Protecting the Rainforest? The Case of Mahogany Prohibition and Deforestation

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Abstract

Tropical deforestation increases carbon emissions, reduces carbon sinks, simplifies ecosystems, affect soil quality, can eliminate endemic species and can drastically change labor market prospects for local populations. All of these consequences may lead to large private gains and losses as well as global externalities and have drawn the attention of scholars and policy makers. More recently, the Paris Agreement stemming from the XXI Conference of the Parties placed protection of tropical forests as a key component for curbing climate change. Among the main causes of tropical deforestation, several commentators have identified logging of high-value timber species as an important precursor of large scale deforestation. A number of countries have accepted this argument and appealed to strict policies such as logging bans to protect specific species and forests. One example of such policy is the Brazilian mahogany market prohibition. We find evidence that the shutting down of this market combined with poor enforcement has led to an even larger volume of illegal mahogany harvesting. We use this result and differences-in-differences estimation to test whether municipalities where mahogany naturally occurs have experienced increased deforestation after prohibition. Our paper contains two main contributions: (i) evaluation of the impact of a timber market prohibition policy on deforestation, and (ii) the testing of the hypothesis that harvesting of high-value timber indirectly leads to large-scale deforestation. To our best knowledge, no study has attempted to directly estimate this hypothesis, despite its prevalence in the tropical deforestation literature and its use to at least partly justify forest protection policies such as logging bans. Our results suggest that the mahogany prohibition policy in Brazil meant to protect the species and the Amazon forest has instead led to increased deforestation in affected areas.

Keywords: Tropical deforestation, market prohibition, illegal markets, mahogany, Brazil

JEL codes: K42, O13, O17, Q23, Q28, Q58

1 Introduction

Tropical deforestation around the world has called the attention of policy makers and researchers for several decades now. Concerns with natural resource management, forest product extraction, economic development, national sovereignty, equity, biodiversity loss, and more recently climate change have motivated the study of tropical forests and the design of policies ranging from colonization to forest protection. The recent Paris Agreement resulting from the twenty first Conference of the Parties of the United Nations Framework Convention on Climate Change has given special attention to forest conservation, with specific language about the developing world, where much of the remaining tropical forests are located.

Not surprisingly, the economic literature on the causes of tropical deforestation and preservation policies is vast. For example, some studies find mixed evidence of the role of economic growth on deforestation, both of which are also influenced by openness to international trade and insecure property rights.[1] Others focus on the rural economy and investigate the contribution of population growth and density, agricultural prices, returns to agriculture and rural wages to the reduction of forested areas.[2] At the macroeconomic level, a number of studies analyze the role of institutions and public policies.[3] Also importantly, several researchers have pointed at the important role roads play in increasing tropical deforestation.[4]

Among the important drivers of tropical deforestation is the logging of high value timber. Penetration in dense tropical forests tends to be prohibitively costly for many economic activities, but these costs might be more than recovered in the case of extraction of high value timber. Whereas the direct impact of extraction of these types

[1]Cropper and Griffiths (1994), Antle and Heidebrink (1995) and Foster and Rosenzweig (2003)study the linkage between growht and deforestation, Foster and Rosenzweig (2003) and Lopez and Galinato (2005) fous on international trade, and Alston, Libecap and Mueller (2000) and Bohn and Deacon (2000) concentrate on property rights.

[2]See for example, Cropper, Griffiths and Mani (1999), Southgate (1990), Barbier and Burgess (1996), Lopez (1997) and Andersen et al. (2002).

[3]See for example, Repetto and Gillis (1988), Biswanger (1991), Hyde and Sedjo (1992), Deacon (1995) and Andersen et al. (2002). More recently, Burgess et al. (2012) study the incentives that provincial and district officers face in Indonesia and show how increased competition among political jurisdictions where enforcement of national conservation policies is weak can lead to increased deforestation.

[4]See for example Pfaff (1999) for a discussion of the case of the Brazilian Amazon region.

of wood on the forest cover tends to be small, the indirect effect on deforestation might be substantial. This happens because harvesting of tropical woods such as mahogany relies on building of basic infrastructure, especially logging roads, which lowers the penetration costs for other economic activities such as harvesting of less valuable timber, slash and burn agriculture, cattle raising and eventually large scale agriculture. That is, logging of the most valuable timber types can serve as a leading activity that opens the forest to large-scale deforestation that follows.

The argument that logging of high-end timber types plays an indirect role in opening up previously inaccessible forest areas has been applied to several tropical parts of the world.[5] In the particular case of mahogany extraction in Brazil, Verissimo et al. (1995, p. 60) claim that "after logging, there is a growing trend to convert forests to cattle pasture, in part perhaps, because the prospects for future mahogany harvests do not appear to be good."

The idea that high value timber extraction is an important determinant of large scale deforestation along with the intent to protect selected species has influenced the implementation of often times drastic forest protection policies in several countries.[6] To the extent that this study focuses on the evaluation of the mahogany market prohibition policy in Brazil, it also relates to the economic literature on the evaluation of market prohibition policies and illegal markets such as in the case of narcotics[7], alcohol[8] and environmental goods and services[9]. Our main contribution in this study, therefore, is the evaluation of the impact of the market for mahogany on deforestation

[5]For example, Cropper et al. (1999) apply this argument to Thailand when analyzing the causes of local deforestation; Amelung and Diel (1992) and Barbier et al. (1995) discuss the cases of Indonesia, Cameroon, Brazil and other "major tropical countries"; and Lykke et al. (2002) specialize to the Brazilian Amazon region.

[6]Durst et al. (2001) discuss timber extraction prohibition policies in New Zealand, China, Vietnam, The Philippines, Sri Lanka and Thailand. Similar prohibition policies are also common in other continents such as Africa (Mozambique), Latin America (Brasil) and Europe (Poland and Albania). In North America, environmental protection groups have file a petition for the banning of timber extraction in Walbran, British Columbia, Canada

[7]See for example, Adda et al. (2014), Dell (2015), Miron (1999, 2001, 2003) and Miron and Zwiebel (1995)

[8]Owens (2014), Miron (1999), Dills and Miron (2004) and Dills et al. (2005).

[9]Chimeli and Boyd (2010), Chimeli and Soares (2017), Burgess et al. (2012), Nelleman (2012) study the case of tropical timber. Other market prohibition policies related to environmental protection include the banning of chlorofluorocarbons (CFCs) mandated by the Montreal Protocol and of markets of species listed on Appendix I of the United Nations Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). See for example, Libecap (2014), Bulte and van Kooten (1999) and Murdoch and Sandler (1997).

of the Brazilian Amazon region. This analysis contributes not only to the evaluation of a national policy, but can also illuminate the design of international policies for the protection of tropical forests in countries with limited ability to monitor and enforce policies for illegal activities. We hope our discussion can aid in the debate on climate change and the understanding of market prohibition policies in general.

The hypothesis that the extraction of high timber value contributes in an important way to large scale deforestation is widely accepted in several circles of policy makers concerned with environmental protection. However, only limited testing of this hypothesis has been conducted so far and the results are not conclusive. To our best knowledge, no study has attempted to directly estimate the hypothesis that logging "opens" the forest to other economic activities, despite its prevalence in the tropical deforestation literature. Therefore, the second contribution of this study is to explore a natural experiment given by a policy change to test the hypothesis that the extraction of tree species with high timber value indirectly leads to large scale deforestation.

Two studies that come close to testing the aforementioned hypothesis are Barbier et al. (1995) and Cropper et al. (1999). Barbier et al. (1995) investigated the role of timber extraction on tropical deforestation in Indonesia using an annual time series ranging from 1958 to 1988. Their main goal was to simulate the impact of different wood market policies in local markets and in local deforestation. To do so, they estimated reduced form models for deforestation and for the supply and demand of wood products. The authors estimated a negative relationship between wood extraction and forest area, but given the correlation between wood production and agriculture, they acknowledge that they were not able to separately estimate the impact of these two drivers of deforestation. They therefore did not attempt to identify the role of timber extraction on deforestation.

Cropper et al. (1999) investigate the determinants of deforestation in a panel for 5 years and 58 provinces in Thailand and focus on road density, agricultural household density, terrain characteristics, transportation costs, agricultural prices and timber prices as their main explanatory variables. The authors estimate a positive impact of timber prices on deforestation both directly (although for only one region of the country and with a marginally significant coefficient) and indirectly through a first stage regression to address the endogeneity of road and agricultural household densities. They interpret timber prices as a proxy for logging roads, which do not appear in their standard measure of road density, and provide indirect evidence that logging contributes to deforestation. The authors, however, do not consider the potential endogeneity of timber prices in their estimation procedure.

Interestingly, in the discussion of their results, given the positive and significant coefficients for timber prices in their first stage regression, Cropper and colleagues indicate that making logging less profitable would make an impact on reducing deforestation and suggest that this was what the Thai government attempted to do by banning logging in 1989. In contrast, we study an event where prohibition combined with weak enforcement seems to have led to an increase in mahogany extraction.[10] Therefore, if mahogany extraction does in fact act as a driving force of large scale deforestation, then deforestation should have increased in areas where the tree naturally occurs relative to other areas after prohibition. It is precisely this unintended consequence of the prohibition policy that we estimate from our analysis.

In this paper, we tap into a unique natural experiment that allows us to shed light into the validity of the hypothesis that extraction of high-value timber leads to large-scale deforestation. In doing so, we can also assess the impact of the mahogany prohibition policy on forest conservation.

This paper is organized in seven sections in addition to the introduction. Section 2 describes the Brazilian mahogany protection policies that culminated in the market shutdown. Section 3 discusses the empirical evidence on the effect of prohibition, while section 4 presents a model that offers a foundation for our analysis. Section 5 discusses the data for our exercise and section 6 presents our empirical strategy. Section 7 presents our results and section 8 concludes.

2 National Policy for Mahogany Protection

Big leaf mahogany (Swietenia macrohylla King) is a tree species that naturally occurs in the Americas, ranging from Mexico to the Amazon forest, although concen-

[10]Chimeli and Boyd (2010) and Chimeli and Soares (2017).

tration of most existing specimens is reduced to the Amazon region as a consequence of centuries of logging of the species. Mahogany is used in the high-end furniture and construction markets and commands high prices due to its durability, color and malleability.

An active international market for big leaf mahogany led, in the 1990s, to the perception by environmental groups that the species was endangered.[11] Furthermore, some researchers claim that extraction of high value timber in tropical forests increases access to the dense forest, lowers the cost of land conversion and leads to large scale deforestation.[12] This perception then spurred international campaigns by both environmental groups and governments to curb harvesting of this tree.[13] At that time and until 2001, Brazil was the main producer of big leaf mahogany and most of the logged trees were processed and exported to North American and European countries, generating annual average revenues of US$129 million between 1971 and 2001 (Grogan et al. 2002).

The Brazilian government attempted to respond to the growing concerns surrounding extraction of mahogany with a policy to regulate this market, starting in the 1990s. The timing of the specific measures the Brazilian government adopted is illustrated in figure 1 by vertical lines, plotted over the time series for the total exports of Brazilian mahogany. These measures included decreasing export quotas that decreased from 150.000 m^3 in the early 1990s (vertical line labeled [1] in figure 1) to 65.000 m^3 in 1998 (line [5]) and finally 30.000 m^3 in 2001 (line [8]). In 1995, following suspicion of fraud in the forest management plans required for the granting of mahogany extraction licenses by the federal government, IBAMA, the executive branch of the ministry of the environment, started a review of the existing plans (line

[11]There was, however, no scientific consensus that mahogany was in fact an endangered species (Roozen, 1998).

[12]See for example, Amelung and Diehl (1992), Barbier et al. (1995), Verissimo et al. (1995) and Cropper et al. (1999).

[13]For example, environmental activists protested in front of a department store in London in 1993 (http://www.theguardian.com/environment/blog/2011/aug/12/photos-friends-earth-greenpeace-wwf), and engaged shoplifting of mahogany products and lumber in a protest in the UK in 1994 (http://articles.orlandosentinel.com/1994-06-15/news/9406150925_1_mahogany-shoplifting-environmental-activists). At the governmental level, some countries proposed increased monitoring of mahogany according to the United Nations Convention on International Trade of Endangered Species of Wild Fauna and Flora (CITES) (inclusion of the species in Appendix II of CITES) in 1992, 1994 and 1997. These proposals failed to gather sufficient international support (Grogan et al., 2002).

[2]). This review process produced evidence of manipulation of information leading to excessive harvesting and led to a moratorium on the issuance of new forest management plans starting in 1996 and extending to 2000 (line [3]). Eventually 85% of all mahogany extraction licenses were suspended in March of 1999 (line [6]) and the federal government created a mahogany working group that first met in June of 1999 (line [7]). All of the suspended licenses were for forest management plans located in the state of Pará, the largest producer of big leaf mahogany.

