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Protecting the Rainforest? The Case of Mahogany Prohibition and Deforestation

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Protecting the Rainforest? The Case of Mahogany Prohibition and Deforestation

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PRELIMINARY - DO NOT QUOTE

Abstract

Tropical deforestation around the world has called the attention of scientists and policy makers trying to understand its causes and design forest protection policies. Several commentators have identified logging of high-value timber species as an important cause of tropical deforestation. They argue that penetrating dense tropical forests is prohibitively costly for most economic activities, except for high-value timber harvesting. Although harvesting of high value timber has a small direct impact on the forest cover, it leaves behind basic infrastructure, especially logging roads, that lowers the penetration costs for other economic activities, which can cause 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 mahogany market prohibition in Brazil. 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 an empirical strategy based on both differences-in-differences and propensity score matching to test whether municipalities where mahogany naturally occurs experienced increased deforestation after prohibition. We find evidence that this was indeed the case. Our paper contains two main contributions: (i) evaluation of the impact of a logging ban 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.

Keywords: Tropical deforestation, loggin bans, 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. The economic literature on the causes of tropical deforestation 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 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

[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.

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."

Despite the prevalence of the idea that logging is an important driver of large scale tropical deforestation and the use of this notion in the desing of often times drastic forest protection policies,[6] 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. Two studies that come closer to addressing this hypothesis are Barbier et al. (1995) and Cropper et al. (1999). Barbier et al. (1995) investigated the role of timber production on tropical deforestation in Indonesia with a time series spanning from 1968 to 1988. Their ultimate goal was to estimate reduced models for deforestation and for the supply and demand for timber products aiming at simulating the impact of different timber policies on the local timber markets and deforestation. Although they estimated a negative relationship between timber production and forest area, given the correlation between timber and agricultural production, they acknowledge their inability to separately quantify the impact of these two drivers of deforestation. They therefore did not attempt to identify the role that timber harvesting plays in driving 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]A number of contries adopted logging bans to protect different species and hoping to eliminate the impact of this activity on conversion of forests to other land uses. See for example, Durst et al. (2001).

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.[7] 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.

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 presentes 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.

[7] Chimeli and Boyd (2010) and Chimeli and Soares (2011).

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 concentration 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.[8] 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.[9] This perception then spurred international campaigns by both environmental groups and governments to curb harvesting of this tree.[10] 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

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

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

[10]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).

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 [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 (2011) 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 (2011).

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, 2011). Finally, the anecdotal evidence that this actually happens supports our interpretation that exports of "other tropical species" is in fact smuggled mahogany.[11]

If mahogany continued to be exported under the guise of "other tropical species",

[11]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).

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.

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 three outcome variables as indicators of deforestation at the municipal level: annual deforestation 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.

The fact that data on deforestation and forest cover starts in 2000 only greatly limits our ability to make inferences on the impact of mahogany market intervention and deforestation. For this reason and given the fact that deforested area is 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 2007. We limit our data set to the period between 1995 and 2007, 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). Our benchmark regressions stop in 2007 because this corresponds to the period of increasing exports of "other tropical timber species," before the enforcement changes introduced in 2008. So this is when we should observe a stronger increase in deforestation in mahogany occurring areas. In some exercises, though, we extend the analysis up to 2013.

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.

We have municipality level information on: (i) total area planted, 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; 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.

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 violence 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 2002 and following years, corresponding to the prohibition of mahogany instituted in October 2001.

Our main results are based on a difference-in-difference strategy, but we also adopt the propensity score method in some robustness exercises. Each of these strategies has advantages and disadvantages, discussed in detail below. The stability of results across these alternatives lends additional credibility to our conclusion.

Difference-in-Difference

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

$$y_{it} = \alpha + \beta_1 \cdot (D_{1999 \leq t \leq 2001} \times M_i) + \beta 2 \cdot (D_{t \geq 2002} \times M_i) + z_{it}' \gamma + \theta_i + \mu_{st} + \epsilon_{it},$$

where y_{it} indicates the direct (deforestation or forest stock as percentage of municipal area) or indirect (bovine density) measure 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; $D_{t \geq 2002}$ is a dummy variable equal to 1 for 2002 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, $E[\epsilon_{it} | D_{1999 \leq t \leq 2001}, D_{t \geq 2002}, M_i, z_{it}, \theta_i, \mu_{st}] = 0$, 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 homicide 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, gdp per capita (ln), share of gdp in agriculture; and number of deaths due to land conflicts. 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 (ii) potential deforestation and bovine density associated with the agricultural frontier (fraction of area planted, share of gdp in agriculture, 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, 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.

