Fines
Cloud Deter	-14.49***	-16.11***	-8.738**	-13.15***
	(2.844)	(2.905)	(3.541)	(4.198)
Rain		0.00103**	-0.00209***	-0.00176***
		(0.000512)	(0.000568)	(0.000575)
Cloud Prodes		0.000170	0.000204	0.000193
		(0.000234)	(0.000148)	(0.000145)
Non-Observed Prodes		-0.000791	0.00162**	0.00169**
		(0.00206)	(0.000681)	(0.000673)
Priority Municipalities				-3.880
				(5.891)
Protected Areas				0.0326
				(0.0649)
Crop Prices 1st Semester				7.476*
				(3.881)
Cattle Prices 1st Semester				-0.342***
				(0.123)
Crop Prices in t-1				-15.64**
				(7.544)
Cattle Prices in t-1				0.0516
				(0.107)
Observations	3,144	2,595	2,595	2,595
R-squared	0.014	0.016	0.024	0.028
Municipality and Year FE	No	No	Yes	Yes
Number of municipalities			519	519

Notes: Coefficients shown are estimated using a municipality-by-year panel data set covering the 2007 through 2011 period. The sample includes all Amazon Biome municipalities. OLS regressions are shown in column (1). Collumn (2) adds rain and Prodes cloud coverage as controls. Column (3) adds municipality and time fixed-effects. Column (4) adds cattle prices (current and lagged), crop prices (current and lagged), priority municipality status, percentage of municipality covered by protected areas and non-observable areas during period of remote sensing as controls. Robust standard errors are clustered at the municipality level. Significance: *** p<0.01, ** p<0.05, * p<0.10.

Table 3
Second Stage Regressions

VARIABLES	(1) Normalized Deforestation	(2) Normalized Deforestation	(3) Deforestation	(4) Deforestation
Number of Fines in t-1	-0.0509**	-0.0543**	-2.562***	-1.440*
	(0.0210)	(0.0255)	(0.907)	(0.763)
Rain in t-1	-0.000224***	-0.000238***	-0.0101***	-0.00624***
	(5.52e-05)	(6.76e-05)	(0.00268)	(0.00199)
Priority Municipalities		0.236		-56.01***
		(0.327)		(16.45)
Protected Areas		0.0146		-0.00177
		(0.00897)		(0.311)
Cloud Prodes	9.91e-06	1.11e-05	0.000370	3.20e-05
	(2.16e-05)	(2.25e-05)	(0.000957)	(0.000706)
Non-Observed Prodes	0.000349***	0.000351***	0.00930	0.00598
	(0.000121)	(0.000131)	(0.00697)	(0.00459)
Crop Prices 1st Semester	-0.309	-0.274	21.37	12.23
	(0.311)	(0.337)	(15.07)	(10.29)
Cattle Prices 1st Semester	0.0190*	0.0209*	0.613	0.225
	(0.0106)	(0.0120)	(0.443)	(0.360)
Crop Prices in t-1	-0.253	-0.162	15.20	7.201
	(0.331)	(0.353)	(11.31)	(7.971)
Cattle Prices in t-1	-0.0215*	-0.0201*	-0.0428	0.0458
	(0.0110)	(0.0112)	(0.464)	(0.305)
Observations	2,490	2,490	2,595	2,595
Number of municipalities	498	498	519	519
Municipality and Year FE	Yes	Yes		Yes

Notes: Coefficients shown are estimated using a municipality-by-year panel data set covering the 2007 through 2011 period. The sample includes all Amazon Biome municipalities. 2SLS regression with normalized deforestation as dependent variable is shown in column (1). Collumn (2) adds controls for priority municipality status, percentage of municipality covered by protected areas . Columns (3) and (4) repeats the first two columns, but with non-normalized deforestation as dependent variable. All regressions have controls for cattle prices (current and lagged), crop prices (current and lagged), lagged rain, Prodes-clouds and non-observable areas during period of remote sensing. Lagged number of fines is instrumented by lagged Deter cloud coverage. Robust standard errors are clustered at the municipality level. Significance: *** p<0.01, ** p<0.05, * p<0.10.