In the years 1992, 1994 and 1997 (line [4]), a number of countries requested the listing of mahogany in Appendix II of the United Nations Convention on International Trade of Endangered Species of Wild Fauna and Flora (CITES) (Grogan et al., 2002 and TRAFFIC International, 2002). Inclusion of a species in CITES-Appendix II does not signify prohibition of trade (Appendix I does), but instead requires both the importing and exporting countries to monitor trade. In all of these occasions the proposals to include big leaf mahogany in Appendix II were defeated and in 1998, following the Brazilian government initiative, the species was included in Appendix III (line [5]). Appendix III calls for monitoring of trade by the exporting country only. Although Brazil had opposed listing of the species in Appendix II, it proposed listing of big leaf mahogany in Appendix III, given that the country was already monitoring production and trade (through extraction licenses based on forest management plans).

After a number of attempts to limit the extraction of big leaf mahogany, the Brazilian federal government prohibited the harvesting, transportation and sales of the species in October of 2001, completely shutting down the market for the species (line [8]). Prohibition was reassessed and maintained in April of 2002 (line [9]) and is still in effect. In November of 2002, mahogany was finally listed in Appendix II of CITES (line [10]), and this resolution entered into force in November of 2003 (line [11]). Interestingly, listing of a species in Appendix II does not require prohibition of its market, but the Brazilian government adopted a much more radical measure despite its initial opposition to listing of mahogany in Appendix II.

Visual inspection of figure 1 suggests that the series of measures adopted by the Brazilian government and the pressures from the international community were successful in progressively reducing and finally eliminating mahogany extraction in the country. However, anecdotal evidence and formal export statistics suggest that this success was only apparent, as mahogany seemed to continue being exported through formal export mechanisms, but now disguised as other timber types. It is this fact that presents us with the opportunity to explore timber export data to estimate the effect of the mahogany prohibition policy on quantity exported, prices and deforestation.

Smuggling of mahogany from Brazil using formal export channels can be accomplished as the exporter fills out export forms reporting an international trade code (from the Mercosur Nomenclature, chapter 44) for a different timber type. The main timber types that are exported from the Brazilian Amazon are mahogany, louro, Brazilian cedar, ipe, virola and balsa wood. Each of these species has a separate international trade code that exporters are required to specify in the appropriate export documents (Registro de Exportação [RE], and Declaraçaão de Despacho de Exportação [DDE]). In addition to these, there is a residual trade code that encompasses "other tropical species" (NCM 4407.29.90).

Since there are presently no export taxes in Brazil, whereas import tariffs are common in the country, the likelihood of monitoring at the port ("yellow light" or "red light" levels of monitoring) is much lower for exports than for imports. The lower probability of apprehension at the port then gives timber exporters from the Amazon an incentive to smuggle mahogany as a different and less regulated timber type. Once this is done, exporters are paid the invoice value through formal export procedures, and the importer obtains a cargo complete with formal documentation.

Strong evidence of the exportation of mahogany under the guise of other species allows us to utilize trade information on the quantity and value of exports compiled by the Brazilian government. We can then use a unique data set to calculate implicit prices and investigate the impact of strict regulation and, ultimately, the prohibition of trade on the quantity and prices of mahogany exports as well as deforestation associated with an illegal mahogany market.

Before we plunge into the impact of mahogany prohibition on deforestation, we discuss two pillars for our study: (i) we summarize the empirical evidence on mahogany smuggling and the impact of the policy on export quantities and prices, and

(ii) we offer a simplified theoretial model that explains the unintended consequences of prohibition on quantities and prices.

3 Prohibition and the Illegal Market for Mahogany

3.1 Mahogany Smuggling: Empirical Evidence

The discussion of the consequences of mahogany prohibition in the remainder of this paper is based on the evidence supporting the hypothesis that a large market for mahogany continued to operate after the formal market shutdown. To test this hypothesis Chimeli and Boyd (2010) and Chimeli and Soares (2017) collected monthly data on exports of all timber types from the Brazilian Amazon from January 1989 to December 2007. The quantity (Kg) and implicit price (US$/Kg) data come from the Brazilian Secretariat on International Trade, from the Ministry of Development, Industry and International Trade (from its "Análise das Informações de Comércio Exterior," or Analysis of Information on International Trade, available at aliceweb.desenvolvimento.gov.br). To construct these series they take into account a change in export codes that took place in 1996. The precise strategy used to match the codes before and after 1996 is described in detail in Chimeli and Soares (2017).

The empirical strategy to test the hypothesis that mahogany was illegally exported involves investigating the time series for the exports of timber types from the Amazon listed under the different international trade codes. More specifically, we analyze the time series for the exports of Brazilian cedar, ipe, virola-balsa and "other tropical species" and use the Bai and Perron (1998) technique to estimate possible unusual changes in a time series – the so-called structural breaks or regime changes. Then, we compare the timing of the possible unusual changes in quantities exported of each of these species (structural breaks) with the timing of mahogany regulation.

The series for "other tropical species" shows a surprising pattern and is depicted in figure 2. The dashed and dark solid lines depicted in figure 2 are the same regulatory measures imposed on the mahogany market shown in figure 1. The red vertical lines are the two estimated dates of regime changes in the series of exports of "other tropical species". For a little over a decade, the exports of other tropical species was virtually zero, but in August of 1999, exports jumped by 3,500% in one single month. This drastic jump occurred quickly after a major intervention in the mahogany market: cancellation of 85% of all the mahogany extraction permits (line [6]), followed by the formation of a working group to oversee mahogany policies (line [7]). When the market was completely shut down in October of 2001 (line [8]), exports of "other tropical species" experienced another upswing. In summary, the exports of "other tropical species" drastically jumped from negligible levels in one single month to levels comparable to those of exported mahogany and remained as such for years to follow.

We interpret the matching of the timing of structural breaks in the exports of "other tropical species" and the timing of major regulation of the mahogany market as evidence that mahogany was actually smuggled under the guise of "other tropical species". We could ask whether the observed increase in exports is in fact simply a consequence of loggers switching their productive activities to the extraction of other species. But if this were the case, we should expect similar patterns in the exports of cedar, ipe and virola-balsa, species that also come from the Amazon region. This would be especially true in the case of cedar and ipe, since, like mahogany, these are typically sold in high-end markets. None of the series for these species presents a pattern that is similar to that of "other tropical species". In addition, the estimated breaks in the exports of "other tropical species" remain unchanged even when we control for the exports of ipe, cedar and virola-balsa in an attempt to account for the possibility of substitution of these species for mahogany after prohibition (Chimeli and Soares, 2017). Finally, the anecdotal evidence that this actually happens supports our interpretation that exports of "other tropical species" is in fact smuggled mahogany.[14]

If mahogany continued to be exported under the guise of "other tropical species", formal statistics on export quantities and value allow us to study the effectiveness and impact of the mahogany prohibition policy. In the following section reports the impact of prohibition on export quantities and price.

[14] Blundell and Rodan (2003), Barreto and Souza (2001), and Gerson (2000) describe the same phenomenon in the case of Brazilian mahogany. More recently a report compiled by the United Nations and the INTERPOL indicate that this method of smuggling is used in other parts of the world where illegal logging is pervasive (Nellemann 2012, p. 7).

3.2 Prices and Quantities: Empirical Evidence

Treating exports of other tropical species as exports of mahogany after major intervention in the market for the latter, we can add both series to investigate the impact of intervention on actual exports of mahogany over time. We do this, based on the fact that exports of other tropical species was negligible for over a decade and drastically jumped by 3,500% in one single month to levels comparable to those of formal mahogany exports quickly after major intervention in the mahogany market.

Figure 3 shows the combined series for mahogany and other tropical species from January of 1989 to December of 2006. It also plots the estimated structural breaks discussed above (red vertical lines) and the two major interventions in the mahogany market: cancelation of 85% of all extraction permits in March of 1999 (dashed vertical line) and prohibition in October of 2001 (solid dark vertical line). The blue horizontal lines indicate average exports before and after the first and more dramatic structural break. Average exports increased by 61% after major contraction of the formal market for mahogany. Exports after intervention bounced back to quantities close to the level of exports in the first two years of the series and after an entire decade of steady decline. This suggests that early intervention relying on declining export quotas and the threat of major intervention (review of existing plans and threat of listing mahogany in Appendix II of CITES) was more effective than actual major intervention that eventually led to prohibition of the mahogany market.

The formal data on Brazilian international trade also includes the value of exports. Adjusting these figures for inflation and dividing the value by the quantity of exports we can calculate the implicit price for the traded good. We use the aggregate series for exports of mahogany and "other tropical species" to calculate implicit prices for the period spanning from January 1989 to December 2006 and plot the data on Figure 4. Average prices declined by approximately one half.

If exports of "other tropical species" indeed represent smuggled mahogany after prohibition as the evidence suggests, our estimates show a striking result: the consequences of prohibition were the opposite to its intended outcomes. When policy makers decide to prohibit certain markets (such as the markets for narcotics, prostitution and other goods and services), they might expect an illegal market to exist, but hope that traded quantities will fall to levels below those that would prevail in a legal market and that prices will rise with prohibition. The evidence suggest that the opposite happened in the Brazilian mahogany case.

The increase in export quantities following prohibition of the mahogany market offers an important opportunity for the study of the connection between mahogany extraction and tropical deforestation. This will enable us to pursue two research questions: (i) assessment of the mahogany policy from the deforestation dimension and (ii) testing of an up to now largely untested hypothesis linking harvesting of high-end tropical species and large scale deforestation. Before we analyze these questions empirically, we offer a simple theoretical famework that explains the unexpected findings described in this section.

4 Prices and Quantities: A Conceptual Framework

The reasons for the observed changes in quantities and prices are varied. Here, we explore the idea that a legal market where private producers monitor illegal activity to protect their profits may produce less and charge a higher price relative to a scenario of prohibition where all producers choose to operate illegally. The appeal for this idea rests on the fact that it is very costly for the Brazilian government to monitor the large and often times difficult to access Amazon region. Private loggers tend to be much better informed about the logging activity in the areas where they operate and might have the incentive to monitor illegal competitors in order to protect their profits. When the market for mahogany became prohibited, the choice was whether to produce illegally or not at all. If illegal production is more profitable than no production, especially with the low ability of the government to monitor logging activity in the region, then it might make sense to save on private monitoring costs and avoid government attention induced by whistle blowing. This argument depends on the demand for mahogany, as well as on the response of the probability of apprehension of illegal logging to costly private monitoring effort.

To fix ideas, we focus on a simple model with two firms. When the market is legal, one of the firms operates legally, whereas the second firm can choose to operate illegally. In this simple model, we concentrate on the main driving forces behind our key results and abstract from rent seeking expenditures (to obtain and maintain an operating license), differential production costs between operation in the legal and illegal markets (due for example to costly measures to avoid apprehension, possibility of imprisonment, compliance with labor, production and product quality regulations as well as to costly resolution of legal disputes), and payments to corrupt officials. When the market is shutdown we assume that government officials have no monitoring capacity and the two firms compete by playing a standard Cournot game. The no monitoring capacity assumption is another simplification meant to characterize the stylized fact that monitoring of illegal activity is highly costly in the vast and often difficult to access Brazilian Amazon.

Consider a regulated market with one legal firm (firm 1) and one illegal firm (firm 2). These two firms compete by choosing the quantity produced, given their identical constant marginal cost c and the inverse linear demand, $p = a - b(q_1 + q_2)$, for their homogeneous product. Furthermore, the legal firm 1 can choose to spend resources m on monitoring the illegal firm 2. Monitoring increases the probability of apprehension $\theta(m)$, with $\theta(m) : \Re_+ \rightarrow [0,1]$, continuous, and $\theta(m)' \geq 0$. For simplicity, we assume that if firm 2 is caught operating illegally by firm 1, then firm 1 reports to the authorities who apprehend and destroy firm 2's output (apprehended output does not enter the market), and firm 2 is left with a loss equal to its total cost of production (cq_2). Firms 1 and 2 then maximize their expected profit functions

$$\max_{q_1,m} E[\pi_1] = [a - bq_1 - (1-\theta(m))bq_2]q_1 - cq_1 - m$$

and

$$\max_{q_2} E[\pi_2] = (1-\theta(m))[a - bq_1 - bq_2]q_2 - cq_2.$$

From the first order conditions we obtain

$$q_1 = \frac{a(1+\theta(m)) - c}{b(3+\theta(m))}, \tag{1}$$

$$q_2 = \frac{a(1-\theta(m)) - c(1+\theta(m))}{b(1-\theta(m))(3+\theta(m))}, \tag{2}$$

and

$$\theta'(m) = \frac{1}{bq_1q_2}. \tag{3}$$

Furthermore, given firm 1 and 2's production decisions from (1) and (2) and the possibility of apprehension of firm 2's output with probability $\theta(m)$, the expected equilibrium quantity and price are given by:

$$Q = q_1 + (1 - \theta(m))q_2 = \frac{2a - c(2 + \theta(m))}{b(3 + \theta(m))} \tag{4}$$

and

$$p = a - bq_1 - b(1 - \theta(m))q_2 = \frac{a(1 + \theta(m)) + c(2 + \theta(m))}{3 + \theta(m)} \tag{5}$$

From equation (2), q_2 is strictly positive when $\theta(m) = 0$ (assuming that $a > c$) and firm 2 does not operate for large enough $\theta(m)$ (since q_2 goes to minus infinity as $\theta(m)$ approaches 1). Assuming continuity of $\theta(m)$, there is, therefore, some $\theta(m) \in (0, 1)$ such that q_2 is positive. Furthermore, equation (3) can only be satisfied for positive q_1 and q_2.