Our benchmark specification already controls for the interaction of the initial measure of deforestation with time dummies, allowing for the possibility of differential dynamics of the dependent variable according to its initial level. 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).

Propensity Score Matching and Weighting

A remaining empirical concern in our difference-in-difference strategy could be associated with some notion of inadequacy of the control groups used as counterfactuals. To address this concern, we use a propensity score strategy. First, using information from the pre-prohibition period, we estimate a probit of the probability of being in the mahogany area on the full set of municipality characteristics that we observe, including the measure of deforestation (area planted, gdp per capita, assassinations due to land conflicts, and fraction of gdp in agriculture, averaged over 1995-1998). Following, once the predicted propensity score is obtained, we conduct a one-to-one nearest neighbor matching and also apply an inverse-probability weighted regression adjustment. In the one-to-one matching, we look at the dependent variable both as the dependent variable averaged over the post-prohibition period (either 1999-2007 or 2002-2007) and the change in the dependent variable between the pre- and post-prohibition periods. In the inverse-probability weighted regression, we use as dependent variable the change deforestation measure between the post- and pre-prohibition periods, and as controls all the variables listed before (including the initial dependent variable). The inverse probability weighted regressions have the additional advantage of being doubly robust, meaning that misspecification of either the regression equation or the propensity score separately do not harm consistency (Imbens and Wooldridge, 2009). In addition, since we run this specification in differences, the propensity score is robust to selection on unobservables, as long as these unobservables are time invariant (Abadie, 2005). We conduct the matching looking at municipalities in mahogany areas of the state of Pará, and compare them to municipalities without mahogany but located in states with some occurrence of mahogany and other than Pará. This choice of sample tries to increase comparability between treatment and potential controls, avoid potential contamination issues, and to focus on the treatment area where most of mahogany activity takes place (Pará).

7 Results

7.1 Differences-in-Differences

Our benchmark results appear in tables 1, 2 and 3. Table 1 reports the the estimated impact of prohibition on deforestation as a percentage of the area of municipality, whereas table 2 reports the effect on the forest cover as a percentage of the municipal area. These tables include only one treatment variable, as municipal satellite image data on deforestation start only in the year 2000 and misses the first intervention in the mahogany market. Furthermore, data on deforestation is further limited by the fact that information for the year 2000 comprises accumulated deforestation up to that year, whereas data for the following years refer to annual variations. Therefore, when looking at the direct impact of prohibition on deforestation, we pay closer attention to the estimates on table 2, which report the total area covered by forests at each point in time. Table 3 reports the results for bovine density. These results are based on a richer data set with information dating back to 1995, when regulation of mahogany extraction began (Garrido Filha, 2002). We can therefore estimate the impact of both regulatory interventions on bovine density through our treatment variables.

The columns of results labeled (1)-(3) in tables 1 through 3 refer to data for all states with mahogany occurring areas, whereas columns (4) and (5) concentrate in the state of Pará, where 70% of extraction took place when the mahogany market was legal. The regressions in columns (1) control for year effects. In columns (2) we control for year effects and year effects interacted with state effects to capture state-specific dynamics during the period of analysis. In columns (3) we add 1995 baseline levels of our municipal controls interacted with time effects to our set of explanatory variables. Finally, columns (4) include time effects only for the Pará regressions whereas columns (5) add baseline municipal controls interacted with time effects.