Table 4
Counterfactual

	Year	Observed Deforestation	Estimated Deforestation (Fines = Fines from 2003)	Difference Estimated-Observed	Estimated Deforestation (Fines=0)	Difference Estimated-Observed
	2007	11097	19179	8082	30401	19303
	2008	12615	21544	8929	32766	20151
	2009	5520	19827	14308	31049	25529
	2010	5877	18976	13098	30197	24320
	2011	5447	14748	9301	25970	20523
Total 2007 - 2011		40556	94274	53718	150383	109827

Notes: Counterfactual simulations are conducted using the sample, specifications, and estimated coefficients from Table 3. Column (1) presents the observed deforestation in Amazon Biome. Column (2) presents the estimated deforestation if the number of fines level was kept on the 2003 levels (before PPCDam and the creation of Deter). Column (3) show the difference between columns (2) and (1). Column (4) presents the estimated deforestation replacing the number of fines by zero. Column (5) shows the difference between columns (4) and (1).

Table 5
Second Stage Regressions with 2 and 3 lags

VARIABLES	(1) Normalized Deforestation	(2) Normalized Deforestation	(3) Normalized Deforestation	(4) Normalized Deforestation
Number of Fines in t-2	-0.0315*	-0.0344		
	(0.0173)	(0.0230)		
Number of Fines in t-3			-0.00244	-0.00231
			(0.00872)	(0.00868)
Rain in t-2	-2.14e-05	-2.70e-05		
	(4.63e-05)	(5.06e-05)		
Rain in t-3			0.000185***	0.000186***
			(5.31e-05)	(5.33e-05)
Priority Municipalities		0.243		-0.0933
		(0.354)		(0.350)
Protected Areas		0.0130		-0.000664
		(0.00858)		(0.00471)
Cloud Prodes	-7.78e-06	-7.93e-06	1.02e-05	1.01e-05
	(1.86e-05)	(1.91e-05)	(1.33e-05)	(1.33e-05)
Non-Observed Prodes	0.000118	0.000113	-0.00836	-0.00861
	(0.000176)	(0.000173)	(0.00759)	(0.00745)
Crop Prices 1st Semester	-1.002**	-1.038*	-0.322	-0.326
	(0.497)	(0.566)	(0.319)	(0.320)
Cattle Prices 1st Semester	0.0187**	0.0196**	0.00768	0.00762
	(0.00913)	(0.00948)	(0.00885)	(0.00883)
Crop Prices in t-1	0.652	0.736	0.421	0.423
	(0.459)	(0.515)	(0.436)	(0.435)
Cattle Prices in t-1	0.00795	0.0106	0.114***	0.114***
	(0.00758)	(0.00785)	(0.0187)	(0.0190)
Observations	1,992	1,992	1,494	1,494
Number of municipalities	498	498	498	498
Municipality and Year FE	Yes	Yes	Yes	Yes

Notes: Coefficients shown are estimated using a municipality-by-year panel data set covering the 2007 through 2011 period. The sample includes all Amazon Biome municipalities. 2SLS regressions with normalized deforestation as dependent variable is shown in all specifications. Column (1) presents results using number of fines lagged two periods and Column (2) adds controls for priority municipality status, percentage of municipality covered by protected areas . Columns (3) and (4) repeats the first two columns, but with number of fines lagged three periods. All regressions have controls for cattle prices (current and lagged), crop prices (current and lagged), two period lagged rain (Columns (3) and (4) use thre period lagged rain), Prodes-clouds and non-observable areas during period of remote sensing. Two and three period lagged Number of fines are instrumented by two and three period lagged Deter cloud coverage. Robust standard errors are clustered at the municipality level. Significance: *** p<0.01, ** p<0.05, * p<0.10.