Next, we consider prohibition when the government has no monitoring capacity. In this scenario the two firms play a standard Cournot game without monitoring. The first order conditions for this game lead to (1), (2), (4) and (5) with $\theta(m) = 0$. Changing notation slightly and using superscripts R and I to denote equilibrium outcomes in the regulated market and full-fledged illegal market, respectively, it then follows that

$$p^R - p^I = \frac{2\theta(m)(2a + c)}{3(3 + \theta(m))} > 0,$$

and

$$Q^R - Q^I = -\frac{\theta(m)(2a + c)}{3b(3 + \theta(m))} < 0.$$

That is, moving from a regulated to a full-fledged illegal market leads to a decrease in equilibrium price and an increase in equilibrium quantity.

Lastly, we consider whether the firm legally operating in the regulated market (firm 1) actually has an incentive to do so and monitor illegal production by firm 2. That is, a formal market will only exist if firm 1's profits in the regulated market are greater than the profits it would obtain if it instead turned to illegality:

$$E[\pi_1^R] - \pi_1^I = (p^R - c)q_1^R - m - (p^I - c)q_1^I > 0. \tag{6}$$

We start exploring condition (6) by first noticing that production by firm 1 is greater in the regulated market than in the unregulated market:

$$q_1^R - q_1^I = \frac{a(1+\theta(m)) - c}{b(3+\theta(m))} - \frac{a-c}{3b} = \frac{\theta(m)(a+c)}{3b(3+\theta(m))} > 0.$$

This result combined with higher prices in the regulated market ($p^R > p^I$) implies that revenues minus production costs for firm 1 are higher in the regulated case than in the illegal market. Condition (6) will then be met if the difference in revenues minus production costs in the two market settings is greater than monitoring expenditures m. Condition (6) reduces to

$$E[\pi_1^R] - \pi_1^I = \frac{\theta(m)(2a+c)(a(4\theta(m)+6) - c(\theta(m)+6))}{9b(\theta(m)+3)^2} - m > 0 \tag{7}$$

The fraction in (7) is the difference in revenues minus production costs for the legal and illegal market scenarios and is clearly positive (since $a > c$). Whether condition (7) holds true will in general depend on the functional form for $\theta(m)$ and the model's parameter values. For example, condition (7) is satisfied assuming $\theta(m) = \frac{e^m - 1}{e^m + 1}$, $a = 10$, $b = 3$ and $c = 2$.

Another factor that might have contributed to the increase in production and decrease in prices after prohibition is that some costs are avoided as a consequence of illegal operations. For example, illegal producers avoid safety and environmental regulations, taxes, license fees and other expenditures to acquire them (rent seeking behavior) and costly dispute resolution in the judicial system. Illegality also involves added costs, such as potential imprisonment, costly measures to avoid apprehension and bribes. In principle, avoided costs can outweigh additional costs, especially if the ability of authorities to monitor trade is severely limited. If this was indeed the case, then prohibition might have contributed to an increase in the supply of mahogany, thus driving equilibrium quantities up and prices down.

Finally, the formal mahogany export data in figure 1 depict a declining trend over time while producers were still legally operating. This trend might have been a direct consequence of progressive smaller export quotas imposed by the Brazilian government – keeping in mind that most mahogany production was exported to other countries. With prohibition and low monitoring ability by the appropriate authorities, producers might have been able to increase production and take advantage of economies of scale that were not possible under the export quota regime. The ability of loggers to tap into economies of scale after prohibition might have contributed to an increase in traded quantities and a decrease in market prices.

5 Data

Mahogany Variables

In order to conduct our exercise, we need some indicator of the relevance of mahogany to a certain area of the country. Lentini et al. (2003), based on Lamb (1966), provide a map of the area of natural occurrence of mahogany in the Brazilian territory. We superimpose this map on a map of the political division of Brazil into municipalities and create a dummy variable equal to 1 if a municipality is located within the area of natural occurrence of mahogany. We plot this dummy variable on a political map of the Brazilian Amazon in the appendix.

The data on exports of mahogany and other tropical timber used to plot figures 1 through 4 come from the Brazilian Secretariat on International Trade, from the Ministry of Development, Industry and International Trade (from its "Análise das Informações de Comércio Exterior," or Analysis of Information on International Trade, available at aliceweb.desenvolvimento.gov.br). The series are monthly exports in kilograms for all exporting states between January 1989 and December 2013.

Outcome Variables

We use four outcome variables as indicators of deforestation at the municipal level: annual deforestation flow as a percentage of municipal area, stock of deforested area as a percentage of municipal area, forest cover as a percentage of municipal area and bovine density. The data on deforestation and forest cover come from the PRODES project compiled by the Brazilian National Institute for Space Resarch from the Brazilian Ministry of Science, Technology and Innovation (http://www.obt.inpe.br /prodes/index.php). The PRODES data are based on satellite images and the information at the municipal level range from 2000 to 2014. Data on annual deforestation refers to accumulated deforested area until the year under consideration. Forested area refers to the observed stock of forest each year. The information on forested and deforested area is impacted by areas that were not observed in the satellite images each year. This can happen due to the presence of excessive clouds or to low radiometric quality of the images for a given area. For this reason, we follow Butler and Moser (2007) and control for these omitted areas in our regressions below.[15]

The fact that the time series on deforestation and forest cover starts in 2000 greatly limits our ability to make inferences on the impact of the mahogany market intervention on deforestation. For this reason and given the fact that deforested areas are typically converted into cattle farms, we use bovine density to indirectly estimate the impact of mahogany prohibition on deforestation. Data on bovine density at the municipal level come from IBGE and range from 1974 to 2013. We limit our data set to the period between 1995 and 2013, because 1995 was the year when Brazilian authorities started regulating mahogany production by issuing licenses to producers and requiring a forest management plan (Garrido Filha, 2002).

Control Variables

The choice of control variables is guided by our main empirical concerns, which we discuss in detail in the next section. Our goal is to account for other relevant changes possibly taking place simultaneously to the prohibition of mahogany trade, and which may also affect deforestation.

[15]The PRODES database contains information on deforested area, forest cover, areas covered by clouds, unobserved areas, non-forest areas (such as urban centers) and water bodies. This allows us to check whether the sum of their data coincide with the area of the municipality. In fact this is true for the overwhelming majority of the municipalities. Among the 8613 observations for all municipalities of the Legal Amazon Region and the years in the sample, only 0,95% of the summed areas exceed the total municipal area by at most 0,5%. Whenever this happens, visual inspection suggests measurement errors where the indicator "unobserved area" also includes the deforestation flow for that year. Since we do not use the "unobserved area" indicator, not even the infrequent cases of suspected measurement error affect our analysis.

We have municipality level information on: (i) area planted with temporary and permanent crops, from the municipal agricultural surveys from IBGE; (ii) number of deaths associated with land conflicts, collected by the "Comissão Pastoral da Terra," a catholic organization that monitors and mediates land conflicts in Brazil; (iii) mortality rates due to homicides, infectious diseases, cardiac diseases, neoplasms, suicide, traffic accidents and child mortality (less than 5 years of age); and (iii) gdp per capita and share of gdp in agriculture, from the Brazilian national accounts. Municipality gdp per capita is available only for 1996 and after 1998. Other variables are available for all years during the period of interest.

The data on planted area from IBGE are a good indicator of the presence of crops in the region, but eventual interpretation must be done with care. This happens, because according to IBGE this indicator "presumes the possibility of planting of successive and simultaneous crops (simple, associated and/or intercalated crops) in the same year and place, making it possible for the informed area for a given crop exceed the area of the municipality" (http://api.sidra.gov.br/home/ajuda).

Given the heterogeneity across regions of Brazil, we conduct our analysis with two samples that restrict attention to areas with more similar characteristics. We start by looking at municipalities in states with natural occurrence of mahogany, and then consider only municipalities in the state of Pará. Treatment and control groups are more homogeneous within Pará, which is also a particularly relevant state because it accounts for more than 70% of mahogany exports before prohibition. On the other hand, geographic proximity may lead to concerns that contamination of the control group is a potential problem over smaller areas, where spillovers of deforestation from mahogany to non-mahogany regions may be more likely. So, given the different strengths and weaknesses of the two samples, we keep both of them throughout the paper, though focusing most of the discussion on the state of Pará.

6 Empirical Strategy

The variation we explore to identify the causal effect of prohibition on deforestation combines the timing of the institutional changes and the distinct relevance of mahogany across different areas. In principle, if the increase in deforestation after prohibition is larger in mahogany occurring areas, it could be attributed to prohibition. The timing of the intervention considered here is unique for the entire country, so identification of the effect of prohibition comes from the heterogeneous response of different areas to prohibition.

Given the institutional discussion from section 2 and the evidence to be presented in the next section, we focus on two years as key moments in the tightening of regulations. First, we create a dummy variable equal to 1 for the interval between 1999 and 2001, capturing the first major step towards prohibition (suspension of 85% of the operating licenses for management plans). Following, we create a second dummy variable equal to 1 for the interval 2002 and 2008 following the prohibition of mahogany instituted in October 2001 and before the generalized decrease in deforestation in the Amazon region due to the Action Plan for Prevention and Control of Deforestation in the Legal Amazon region (PPCDAm). We also create a dummy variable equal to 1 for the year 2009 e subsequent years to capture the effect of prohibition along with the generalized decrease in deforestation. In some specifications, we consider two time dummies: one for the 1999 through 2001 period and another for 2002 and following years, therefore focusing only on the interventions in the mahogany market. For the case of the deforestation variables, the available time series does not allow us to estimate the impact of the first intervention.

Our main results are based on a difference-in-difference strategy applied to a number of direct and indirect indicators of deforestation, as well as a number of municipal level indicators that we do not expect to be affected by the mahogany market interventions.

We start by estimating the following difference-in-difference regression:

$$y_{it} = \alpha + \beta_1 \cdot (D_{1999 \leq t \leq 2001} \times M_i) + \beta_2 \cdot (D_{2002 \leq t \leq 2008} \times M_i) + \beta_3 \cdot (D_{t \geq 2009} \times M_i) + z'_{it}\gamma + \theta_i + \mu_{st} + \epsilon_{it}, \quad (8)$$

where y_{it} indicates the direct (deforestation flow, deforestation stock or forest stock as percentages of municipal area) or indirect (bovine density) measures of deforestation for municipality i in year t; $D_{1999 \leq t \leq 2001}$ is a dummy variable equal to 1 for the years between 1999 and 2001; $D_{2002 \leq t \leq 2008}$ é dummy variable equal to 1 to the years 2002 through 2008; $D_{t\geq 2009}$ is a dummy variable equal to 1 for 2009 and all following years; M_i is a dummy variable equal to one if the municipality i is located in the mahogany area and zero otherwise; z_{it} is a vector of control variables; θ_i is a municipality fixed-effect; μ_{st} is a state-specific year dummy; ϵ_{it} is a random term; and α, β_1, β_2, and γ are parameters. Under the usual assumptions, $E[\epsilon_{it}|D_{1999\leq t\leq 2001}, D_{2002\leq t\leq 2008}, D_{t\geq 2009}, M_i, z_{it}, \theta_i, \mu_{st}] = 0$, and OLS estimation of the above equation provides unbiased estimates of the β's.

In our context, there are two potential concerns with the difference-in-difference strategy: omitted variables and differential dynamic behavior of deforestation rates. There may be other changes happening simultaneously to the prohibition of mahogany. In particular, prohibition has economic impacts that may indirectly affect deforestation, through reduced income and worsened labor market opportunities, or through changes in the pattern of agricultural activity not directly affected by mahogany extraction. In addition, some of the mahogany areas are remote regions of the country that may be going through modernization and increased urbanization. To partly address these concerns, we allow for state-specific time dummies, so that any systematic differences across states due to policy or socioeconomic changes are immediately controlled for.