Table 1 contains our weakest results. This is not surprising, given the fact that it contains only 2 pre-intervention observations and the first observation on deforestation is not consistent with subsequent data. Nevertheless, all of the estimated coefficients suggest an increase in deforestation in mahogany areas after prohibition. The post 2001 treatment variable is, however, only marginally significant in most regressions and insignificant in the regression for all mahogany states and with all controls. Stronger results appear on table 2, which are baed on data on forest cover that are consistently measured throughout the sample period. Table 2 reports a significant negative impact of mahogany prohibition on tropical forest cover for both the mahogany occurring states and the state of Pará alone. Column (5) reports that the fraction of the municipal area covered by forests in mahogany occurring municipalities shrank by 3.5 percentage points on average when compared to those municipalities without the tree species in the state of Pará.

The main benchmark results of our study appear in table 3. We pay special attention to these results, because cattle raising is said to be the predominant economic activity in deforested areas in the Brazilian Amazon region. Furthermore, the intertemporal coverage of the bovine data enables us to have a better sense of the impact of the mahogany prohibition policy on local deforestation. Our results suggest a strong and significant growth in bovines in mahogany producing areas after prohibition. The diff-in-diff coefficients are particularly large and precisely estimated in the case of the second treatment. This is a likely consequence of the fact that an time lag is likely to occur between mahogany extraction and the occupation of the land by the bovine raising activity. To put this result in perspective, we contrast the growth of around 15 heads per hectare in mahogany producing areas of Pará relative to the average 23.5 heads per hectare in the same region before prohibition.

In order to investigate the possibility of pre-existing trends related to bovine raising in mahogany producing areas, we re-estimate the intervention coefficients controlling for a placebo effect, a pre-treatment variable constructed with the interaction between the mahogany municipality dummy and a time dummy for the 1997-1998 period. The treatment coefficients remain significant and the placebo treatment is marginally significant for the Pará regression (table 4).

To gain further insight into the dynamics of the effect of prohibition and submit our diff-in-diff results to an additional test, we run a series of cross-sectional regressions of the following form:

$$y_{it} - y_{it_0} = \delta + \beta \cdot M_i + \Gamma \cdot Z_{it} + \epsilon_{it},$$

where y_{it} is our outcome variable (forest cover as percentage of municipal area or bovine density), t_0 is a baseline year, M_i is a dummy variable equal to one if the municipality is located in the mahogany area and zero otherwise, Z_{it} represents municipal controls and ϵ_{it} is the error term. Figures 5 and 6 plot the estimated β coefficients for both sets of regressions. Forest cover is not significantly different between mahogany and non-mahogany municipalities in 2001, but mahogany localities are significantly different after 2001. The magnitude of the coefficient increases over time. Similarly, bovine densities are not statistically different between mahogany and non-mahogany areas from 1995 to 2001, but are significantly larger for mahogany municipalities starting in 2002.

7.2 Propensity Score Matching

We concentrate our analysis on bovine density in order to explore a larger time series and coverage of both treatment periods. We implement the propensity score matching by averaging all dependent and independent variables over the pre-intervention period (1995-1998). We then estimate a probit of the probability that the municipality belongs to the mahogany area on all variables that can be observed at the municipality level: gdp per capita (natural logarithm, observed only in 1996), fraction of gdp in agriculture (also in 1996), fraction of area planted, land conflict deaths, and also bovine density (the dependent variable before treatment). Following, we use the propensity score in a one-to-one nearest neighbor matching comparison and in an inverse-probability weighted regression.

Since our goal is to minimize problems of heterogeneity, we use an initial sample of treatment and pool of potential controls that already takes that into account. The evidence from tables 1 through 3 suggest that the most important effect of prohibition was concentrated on Pará, which played a prominent role in the trade of mahogany. So we consider municipalities in the mahogany area within the state of Pará as our treatment group. For the pool of potential controls, we consider municipalities without mahogany, but located in states other than Pará and with some mahogany occurrence. In all cases we estimate the average treatment effect on the treated, meaning the impact of prohibition on municipalities of Pará that were located in the mahogany area.