Table 6
Second Stage Regressions on Agriculture GDP

VARIABLES	(1) Agriculture GDP	(2) Crop Production
Number of Fines in t-1	-0.00778	-7.90e-05
	(0.00761)	(0.0107)
Rain in t-1	-3.24e-05	-4.00e-05
	(3.12e-05)	(3.08e-05)
Priority Municipalities	0.434**	0.0437
	(0.203)	(0.119)
Protected Areas	0.0163*	0.0115**
	(0.00848)	(0.00526)
Cloud Prodes	9.30e-06	-2.39e-06
	(6.22e-06)	(1.47e-05)
Non-Observed Prodes	0.000155**	0.000109
	(6.66e-05)	(7.13e-05)
Crop Prices 1st Semester	1.439***	0.532***
	(0.429)	(0.175)
Crop Prices in t-1	-0.545**	-0.356*
	(0.238)	(0.186)
Cattle Prices 1st Semester	0.00147	-0.00616
	(0.00320)	(0.00570)
Cattle Prices in t-1	3.25e-07	-0.00524
	(0.00264)	(0.00468)
Observations	1,557	2,435
Number of municipalities	519	495
Municipality and Year FE	Yes	Yes

Notes: Coefficients shown are estimated using a municipality-by-year panel data set covering the 2007 through 2011 period. The sample includes all Amazon Biome municipalities. 2SLS regression with agriculture GDP as dependent variable is shown in column (1). Collumn (2) presents the same regression with agriculture revenues (from the Municipal Agricultural Survey) as the dependent variable. All regressions have controls for cattle prices (current and lagged), crop prices (current and lagged), and lagged rain. Lagged number of fines is instrumented by lagged Deter cloud coverage. Robust standard errors are clustered at the municipality level. Significance: *** p<0.01, ** p<0.05, * p<0.10.

Table 7
Robustness Checks

VARIABLES	(1) Normalized Deforestation	(2) Normalized Deforestation	(3) Normalized Deforestation	(4) Normalized Deforestation
Number of Fines in t-1	-0.0329**	-0.0538***	-0.0617**	-0.0474**
	(0.0161)	(0.0202)	(0.0263)	(0.0221)
Rain in t-1	-0.000194***	-0.000270***	-0.000239***	-0.000207***
	(4.63e-05)	(9.25e-05)	(7.32e-05)	(5.68e-05)
Priority Municipalities	0.0295	0.257	0.272	0.356
	(0.214)	(0.358)	(0.351)	(0.346)
Protected Areas	0.0106	0.0126	0.0144	0.0139*
	(0.00666)	(0.00886)	(0.00958)	(0.00838)
Cloud Prodes	5.09e-06	6.54e-06	1.07e-05	9.02e-06
	(1.83e-05)	(2.26e-05)	(2.42e-05)	(2.02e-05)
Non-Observed Prodes	0.000279***	0.000380***	0.000378***	0.000328***
	(8.59e-05)	(0.000132)	(0.000141)	(0.000114)
Crop Prices 1st Semester	-0.407	0.111	-0.0849	-0.345
	(0.267)	(0.521)	(0.317)	(0.299)
Cattle Prices 1st Semester	0.0132	-0.0695	0.0302**	0.0173*
	(0.00882)	(0.0507)	(0.0126)	(0.0103)
Crop Prices in t-1	-0.257	0.170	0.155	-0.213
	(0.294)	(0.561)	(0.389)	(0.341)
Cattle Prices in t-1	-0.0137*	0.0417	-0.0130	-0.0182*
	(0.00822)	(0.0634)	(0.0126)	(0.0100)
Observations	2,490	1,385	2,490	2,490
Number of municipalities	498	277	498	498
Municipality and Year FE	Yes	Yes	Yes	Yes
Time trend * initial deforestation rate				Yes
Time trend * initial forest share			Yes	

Notes: Coefficients shown are estimated using a municipality-by-year panel data set covering the 2007 through 2011 period. The sample includes all Amazon Biome municipalities. All specifications present 2SLS regressions with normalized deforestation as dependent variable. Column (1) presents robustness test substituting yearly average Deter cloud coverage by average Deter cloud coverage keeping only the months Prodes is not calculating deforestation. Column (2) presents a robustness test keeping only municipalities where the forest coverage is still higher than 50% of the territory. Column (3) shows a robustness test controlling for a trend that depends on the initial share of deforested territory. Column (4) presents a robustness check controlling for a trend that depends on the initial deforestation rates. All regressions have controls for cattle prices (current and lagged), crop prices (current and lagged), lagged rain, Prodes-clouds and non-observable areas during period of remote sensing. Lagged number of fines is instrumented by lagged Deter cloud coverage. Robust standard errors are clustered at the municipality level. Significance: *** p<0.01, ** p<0.05, * p<0.10.