We also control for several municipality characteristics: area planted with temporary and permanent crops, gdp per capita (ln), share of gdp in agriculture; number of deaths due to land conflicts; and rates of death from several causes. Since most of these variables could in principle be endogenous to the restrictions to mahogany trade, our benchmark specification controls for interactions of the baseline (1995) values of these variables with time dummies. The benchmark specification also includes an interaction between the baseline dependent variable and time dummies, to allow for differential dynamics of deforestation and bovine density according to initial conditions. So, in effect, municipalities are allowed to have arbitrarily different dynamics of deforestation as a function of this set of initial characteristics.

Our controls account for: (i) socioeconomic conditions (gdp per capita and several rates of death from different causes potentially associated with modernization, urbanization of remote areas, as well as economic development - as in the case of infant deaths and from infectious diseases) and (ii) potential deforestation and bovine density associated with the agricultural frontier (fraction of area planted with temporary and permanent crops, share of gdp in agriculture, equine, swine and chicken density, and assassinations due to land conflicts). In our context, controlling for changes in the agricultural frontier as represented by the fraction of area planted, the share of gdp in agriculture, livestock and the number of assassinations due to land conflicts is particularly important. Ill-defined property rights in the Brazilian agricultural frontier, which is partly located in the Amazon region, are commonly associated with violence and deforestation (see Alston et al., 2000, and Altson and Mueller, 2010). It is important therefore to isolate the deforestation associated with illegal extraction of mahogany from that related to irregular occupations associated with agricultural activities. Though related to each other, these are different types of deforestation, driven by distinct mechanisms.

Finally, as the difference-in-difference strategy may lead to underestimation of standard errors due to autocorrelation in the residuals, we cluster standard errors at the municipality level in all specifications, allowing for an arbitrary structure of correlation over time (as suggested by Bertrand et al., 2004).

7 Results

Our primary specification uses bovine density in the treated municipalities (where mahogany naturally occurs) and control municipalities (without mahogany). The reason for our focus on this indirect evidence on deforestation is that the literature points at bovine farms following mahogany extraction, and because the time series on deforestation at the municipal level is too small to allow us to confidently estimate the causal relationship between mahogany prohibition and deforestation. Nevertheless, before we delve into the results for bovine density, it is informative to look at the direct evidence that links the mahogany market prohibition and the flow of deforestation, stock of deforested area and the forest cover in the affected municipalities relative to the control group.

7.1 Mahogany Prohibition and Deforestation

Table 1 describes the estimated coefficients from specification (8) where the dependent variable is the annual flow of deforestation. The data on deforestation flow at the municipal level cover the years from 2001 to 2013, making it impossible for us to estimate the impact of the first large intervention in the mahogany market and capturing only the second intervention (prohibition). Columns (1) through (5) show the results for all the states containing an area where mahogany naturally occurs, whereas columns (6) to (9) show the results for the state of Pará, where most of the production of mahogany took place when the market was legal. Columns (4) and (5) summarize the results for triple differences that take into account the relative importance of the mahogany market in each state. In column (4), the triple difference is defined as the interaction between the treatment period, the treated municipalities and the percentage of the total exports attributed to the state where the municipality is located. In column (5), the triple difference is defined as the interaction between the treatment period, the treated municipalities and the total suspected mahogany exports from the state where the municipality is located. The models in columns (3), (4), (5), (8) and (9) include the control variables in their pre-treatment levels interacted with a year time effect. We use this strategy to avoid the probable endogeneity of the control variables and to consider possible differential deforestation dynamics for each municipality given their initial conditions. Columns (7) and (9) include the interaction between the treatment variables with a linear trend in order to capture possible specific dynamics of deforestation in the treated areas after treatment.

The results from table 1 suggest weak evidence that the flow of deforestation has indeed increased in the municipalities where mahogany occurs relative to other municipalities after prohibition. Except for column (5), all coefficients of the treatment variables are positive and marginally significant in some cases. Columns (7) and (9) suggest that the level of deforestation was higher in the mahogany municipalities after intervention, but with a negative trend after 2008, when deforestation fell in the Amazon region as a whole. These results are consistent with higher deforestation rates after mahogany prohibition in the affected municipalities and rates that converge to the general deforestation rates for the untreated municipalities. This hypothesis is also captured by figure 5 to be discussed below.

Table 2 shows the results for the accumulated stock of deforestation each year. The treatment variables are positive and significant in several of the specifications, especially after 2009, when accumulated deforestation was larger. Finally, table 3 sugere, as we would expect, the opposite of what we observed with the stock of deforestation. That is, the forest cover decreased after prohibition in the regions where mahogany naturally occurs.

In order for us to gain further insight into our results, it is instructive to explore the dynamic effects of prohibition on deforestation and submit the results from our differences in differences models to an additional test. We do so by estimating the following model:

$$y_{it} - y_{it_0} = \delta + \sum_{t=0}^{T} \beta_t \cdot M_i \cdot D_t + \Gamma \cdot Z_{it} + \epsilon_{it}, \quad (9)$$

where y_{it} is a response variable (deforestation or forest cover), t_0 is a base year (2000 in the case of deforestation stock and forest cover, and 2001 in the case of deforestation flow), M_i is a dummy variable equal to 1 if the municipality is located in the mahogany area and 0 otherwise, and D_t is a set of time dummies equal to 1 if the year is t and 0, otherwise. Z_{it} represents municipal controls for the base year (1995 for most controls, 1996 for the case of GDP per capita and fraction of GDP in agriculture, and 2000 or 2001 in the case of the deforestation variables as described above) so that we can avoid the endogeneity problem associated with these variables and capture differential municipal dynamics possibly associated with each municipality's initial conditions. Lastly, ϵ_{it} is a random term. We estimate equation (9) as a pooled OLS model with robust standard errors clustered at the municipal level. The data refer to the state of Pará only, where most of the legal extraction of mahogany used to take place.

Figures 5, 6 and 7 plot the β_t coefficients for the response variables deforestation flow, deforestation stock and forest cover, respectively. As figure 5 shows, we estimate that the flow of deforestation as a percentage of the municipal area is significantly larger for the mahogany municipalities between 2002 and 2005, relative to the other municipalities in the state of Pará. Deforestation slows down between

2006 and 2008, although it remains more at a higher level in the mahogany area and, finally converges to levels comparable to those from the municipalities without mahogany. The results for deforestation flow are compatible with the results for the stock of deforestation as a fraction of the municipal area shown in figure 6. The stock of deforestation was significantly smaller in the municipalities with mahogany in 2001, expanded to the same level as in the areas without mahogany by 2004 and continued to grow at a decreasing rate until 2013. Figure 7, in turn, depicts the impact of prohibition from the perspective of the forest stock as a fraction of the municipal area: the forest cover in the mahogany area was larger than in the non-mahogany area until 2005 and these two started converging beginning in 2006. We might expected a symmetry between figures 6 and 7, but this did no result. A possible reason for this is that the occurrence of unobserved areas due to clouds and low radiometric quality might be correlated with the presence of forests. It might be reasonable to suppose that deforestation may change the micro-climate and concentrate clouds in specific areas. For this reason and following Butler and Moser (2004) and Assunção et al. (2015), all the deforestation and forest cover regressions control for cloud area as a fraction of the municipal area.

Given the data limitation in the case of deforestation as well as the connection between mahogany and bovine farms in the Amazon region, the next section discusses the results for bovine density. The time series for these data is longer and we can explore the impact of all of the most significant interventions in the mahogany market using specifications (8) and (9).

7.2 Mahogany Prohibition and Bovine Density

Table 4 shows an increase in bovine density in the mahogany municipalities relative to other municipalities after the interventions in the mahogany market, especially after prohibition was in effect starting in 2001. In the specification in table 4, we include two treatments given by $1999 \leq t \leq 2001$ (time period immediately after banning of 80% of the mahogany extraction licenses) and by $t \geq 2002$ (post prohibition period). The coefficients for the second treatment are positive and significant in all specifications. This result may reflect not only the effect of the second intervention, but also the lagged effect of the first intervention, since there may be a time lapse between mahogany extraction and the introduction of bovines in a given area.

Table 5 reports the results for equation (8) including three treatment variables in order for us to separate the impacts of cancellation of licenses ($1999 \leq t \leq 2001$), prohibition ($2002 \leq t \leq 2008$) and prohibition combined with a generalized decline in deforestation in the Brazilian Amazon region ($t \geq 2009$). Like in the case with only two treatment variables, bovine density increased significantly in the mahogany municipalities relative to those without mahogany. As we compare tables 4 and 5, we notice that the coefficients from the second treatment are close in magnitude, although smaller in the second case. The results in columns (4) and (9) include linear trends interacted with the treatment variables and indicate a statistically significant increase in the bovine density after 2001 and 2008, with an upward trend between 2002 and 2008. After 2008, when deforestation fell in the Brazilian Amazon as a whole, we do not observe any significant trends in the mahogany area relative to the control group.

Lastly, figure 8 shows the dynamics of the bovine density in the mahogany municipalities relative to the other municipalities in the state of Pará and according to equation (9). Bovine density in the mahogany municipalities is not statistically different from that for the municipalities without mahogany between 1996 and 2001 (although our point estimates shows a jump in the β coefficients from 1999 to 2000). Starting in 2002, bovine density becomes higher in the mahogany municipalities than in the control group, grows over the following years and stabilizes at a higher level between 2010 and 2013. This patterns is consistent with those presented in figures 5, 6 and 7, and with the hypothesis that mahogany extraction is followed by the bovine activity and opens up the forest for large scale deforestation.

7.3 Mahogany Prohibition and Bovine Density: Robusteness Checks

The differences in differences model hinges on the hypothesis that parallel trends exist between the treated and control groups. Table 6 shows the results for regressions that include a placebo treatment defined as the interaction between a time dummy equal to 1 for the years 1997 and 1998 and a dummy for the mahogany municipalities. The results for the mahogany states, mahogany states except Pará and the state of Pará separately appear in columns (1), (3) and (5). The results suggest different trends for mahogany and non-mahogany municipalities outside the state of Pará, but not for those within this state. This gives us an additional reason to concentrate on the results for the state of Pará (for this reason and the leading role Pará played in the exports of mahogany whent the market was legal, figures 5, 6, 7 and 8 refer only to data for Pará). The specificaitons in columns (2), (4) and (6) explore the possibility of differential trends at the municipal level by including the interaction between a municipal fixed effect with a linear trend. In all instances, bovine density is higher in the mahogany municipalities than in those without mahogany after prohibition of the market for the species.

Table 7 re-estimates our basic specification for the state of Pará without weights (column (1)) and with standard errors that are robust to spatial correlation (column (2)). The impact of the restriction of the mahogany market on the bovine density remains positive and significant. We also notice the similar magnitude of the coefficients for the second treatment in all of the models for bovine density.

Next, we investigate the impact of mahogany prohibition on the density of equines, chicken and swines. Table 8 presents the differences in differences results for the state of Pará. Like in the case of bovines, the equine density increased in the mahogany municipalities after prohibition relative to other municipalities. This result can be a consequence of the use of equines as an input in the extensive bovine farming activity in most of the Brazilian Amazon region.[16]. As for the density of chicken and swines, we do not estimate any impact of mahogany prohibition, as expected.

Lastly, tables 9 and 10 report the effect of the mahogany policy in the areas planted with temporary and permanent crops as a percentage of the municipal areas, respectively, in the state of Pará. Based on the literature, we did not expect these crops to affected by the mahogany prohibition policy. Alternatively, we can take an agnostic point of view and ask whether mahogany extraction spurs the occupation of the territory with specific crops. The indicators for planted area with temporary crops are total area, and areas with rice, beans cassava and soybeans. These are the main

[16]See for example, Silva et al. (2013), p. 3.

temporary crops in the state of Pará.[17] The estimated coefficients on table 9 do not suggest any robust and significant impact on these variables. Table 10, shows the results for total area planted with permanent crops, and more specifically with banana, cacao and dende, the main permanent crops in the state.[18] Except for the case of banana, where we estimate an increase in production in the mahogany municipalities after the first treatment, we do not observe a significant and robust impact of the mahogany policy on the remaining crops.