Table 5 presents the results from our exercises using propensity score matching. We consider two alternative treatment periods (post-1999 and post-2002) and four different specifications. For purposes of comparison, the first row presents the results from a simple difference-in-difference regression, analogous to that estimated before, but using the data collapsed in the before-after periods (just two observations in time), without using the propensity score. The second row conducts a simple one-to-one nearest neighbor matching comparison, where the dependent variable is the average bovine density in the post intervention period. The third row repeats the same exercise, except that the dependent variable is the change in bovine densities between the post- and the pre-intervention periods. Finally, the fourth row presents results from an inverse-probability weighted regression, where the dependent variable is the change in bovine densities and the controls are the pre-intervention values of all variables included in the propensity score estimation (including the initial value of the bovine density). The inverse probability weighted regressions have the additional advantage of being doubly robust, meaning that misspecification of either the regression equation or the propensity score separately do not harm consistency (Imbens and Wooldridge, 2009). In addition, since we run these equations in differences, the propensity score is robust to selection on unobservables, as long as these unobservables are time invariant (Abadie, 2005). For the interested reader, the appendix presents the results from our propensity score estimation and for a means difference test between treatment and control for the case of the nearest neighbor matching.

The estimated treatment effects are positive and statistically significant, except for the first treatment in the second row of results. Though the coefficients vary a bit in magnitude across specifications and treatments, they all fall within the range of those presented in table 3. The average estimated impact across the propensity score specifications that consider the post-1999 treatment is 8.42, close to the simple pre-post difference-in-difference from the first row in table 5. When considering the post-2002 treatment, the average effect across the propensity score specifications is 11.42, similar to the simple diff-in-diff specification from the first row in table 5, and also to the results from table 3. Also as in table 3, estimated effects for the post-2002 period are systematically larger than the analogous effects for the post-1999 period.

Overall, results from the propensity score strategies endorse the results from the difference-in-difference strategy. Most importantly, the similarity of results across the various specifications indicates that heterogeneity across control and treatment groups before prohibition does not seem to be affecting the evidence presented in table 3. This was already suggested by our previous estimates considering different samples, and is confirmed here.

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 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 guidance 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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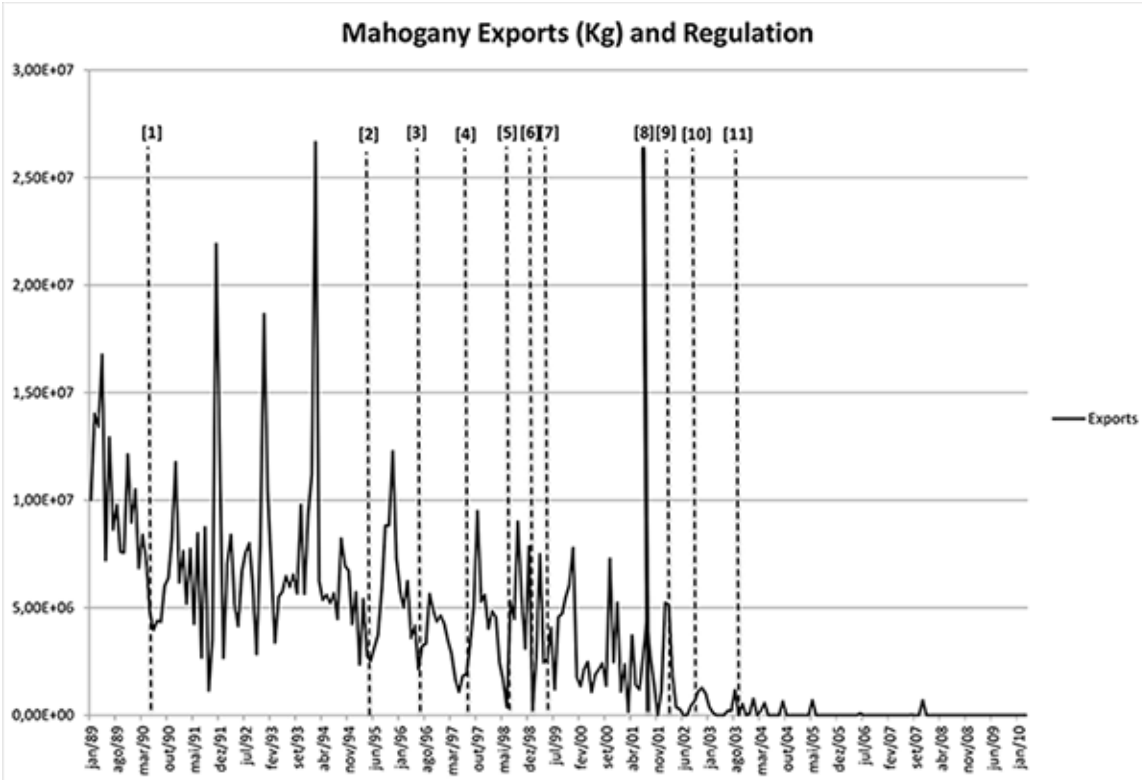