8 Conclusion

This paper presents evidence of the increase in deforestation in Brazilian regions with natural occurrence of mahogany following the introduction of restrictive regulations and eventual prohibition of mahogany exploration. Much has been said in the popular press and in the academic literature about the importance of protecting rainforests, a debate that gained importance with recent discussions on climate change and measures to curb global warming. The design of policies for the protection of tropical forests is still largely debated and existing policies are constantly reassessed. This paper adds to this debate and sheds light into two issues relevant to tropical deforestation. First, we present evidence of a mechanism leading to tropical deforestation that was largely untested in the formal literature: despite an allegedly small direct impact on forest cover, harvesting of high value timber leads to large-scale tropical deforestation. Second we provide an assessment of a market prohibition policy that not only was largely ineffective, but indeed exacerbated the problems it wanted to attack: mahogany extraction and deforestation. Logging bans are not uncommon around the world and the evidence we present here places an extra burden of proof in establishing their effectiveness. Perhaps for this reason, the recent Paris Agreement resulting from the UNFCCC conference of the parties (COP 21) places an added emphasis on positive incentives for forest protection mechanisms.

Different markets are embedded in different institutional settings and the consequences of illegality are likely to vary across contexts. For example, corruption and

[17] Fundação Amazônia de Amparo a Estudos e Pesquisas do Pará (2015).

[18] Fundação Amazônia de Amparo a Estudos e Pesquisas do Pará (2015).

high monitoring costs may make it difficult to enforce the prohibition of narcotics in different parts of the world, whereas the existence of low cost substitutes for chlorofluorocarbons (CFCs) may have contributed to the largely successful – although not perfect – worldwide ban on this substance. With these caveats in mind, our analysis provides one piece of evidence pointing at a causal effect of logging bans on tropical deforestation, and exemplifies how enforcement capacity interferes in this relationship.

Our results highlight the relevance of limited enforcement ability and serve as guide for policy makers wishing to regulate markets associated with perceived negative externalities. Consider US Executive Order 12866 of 1993 stating that "Each agency shall assess both the costs and the benefits of the intended regulation and, recognizing that some costs and benefits are difficult to quantify, propose or adopt a regulation only upon a reasoned determination that the benefits of the intended regulation justify its costs." Deforestation is an important social cost to be accounted for in the cost-benefit analysis of bans for forest products. In the absence of adequate enforcement capabilities, addressing unwanted externalities with overly restrictive regulations may create or exacerbate social losses.

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Table 1 - Mahogany Prohibition and Deforestation Flow, 2001-2013, Differences in Differences, Results for States with Natural Ocurrence of Mahogany and for the State of Pará.

	Municipalities in states with mahogany occurrence					Municipalities in Pará			
				Triple Difference					
				State percentage in exports before 1999	Suspected state exports after 1999		Treatment interacted with linear trends		Treatment interacted with linear trends
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treatament 2002	0.0489***	0.0126*	0.00403***	0.00469*	-1.46e-06	0.0221*	0.0222*	0.00350*	0.00270
	[0.0143]	[0.00678]	[0.00135]	[0.00273]	[1.06e-05]	[0.0115]	[0.0114]	[0.00201]	[0.00270]
Treatament 2002 x Trend							-4.00e-05		0.000265
							[0.000327]		[0.000348]
Treatament 2009	0.0461***	0.00811	0.000804*	0.00193*	-6.39e-05*	0.0189	0.0199	0.00112	0.00196*
	[0.0156]	[0.00712]	[0.000459]	[0.00101]	[3.75e-05]	[0.0121]	[0.0121]	[0.000792]	[0.00109]
Treatament 2009 x Trend							-0.000463***		-0.000426*
							[0.000153]		[0.000215]
Constant	-0.00975*	-0.000512	0.00115***	0.00110***	0.00137***	-0.00402	-0.00378	0.00163***	0.00189***
	[0.00528]	[0.00228]	[0.000360]	[0.000322]	[0.000322]	[0.00444]	[0.00443]	[0.000518]	[0.000538]
State FE x Year FE		X	X	X	X				
Baseline Charac. x Year FE			X	X	X			X	X
Year FE	X	X	X	X	X	X	X	X	X
Number of Observations	7,696	7,696	6,864	7,436	7,436	1,664	1,664	1,352	1,352
R^2	0.219	0.384	0.977	0.976	0.976	0.333	0.333	0.961	0.961

Notes: Robust standard errors in brackets (clustered at the municipal level), *** p<0.01, ** p<0.05, * p<0.1. Dependent variable is the flow of deforestation as a percentage of municipal area. All regressions include a constant, municipality fixed effects and year fixed effects, and are weighted by municipal population. Treatment variables are dummies = 1 for the period 1999-2001, 2002-2008 and after 2009 interacted with mahogany occurrence area. Columns (2)-(5) control for state fixed effects interacted with year fixed effects. Columns (3), (4), (5) , (8) and (9) control for year dummies interacted with baseline values (1995) for the following variables: homicide rate, political deaths, rate of infant deaths, rate of death by infections diseases, cardiac diseases, neoplasms, suicide and traffic accidents, area planted with temporary and permanent crops, bovine, equine, swine and chicken density, deforested area (annual flow and stock) and stock of forest as a percentage of the municipal area, ln of GDP per capita (1996) and fraction of GDP in agriculture (1996).

Table 2 - Mahogany Prohibition and Deforestation Stock, 2000-2013, Differences in Differences, Results for States with Natural Ocurrence of Mahogany and for the State of Pará.

	Municipalities in states with mahogany occurrence					Municipalities in Pará			
				Triple Difference					
				State percentage in exports before 1999	Suspected state exports after 1999		Treatment interacted with linear trends		Treatment interacted with linear trends
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treatament 2002	-0.00593	0.0236***	0.0177***	0.0169	5.91e-05*	0.0157	-0.00126	0.0131	0.00188
	[0.0168]	[0.00788]	[0.00648]	[0.0125]	[3.36e-05]	[0.0112]	[0.00752]	[0.00898]	[0.00345]
Treatament 2002 x Trend							0.00566***		0.00379*
							[0.00161]		[0.00205]
Treatament 2009	0.0120	0.0457***	0.0308***	0.0389*	0.000662***	0.0408**	0.0361**	0.0311*	0.0277*
	[0.0196]	[0.0115]	[0.0102]	[0.0213]	[0.000244]	[0.0174]	[0.0165]	[0.0164]	[0.0152]
Treatament 2009 x Trend							0.00236***		0.00191*
							[0.000565]		[0.000992]
Constant	0.351***	0.343***	0.349***	0.348***	0.348***	0.389***	0.388***	0.427***	0.425***
	[0.00752]	[0.00377]	[0.00264]	[0.00148]	[0.00126]	[0.00749]	[0.00727]	[0.00569]	[0.00646]
State FE x Year FE		X	X	X	X				
Baseline Charac. x Year FE			X	X	X			X	X
Year FE	X	X	X	X	X	X	X	X	X
Number of Observations	8,288	8,288	7,392	8,008	8,008	1,792	1,792	1,456	1,456
R^2	0.984	0.989	0.998	0.998	0.998	0.993	0.993	0.997	0.997

Notes: Robust standard errors in brackets (clustered at the municipal level), *** p<0.01, ** p<0.05, * p<0.1. Dependent variable is the stock of deforestation as a percentage of municipal area. All regressions include a constant, municipality fixed effects and year fixed effects, and are weighted by municipal population. Treatment variables are dummies = 1 for the period 1999-2001, 2002-2008 and after 2009 interacted with mahogany occurrence area. Columns (2)-(5) control for state fixed effects interacted with year fixed effects. Columns (3), (4), (5) , (8) and (9) control for year dummies interacted with baseline values (1995) for the following variables: homicide rate, political deaths, rate of infant deaths, rate of death by infections diseases, cardiac diseases, neoplasms, suicide and traffic accidents, area planted with temporary and permanent crops, bovine, equine, swine and chicken density, deforested area (annual flow and stock) and stock of forest as a percentage of the municipal area, ln of GDP per capita (1996) and fraction of GDP in agriculture (1996).

Table 3 - Mahogany Prohibition and Forest Cover, 2000-2013, Differences in Differences, Results for States with Natural Ocurrence of Mahogany and for the State of Pará.

	Municipalities in states with mahogany occurrence					Municipalities in Pará			
				Triple Difference					
				State percentage in exports before 1999	Suspected state exports after 1999		Treatment interacted with linear trends		Treatment interacted with linear trends
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treatament 2002	-0.00931	-0.0515***	-0.0161**	-0.0410***	6.82e-05	-0.0637***	0.0114	-0.0165	-0.0131**
	[0.0187]	[0.00955]	[0.00743]	[0.0154]	[6.16e-05]	[0.0128]	[0.00698]	[0.0113]	[0.00603]
Treatament 2002 x Trend							-0.0250***		-0.00111
							[0.00432]		[0.00258]
Treatament 2009	-0.0713**	-0.146***	-0.00961	-0.0978**	-0.000584	-0.226***	-0.221***	-0.0110	-0.0144
	[0.0327]	[0.0303]	[0.0176]	[0.0386]	[0.000464]	[0.0427]	[0.0418]	[0.0228]	[0.0215]
Treatament 2009 x Trend							-0.00248***		0.00174
							[0.000559]		[0.00188]
Constant	0.375***	0.397***	0.366***	0.356***	0.352***	0.452***	0.453***	0.422***	0.420***
	[0.0189]	[0.0151]	[0.00692]	[0.00543]	[0.00490]	[0.0276]	[0.0269]	[0.00888]	[0.00995]
State FE x Year FE		X	X	X	X				
Baseline Charac. x Year FE			X	X	X			X	X
Year FE	X	X	X	X	X	X	X	X	X
Number of Observations	8,288	8,288	7,392	8,008	8,008	1,792	1,792	1,456	1,456
R^2	0.955	0.966	0.988	0.989	0.988	0.939	0.942	0.990	0.990

Notes: Robust standard errors in brackets (clustered at the municipal level), *** p<0.01, ** p<0.05, * p<0.1. Dependent variable is the forest cover as a percentage of municipal area. All regressions include a constant, municipality fixed effects and year fixed effects, and are weighted by municipal population. Treatment variables are dummies = 1 for the period 1999-2001, 2002-2008 and after 2009 interacted with mahogany occurrence area. Columns (2)-(5) control for state fixed effects interacted with year fixed effects. Columns (3), (4), (5) , (8) and (9) control for year dummies interacted with baseline values (1995) for the following variables: homicide rate, political deaths, rate of infant deaths, rate of death by infections diseases, cardiac diseases, neoplasms, suicide and traffic accidents, area planted with temporary and permanent crops, bovine, equine, swine and chicken density, deforested area (annual flow and stock) and stock of forest as a percentage of the municipal area, ln of GDP per capita (1996) and fraction of GDP in agriculture (1996).

Table 4 - Mahogany Prohibition and Bovine Density, 1995-2013, Differences in Differences, Results for States with Natural Ocurrence of Mahogany and for the State of Pará.

	Municipalities in states with mahogany occurrence						Municipalities in Pará		
					Triple Difference				
				Treatment interacted with linear trends	State percentage in exports before 1999	Suspected state exports after 1999			Treatment interacted with linear trends
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treatment 1999	6.135***	2.495**	4.031**	1.944*	6.133*	-0.00106	1.773	3.169	0.929
	[1.217]	[1.055]	[1.719]	[1.107]	[3.653]	[0.0268]	[1.596]	[2.538]	[1.570]
Treatament 1999 x Trend				0.551					0.843
				[0.674]					[0.965]
Treatament 2002	18.28***	11.58***	10.71***	9.282***	17.85***	0.0660***	14.50***	14.19***	11.75***
	[2.278]	[2.152]	[2.574]	[1.917]	[5.638]	[0.0182]	[3.003]	[3.776]	[2.756]
Treatament 2002 x Trend				0.418**					0.500**
				[0.167]					[0.244]
Constant	18.19***	18.19***	19.15***	18.19***	18.28***	18.28***	10.92***	13.31***	10.92***
	[1.115]	[1.089]	[0.872]	[1.089]	[0.859]	[0.872]	[1.132]	[1.241]	[1.132]
State FE x Year FE		X	X	X	X	X			
Baseline Charac. x Year FE			X		X	X		X	
Year FE	X	X	X	X	X	X	X	X	X
Number of Observations	11,932	11,932	10,716	11,932	11,552	11,552	2,432	1,976	2,432
R^2	0.916	0.926	0.945	0.926	0.944	0.944	0.896	0.929	0.897

Notes: Robust standard errors in brackets (clustered at the municipal level), *** p<0.01, ** p<0.05, * p<0.1. Dependent variable is bovine density in the municipality (number of heads/area in Km2). All regressions include a constant, municipality fixed effects and year fixed effects, and are weighted by municipal population. Treatment variables are dummies = 1 for the period 1999-2001 and after 2002 interacted with mahogany occurrence area. Columns (2) through (6) control for state fixed effects interacted with year fixed effects. Columns (3), (5) , (6) and (8) control for year dummies interacted with baseline values (1995) for the following variables: homicide rate, political deaths, rate of infant deaths, rate of death by infections diseases, cardiac diseases, neoplasms, suicide and traffic accidents, area plantada with temporary and permanent crops, bovine, equine, swine and chicken density, ln of GDP per capita (1996) and fraction of GDP in agriculture (1996).