Figure 1: Total Brazilian mahogany exports (Kg) and domestic regulation of the mahogany market.

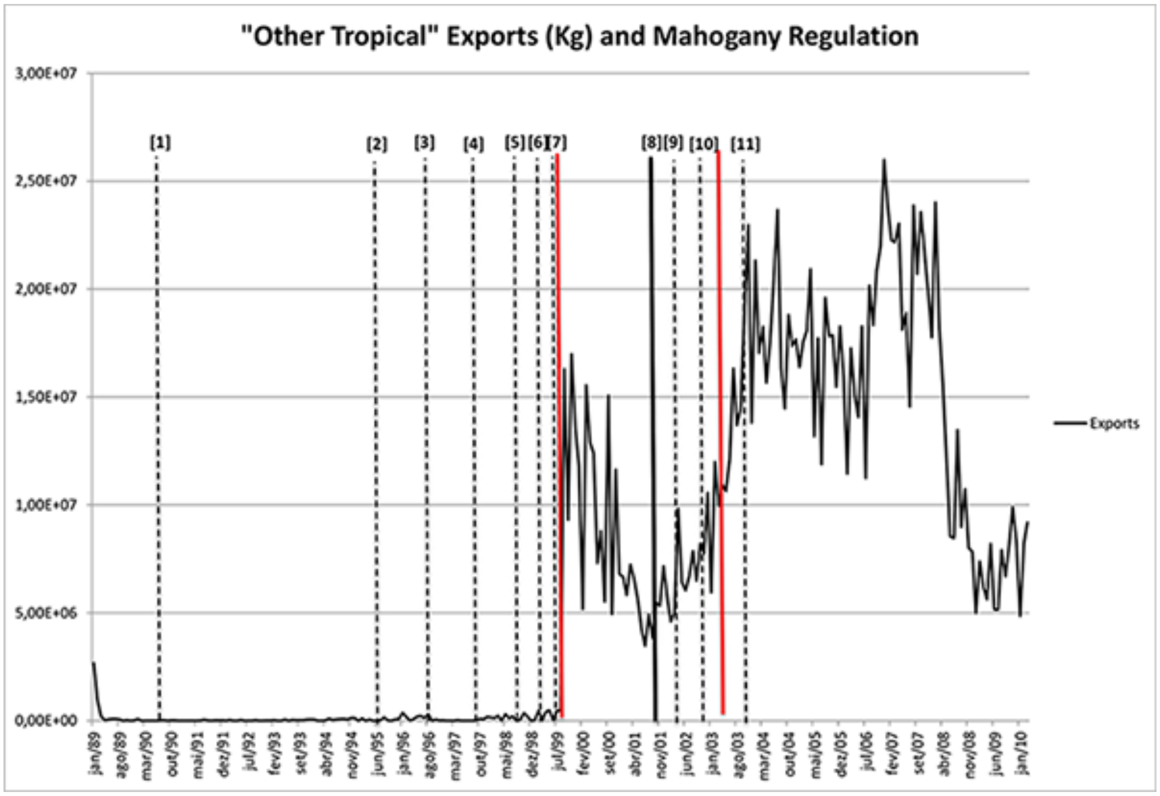

Figure 2: Total Brazilian exports of "other tropical" timber species (Kg) and domestic regulation of the mahogany market.

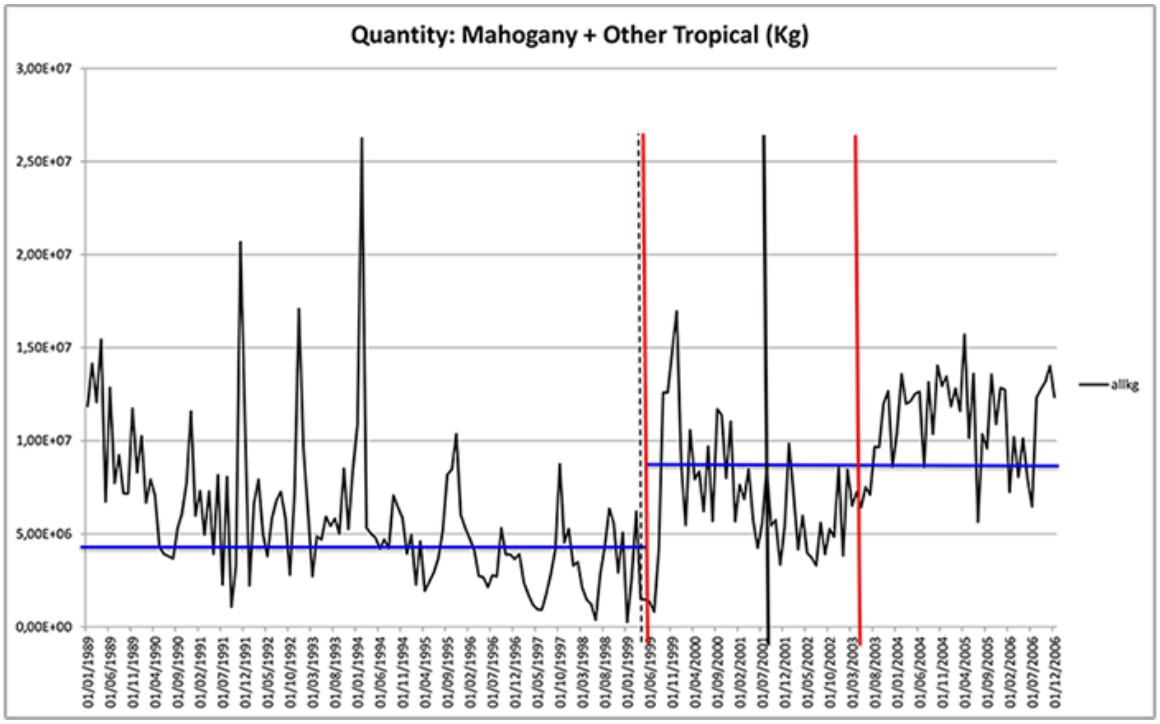

Figure 3: Quantity of exports of mahogany and other tropical species (Kg). January 1989 to December 2006.