Table 5 - Mahogany Prohibition and Bovine Density, 1995-2013, Differences in Differences, Results for States with Natural Ocurrence of Mahogany and for the State of Pará.

	Municipalities in states with mahogany occurrence						Municipalities in Pará		
					Triple Difference				
				Treatment interacted with linear trends	State percentage in exports before 1999	Suspected state exports after 1999			Treatment interacted with linear trends
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treatment 1999	6.135***	2.495**	4.031**	1.944*	6.133*	0.0364	1.773	3.169	0.929
	[1.217]	[1.055]	[1.719]	[1.107]	[3.654]	[0.0234]	[1.596]	[2.539]	[1.570]
Treatament 1999 x Trend				0.551					0.843
				[0.674]					[0.966]
Treatament 2002	17.44***	10.72***	9.823***	8.467***	16.81***	0.0834***	13.59***	12.98***	10.69***
	[2.183]	[2.028]	[2.430]	[2.011]	[5.279]	[0.0219]	[2.869]	[3.672]	[2.892]
Treatament 2002 x Trend				0.750***					0.967**
				[0.281]					[0.457]
Treat 2009	19.47***	12.79***	11.95***	12.29***	19.30***	0.332***	15.77***	15.88***	14.52***
	[2.476]	[2.437]	[2.898]	[2.189]	[6.388]	[0.0862]	[3.352]	[4.079]	[3.083]
Treatament 2009 x Trend				0.252					0.628
				[0.316]					[0.467]
Constant	18.19***	18.19***	19.15***	18.19***	18.28***	18.28***	10.92***	13.31***	10.92***
	[1.115]	[1.089]	[0.872]	[1.089]	[0.859]	[0.861]	[1.132]	[1.241]	[1.133]
State FE x Year FE		X	X	X	X	X			
Baseline Charac. x Year FE			X		X	X		X	
Year FE	X	X	X	X	X	X	X	X	X
Number of Observations	11,932	11,932	10,716	11,932	11,552	11,552	2,432	1,976	2,432
R^2	0.916	0.926	0.945	0.926	0.944	0.945	0.896	0.930	0.897

Notes: Robust standard errors in brackets (clustered at the municipal level), *** p<0.01, ** p<0.05, * p<0.1. Dependent variable is bovine density in the municipality (number of heads/area in Km2). All regressions include a constant, municipality fixed effects and year fixed effects, and are weighted by municipal population. Treatment variables are dummies = 1 for the period 1999-2001, 2002-2008 and after 2009 interacted with mahogany occurrence area. Columns (2) through (6) control for state fixed effects interacted with year fixed effects. Columns (3), (5) , (6) and (8) control for year dummies interacted with baseline values (1995) for the following variables: homicide rate, political deaths, rate of infant deaths, rate of death by infections diseases, cardiac diseases, neoplasms, suicide and traffic accidents, area plantada with temporary and permanent crops, bovine, equine, swine and chicken density, ln of GDP per capita (1996) and fraction of GDP in agriculture (1996).

Table 6 - Mahogany Prohibition and Bovine Density, 1995-2013, Test for Parallel Trends, Municipality-Specific Trends.

	Municipalities in mahogany states		Municipalities in mahogany states excluding Pará		Municipalities in Pará	
Variables	(1)	(2)	(3)	(4)	(5)	(6)
Treatment 1999	8.572***	3.134**	12.16***	5.077***	1.324	-0.903
	[2.107]	[1.280]	[2.823]	[1.524]	[2.163]	[2.131]
Treatment 2002	19.87***	10.15***	23.48***	11.76***	13.14***	7.097**
	[2.643]	[1.909]	[3.662]	[2.504]	[3.192]	[3.055]
Treatment 2009	21.90***	7.032***	25.64***	8.352***	15.32***	4.690
	[2.894]	[1.951]	[3.917]	[2.425]	[3.793]	[3.426]
Placebo	4.873**		7.670***		-0.899	
	[2.030]		[2.768]		[1.831]	
Constant	18.19***	18.19***	21.57***	21.57***	10.92***	10.92***
	[1.107]	[1.036]	[1.524]	[1.439]	[1.135]	[0.919]
Municipality-specific linear trend		X		X		X
Year FE	X	X	X	X	X	X
Number of Observations	11,932	11,932	9,500	9,500	2,432	2,432
R^2	0.916	0.957	0.920	0.959	0.896	0.941

Notes: Robust standard errors in brackets (clustered at the municipal level), *** p<0.01, ** p<0.05, * p<0.1. Dependent variable is bovine density in the municipality (number of heads/area in Km2). All regressions include a constant, municipality fixed effects and year fixed effects, and are weighted by municipal population. Treatment variables are dummies = 1 for the period 1999-2001, 2002-2008 and after 2009 interacted with mahogany occurrence area. The pre-treatment placebo is a dummy for 1997-1998 interacted with a mahogany area dummy. Columns (2), (4) and (6) include a municipal fixed effect interacted with a linear trend.

Table 7 - Mahogany Prohibition and Bovine Density, 1995-2013, Pará, Unweighted Regression and Standar Errors Robust to Spatial Correlation (Driscoll-Kraay).

	Unweighted	Standard errors robust to spatial correlation
Variables	(1)	(2)
Treatment 1999	2.979	1.773***
	[1.997]	[0.403]
Treatment 2002	14.77***	13.59***
	[3.256]	[2.874]
Treatment 2009	15.94***	15.77***
	[3.168]	[0.615]
Constant	15.96***	33.78***
	[1.407]	[3.256]
Year FE	X	X
Number of Observations	2,432	2,432
R^2	0.894	0.881
Number of groups		128

Notes: Robust standard errors in brackets (clustered at the municipal level) in column (1); Driscoll Kraay standard errors in bracked in column (2); Dependent variable is bovine density in the municipality (number of heads/area in Km2). All regressions include a constant, municipality fixed effects and year fixed effects. In column (2), the regression is weighted by municipal population. Treatment variables are dummies = 1 for the period 1999-2001, 2002-2008 and after 2009 interacted with mahogany occurrence area.

Table 8 - Mahogany Prohibition and Equine, Chicken and Swine Density, 1995-2013, Differences in Differences, Results for Pará.

	Equine			Chicken			Swine		
			Treatment interacted with linear trends			Treatment interacted with linear trends			Treatment interacted with linear trends
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treatment 1999	0.0434	0.0578	0.0398	-31.52	-15.89	-87.43	-2.022	-0.0463	-1.871
	[0.0373]	[0.0515]	[0.0372]	[29.86]	[27.50]	[86.59]	[1.612]	[0.428]	[1.510]
Treatament 1999 x Trend			0.00360			55.91			-0.151
			[0.0167]			[57.67]			[0.134]
Treatament 2002	0.207***	0.225***	0.154**	93.50	54.13	64.31	-0.543	0.125	-2.430
	[0.0631]	[0.0842]	[0.0601]	[122.0]	[48.67]	[94.35]	[0.610]	[0.381]	[1.924]
Treatament 2002 x Trend			0.0178**			9.728			0.629
			[0.00819]			[12.39]			[0.549]
Treat 2009	0.354***	0.213***	0.299***	100.1	92.51	101.6	1.367	0.238	0.746
	[0.0862]	[0.0801]	[0.0784]	[139.6]	[71.44]	[134.3]	[1.535]	[0.407]	[1.322]
Treatament 2009 x Trend			0.0275*			-0.781			0.311**
			[0.0143]			[5.048]			[0.128]
Constant	0.475***	0.632***	0.475***	316.3***	451.9***	316.3***	6.044***	8.368***	6.044***
	[0.0796]	[0.0262]	[0.0797]	[111.0]	[16.34]	[111.0]	[0.977]	[0.177]	[0.978]
Baseline Charac. x Year FE		X			X			X	
Year FE	X	X	X	X	X	X	X	X	X
Number of Observations	2,432	1,976	2,432	2,432	1,976	2,432	2,432	1,976	2,432
R^2	0.759	0.896	0.759	0.833	0.969	0.833	0.715	0.977	0.717

Notes: Robust standard errors in brackets (clustered at the municipal level), *** p<0.01, ** p<0.05, * p<0.1. Dependent variables are equine (columns (1) -(3)), chicken (columns (4)-(6)) and swines (columns (7)-(9)) densities in the municipality (number of heads/area in Km2). All regressions include a constant, municipality fixed effects and year fixed effects, and are weighted by municipal population. Treatment variables are dummies = 1 for the period 1999-2001, 2002-2008 and after 2009 interacted with mahogany occurrence area. Columns (2), (5) and (8) control for year dummies interacted with baseline values (1995) for the following variables: homicide rate, political deaths, rate of infant deaths, rate of death by infections diseases, cardiac diseases, neoplasms, suicide and traffic accidents, area plantada with temporary and permanent crops, bovine, equine, swine and chicken density, ln of GDP per capita (1996) and fraction of GDP in agriculture (1996).

Table 9 - Mahogany Prohibition and Fraction of Municipal Area Planted with Temporary Crops: Total, Rice, Beans, Cassava and Soy, 1995-2013, Differences in Differences, Results for the State of Pará.

	Total Temporary			Rice			Beans			Cassava			Soy		
			Treatment interacted with linear trend			Treatment interacted with linear trend			Treatment interacted with linear trend			Treatment interacted with linear trend			Treatment interacted with linear trend
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Treatment 1999	0.00409	0.000179	0.00543*	0.00103	0.00101	0.00185*	-0.000599	-0.00121**	-0.000621	0.00293	-0.00227*	0.00247	1.81e-05	-1.55e-05	2.29e-05
	[0.00301]	[0.00275]	[0.00323]	[0.000642]	[0.000739]	[0.000949]	[0.000524]	[0.000592]	[0.000545]	[0.00218]	[0.00127]	[0.00210]	[2.18e-05]	[1.60e-05]	[3.25e-05]
Treatament 1999 x Trend			-0.00133			-0.000827*			2.19e-05			0.000466			-4.91e-06
			[0.00127]			[0.000494]			[0.000190]			[0.000447]			[1.28e-05]
Treatament 2002	-0.00365	-0.0112***	-0.00219	-0.00176	-0.000854	-0.00166	-0.00195	-0.00189	-0.00229	0.000478	-0.00419**	0.00214	-0.000118	-0.000972*	-0.000121
	[0.00453]	[0.00412]	[0.00428]	[0.00160]	[0.00139]	[0.00178]	[0.00133]	[0.00145]	[0.00162]	[0.00270]	[0.00208]	[0.00263]	[0.000505]	[0.000518]	[0.000145]
Treatament 2002 x Trend			-0.000480			-3.37e-05			0.000110			-0.000546			6.60e-07
			[0.000511]			[0.000183]			[0.000141]			[0.000341]			[0.000125]
Treat 2009	-0.00170	-0.0104**	-0.00506	-0.00212	0.00151	-0.00186	-0.000219	-0.00126	-0.000813	-0.00137	-0.00545*	-0.00215	0.00146	-0.00141*	8.50e-05
	[0.00501]	[0.00465]	[0.00527]	[0.00182]	[0.00163]	[0.00165]	[0.000710]	[0.000860]	[0.000940]	[0.00257]	[0.00300]	[0.00312]	[0.00132]	[0.000803]	[0.000836]
Treatament 2009 x Trend			0.00162**			-0.000130			0.000291*			0.000373			0.000667*
			[0.000781]			[0.000284]			[0.000169]			[0.000404]			[0.000373]
Constant	0.0227***	0.0241***	0.0227***	0.00335***	0.00350***	0.00335***	0.00271***	0.00319***	0.00271***	0.0114***	0.0116***	0.0114***	-3.63e-05	1.39e-06	-3.00e-05
	[0.00269]	[0.00146]	[0.00269]	[0.000375]	[0.000228]	[0.000373]	[0.000498]	[0.000566]	[0.000497]	[0.00209]	[0.000760]	[0.00210]	[0.000253]	[0.000159]	[0.000250]
Baseline Charac. x Year FE		X			X			X			X			X	
Year FE	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Number of Observations	2,349	1,938	2,349	2,349	1,938	2,349	2,349	1,938	2,349	2,349	1,938	2,349	2,349	1,938	2,349
R^2	0.764	0.838	0.765	0.554	0.784	0.555	0.797	0.862	0.798	0.744	0.844	0.744	0.403	0.652	0.410

Notes: Robust standard errors in brackets (clustered at the municipal level), *** p<0.01, ** p<0.05, * p<0.1. Dependent variables are the fraction of the municipal area planted with total temporary crops (columns (1)-(3)), rice (columns (4)-(6)), beans (columns (7)-(9)), cassava (columns (10), (11) and (12)) and soy (columns (13), (14) and (15)). All regressions include a constant, municipality fixed effects and year fixed effects, and are weighted by municipal population. Treatment variables are dummies = 1 for the period 1999-2001, 2002-2008 and after 2009 interacted with mahogany occurrence area. Columns (2), (5), (8), (11) and (14) control for year dummies interacted with baseline values (1995) for the following variables: homicide rate, political deaths, rate of infant deaths, rate of death by infections diseases, cardiac diseases, neoplasms, suicide and traffic accidents, area planted with temporary and permanent crops, bovine, equine, swine and chicken density, deforested area (annual flow and stock) and stock of forest as a percentage of the municipal area, ln of GDP per capita (1996) and fraction of GDP in agriculture (1996).