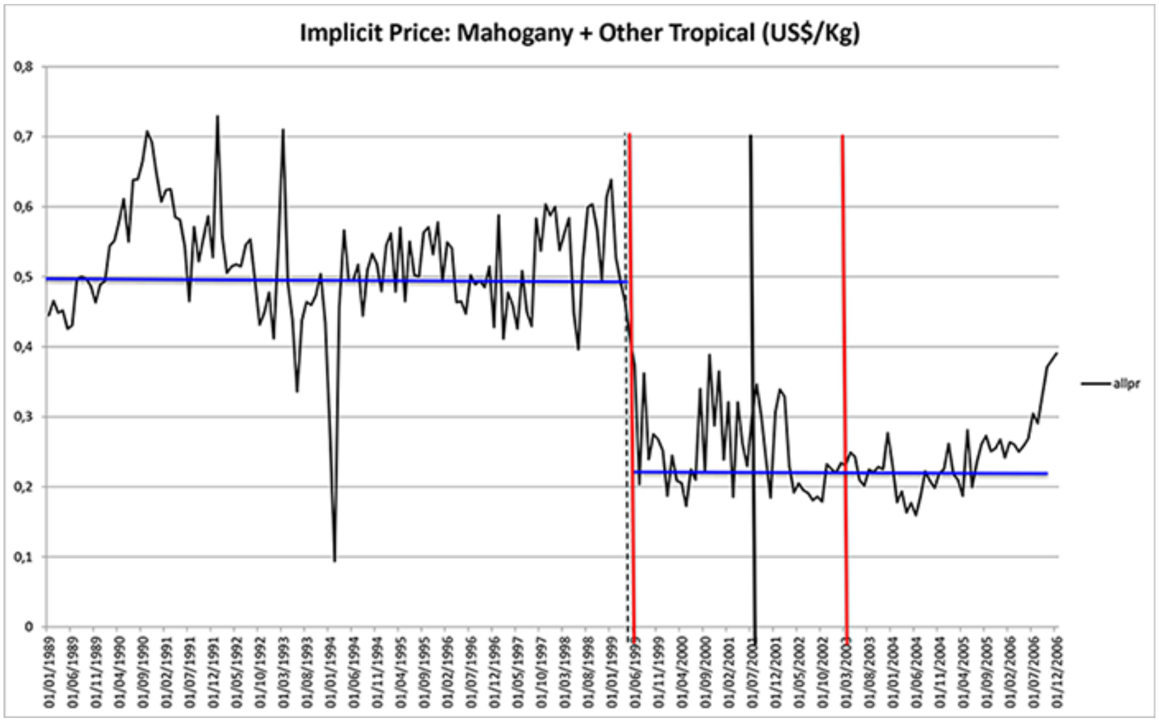

Figure 4: Implicit price of exports of mahogany and other tropical species (Kg). January 1989 to December 2006.

Figure 5: Timing of the Effect on Forest Coverage (%), Differences-in-Differences, Pará, 2001-2007.

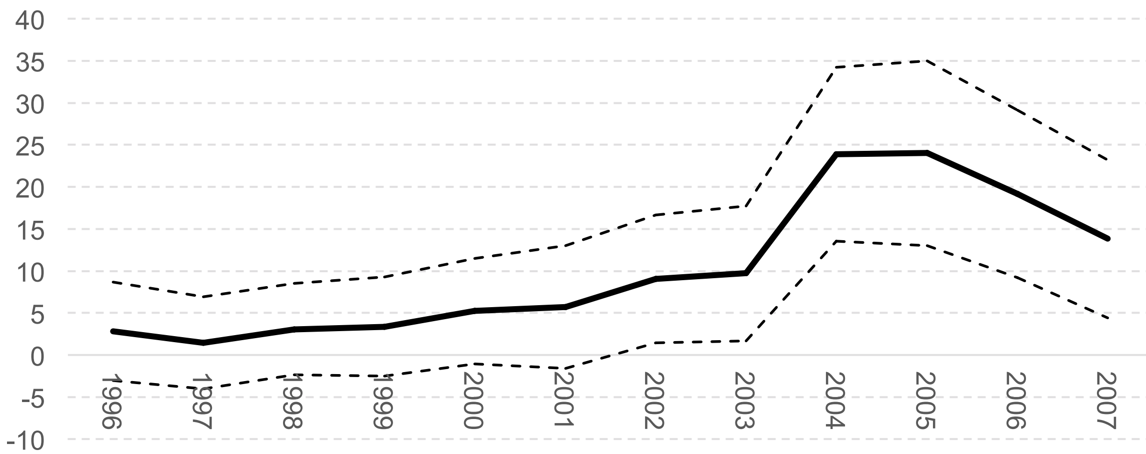

Figure 6: Timing of the Effect on Cattle Density, Differences-in-Differences, Pará, 1996-2007.