Table 10 - Mahogany Prohibition and Fraction of the Municipality with Area Planted with Permanent Crops: Total, Banana, Cacao, and Dende, 1995-2013, Differences in Differences, Results for the State of Pará.

	Total Permanent			Banana			Cacao			Dende		
			Treatment interacted with linear trend			Treatment interacted with linear trend			Treatment interacted with linear trend			Treatment interacted with linear trend
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Treatment 1999	0.00163**	-0.00134**	0.00129*	0.000353***	0.000619***	0.000290***	0.000158	-9.01e-05	0.000146	-1.19e-05	-0.00152**	-0.000118
	[0.000742]	[0.000628]	[0.000747]	[0.000132]	[0.000191]	[9.28e-05]	[0.000190]	[0.000148]	[0.000200]	[0.000421]	[0.000664]	[0.000484]
Treatament 1999 x Trend			0.000328			6.02e-05			1.11e-05			0.000102
			[0.000225]			[7.84e-05]			[4.31e-05]			[0.000138]
Treatament 2002	0.000506	-0.00191*	-3.48e-05	0.000285	0.000464**	0.000140	0.000188	3.07e-05	6.06e-05	-0.000162	-0.00152**	-0.000319
	[0.000823]	[0.00109]	[0.000667]	[0.000179]	[0.000210]	[0.000123]	[0.000175]	[0.000237]	[0.000164]	[0.000446]	[0.000748]	[0.000425]
Treatament 2002 x Trend			0.000173			4.67e-05			4.11e-05			5.02e-05
			[0.000139]			[4.58e-05]			[3.07e-05]			[8.29e-05]
Treat 2009	0.00144	0.000259	0.00143	0.000482	0.000625*	0.000470	0.000541	0.000474	0.000452	-0.000235	-0.000449	8.15e-05
	[0.00109]	[0.00195]	[0.00103]	[0.000303]	[0.000375]	[0.000303]	[0.000356]	[0.000377]	[0.000287]	[0.000808]	[0.00173]	[0.000754]
Treatament 2009 x Trend			2.63e-06			4.68e-06			4.38e-05			-0.000160
			[0.000134]			[2.15e-05]			[4.19e-05]			[0.000128]
Constant	0.00718***	0.00710***	0.00718***	0.000592***	0.000661***	0.000591***	0.00109***	0.00117***	0.00108***	0.00207***	0.00222***	0.00207***
	[0.000684]	[0.000563]	[0.000681]	[7.84e-05]	[6.48e-05]	[7.87e-05]	[0.000138]	[6.85e-05]	[0.000138]	[0.000443]	[0.000378]	[0.000443]
Baseline Charac. x Year FE		X			X			X			X	
Year FE	X	X	X	X	X	X	X	X	X	X	X	X
Number of Observations	2,351	1,928	2,351	2,351	1,928	2,351	2,351	1,928	2,351	2,351	1,928	2,351
R^2	0.858	0.928	0.858	0.683	0.803	0.684	0.909	0.971	0.909	0.812	0.916	0.812

Notes: Robust standard errors in brackets (clustered at the municipal level), *** p<0.01, ** p<0.05, * p<0.1. Dependent variables are the fraction of the municipal area planted with total permanent crops (columns (1)-(3)), banana (columns (4)-(6)), cacao (columns (7)-(9)), and dende (columns (10), (11) and (12)). All regressions include a constant, municipality fixed effects and year fixed effects, and are weighted by municipal population. Treatment variables are dummies = 1 for the period 1999-2001, 2002-2008 and after 2009 interacted with mahogany occurrence area. Columns (2), (5), (8) and (11) control for year dummies interacted with baseline values (1995) for the following variables: homicide rate, political deaths, rate of infant deaths, rate of death by infections diseases, cardiac diseases, neoplasms, suicide and traffic accidents, area planted with temporary and permanent crops, bovine, equine, swine and chicken density, deforested area (annual flow and stock) and stock of forest as a percentage of the municipal area, ln of GDP per capita (1996) and fraction of GDP in agriculture (1996).

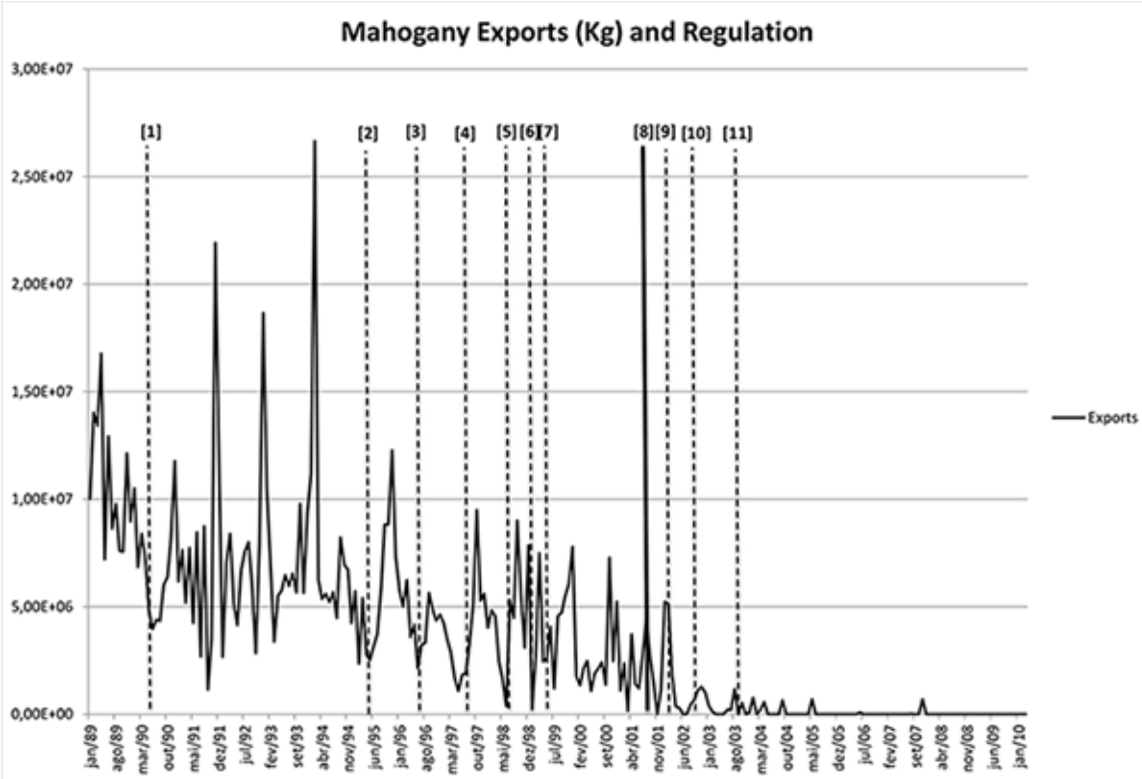

Figure 1: Total Brazilian mahogany exports (Kg) and domestic regulation of the mahogany market.

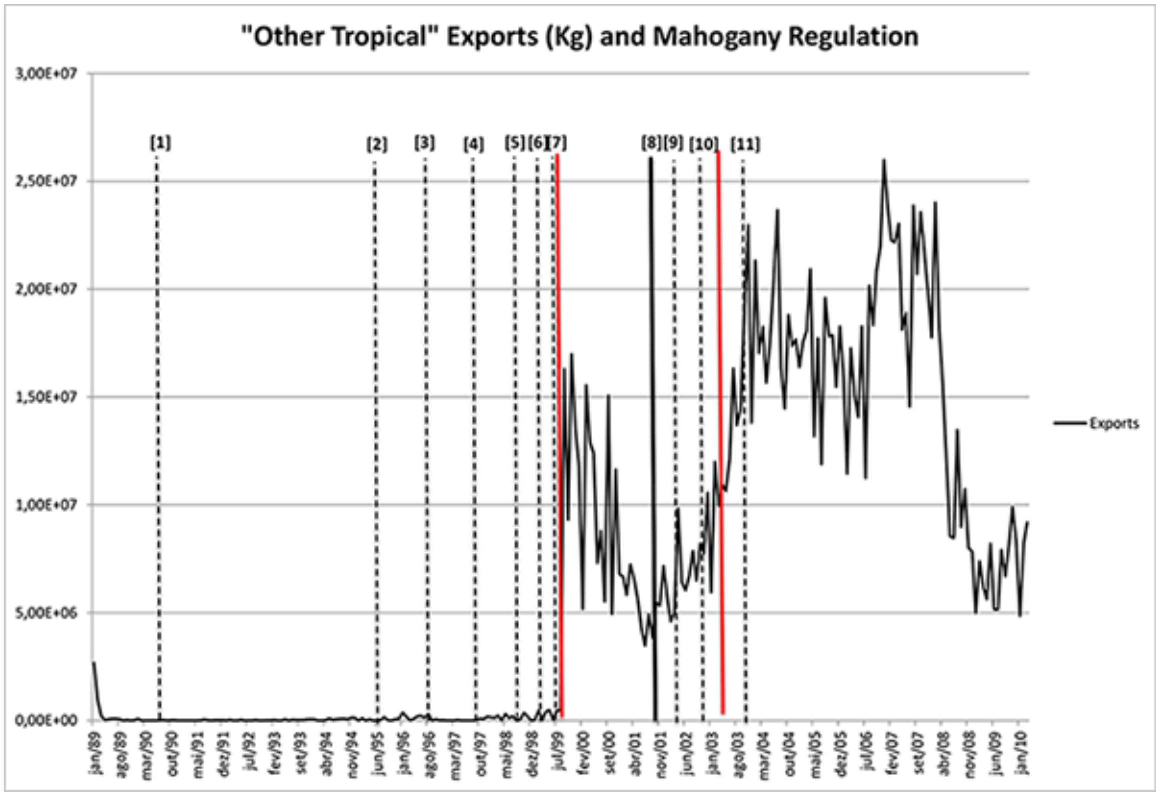

Figure 2: Total Brazilian exports of "other tropical" timber species (Kg) and domestic regulation of the mahogany market.

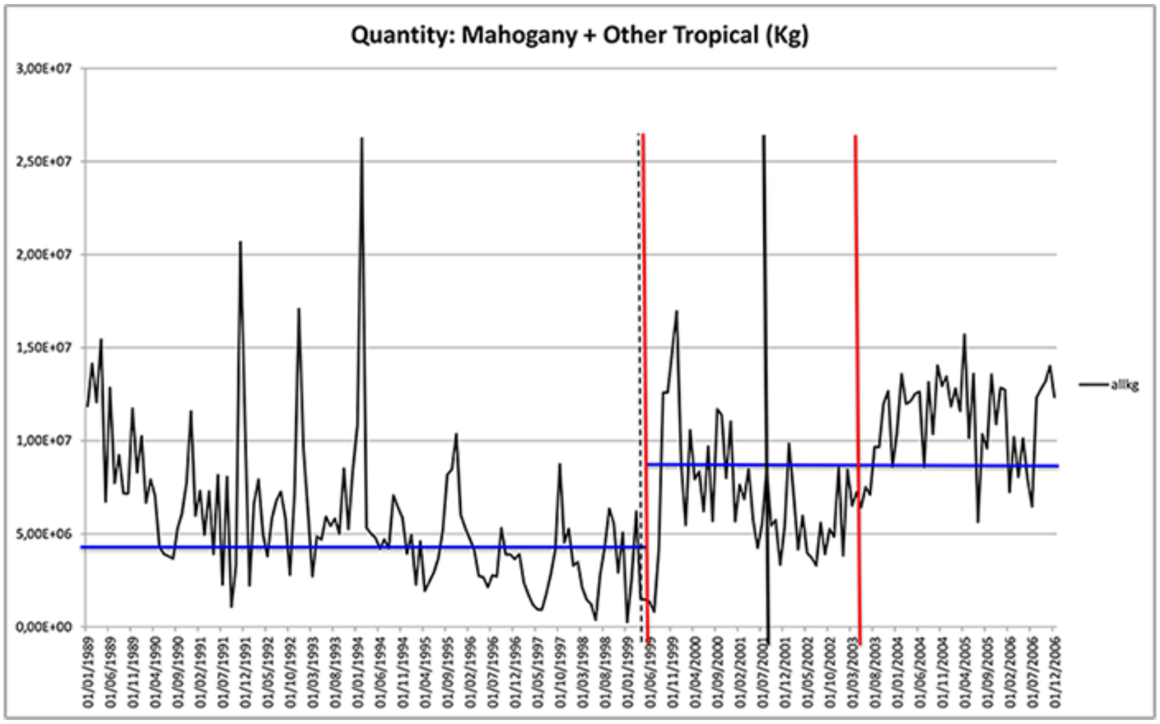

Figure 3: Quantity of exports of mahogany and other tropical species (Kg). January 1989 to December 2006.

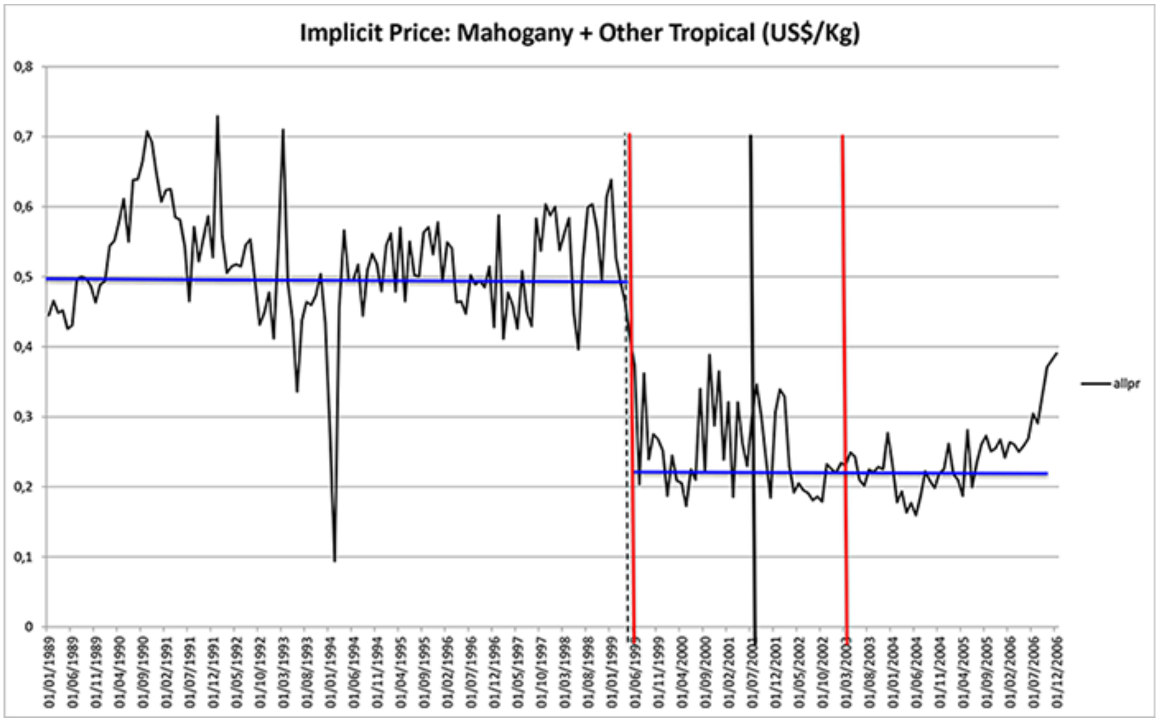

Figure 4: Implicit price of exports of mahogany and other tropical species (Kg). January 1989 to December 2006.

Figure 5: Deforestation Flow - Mahogany Municipalities in Pará

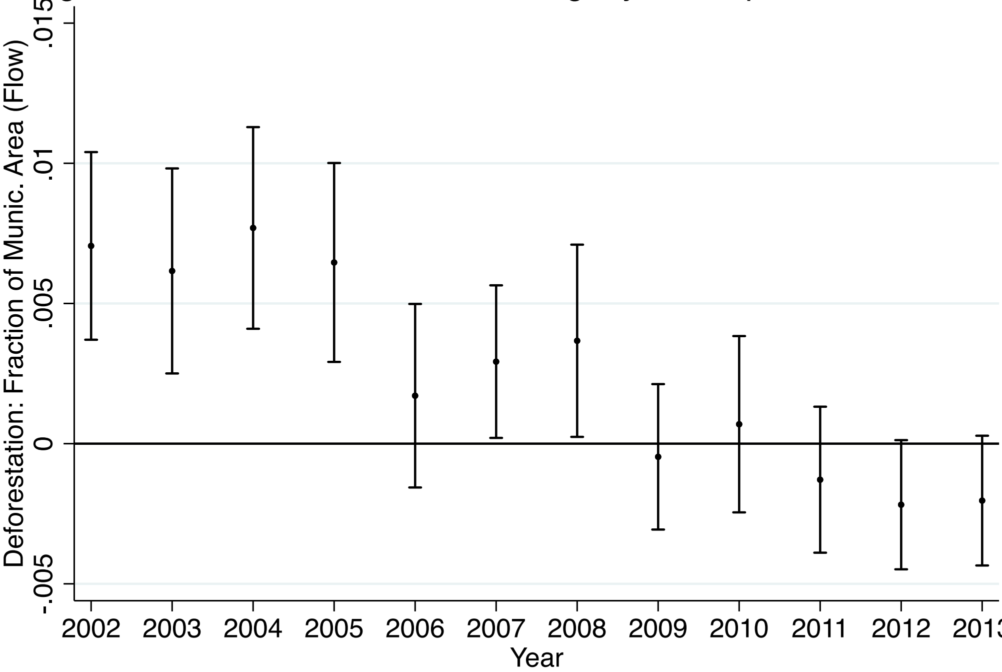

Figure 6: Deforestation Stock - Mahogany Municipalities in Pará

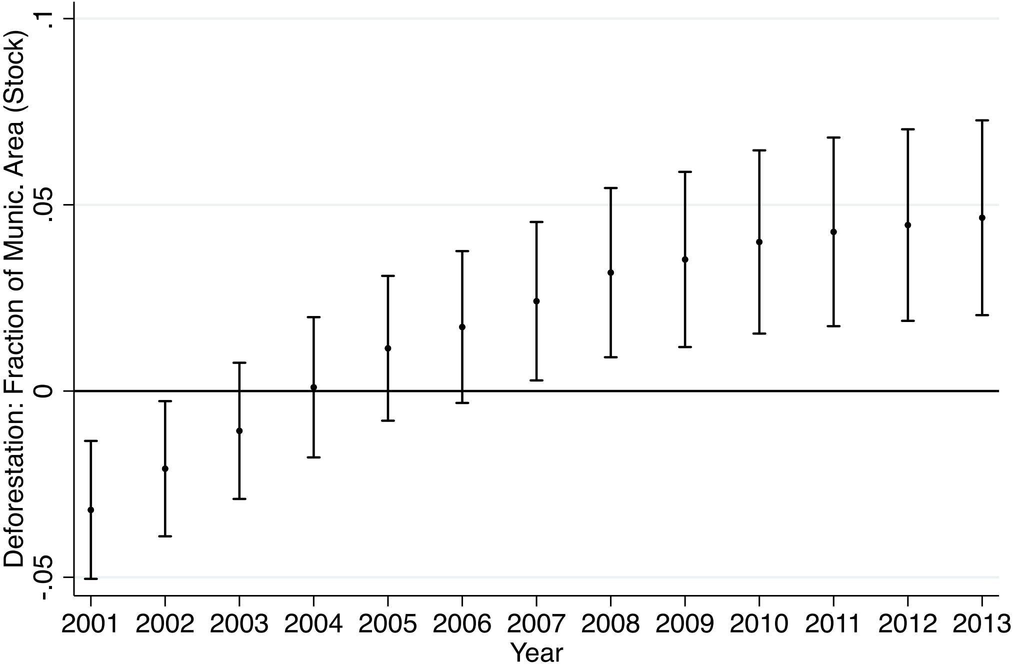

Figure 7: Forest Cover - Mahogany Municipalities in Pará

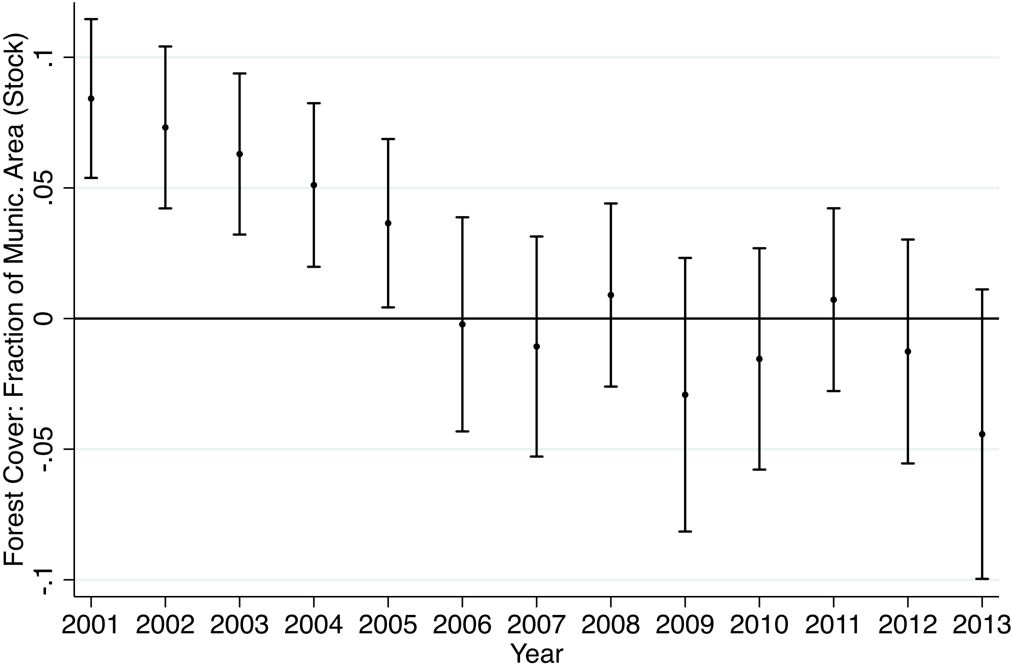

Figure 8: Bovine Density - Mahogany Municipalities in Pará

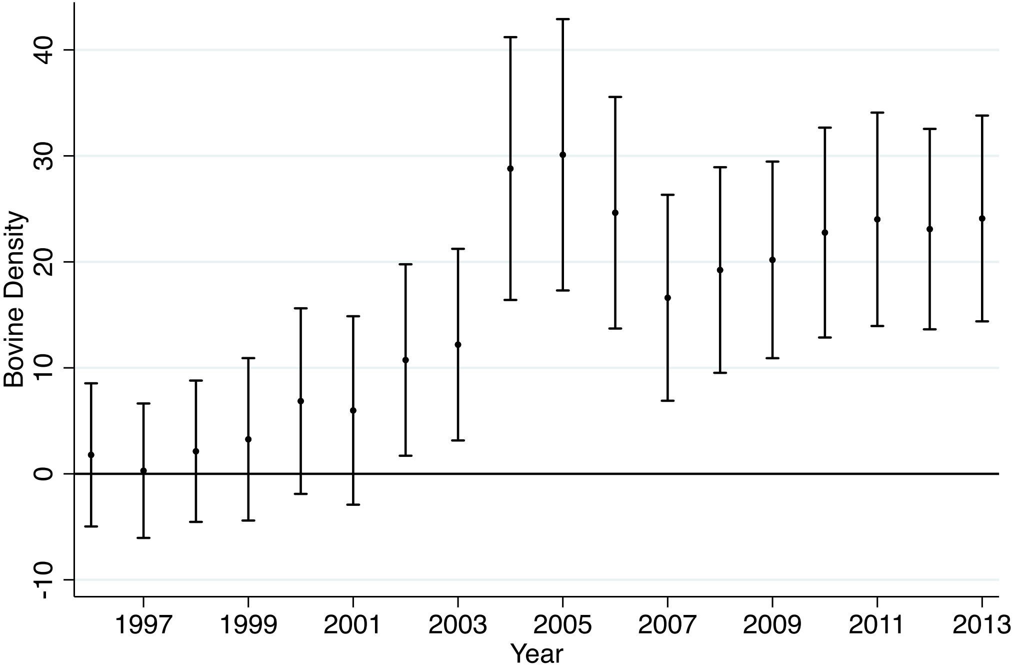

Figure A1: Municipalities in the Area of Natural Occurrence of Mahogany in Brazil (built from the map provided in Lentini et al., 2003).