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

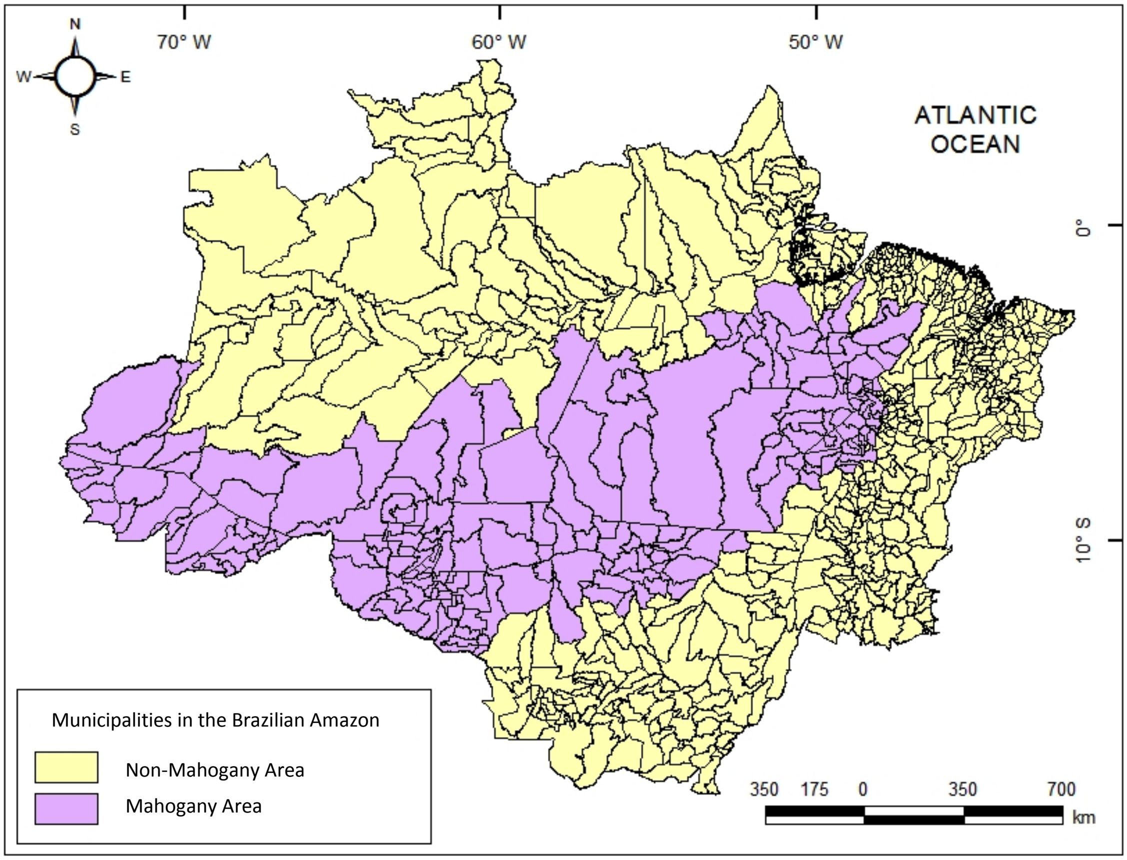

Table 1: Illegality of Mahogany Trade and Deforestation, 2000-2007, Difference-in-Difference Results

Deforestation (% of Municipal Area)

	(1)	(2)	(3)	(4)	(5)
VARIABLES	mahog_states	with_state_t	with_interac_t	PA	PA_with_interac_t
treat2	0.0363***	0.00603*	0.00444	0.0144*	0.0119*
	[0.00767]	[0.00310]	[0.00340]	[0.00768]	[0.00628]
Year	X	X	X	X	X
YearxState		X	X		
YearxControlsM			X		X
Observations	4,242	4,242	4,207	896	875
R-squared	0.214	0.328	0.332	0.352	0.380

Robust standard errors in brackets
*** p<0.01, ** p<0.05,
*p<0.1

Table 2: Illegality of Mahogany Trade and Forest Cover, 2000-2007, Difference-in-Difference Results

Forest Cover (% of Municipal Area)

	(1)	(2)	(3)	(4)	(5)
VARIABLES	mahog_states	with_state_t	with_interac_t	PA	PA_with_interac_t
treat2	-0.0154***	-0.0335***	-0.0338***	-0.0425***	-0.0349***
	[0.00531]	[0.00402]	[0.00417]	[0.00708]	[0.00848]
Year	X	X	X	X	X
YearxState		X	X		
YearxControlsM			X		X
Observations	4,848	4,848	4,808	1,024	1,000
R-squared	0.983	0.986	0.986	0.996	0.996

Robust standard errors in brackets
*** p<0.01, ** p<0.05, *
p<0.1

Table 3: Illegality of Mahogany Trade and Bovine Density, 1995-2007, Difference-in-Difference Results

Bovine Density (Bovines/Municipal Area)					
	(1)	(2)	(3)	(4)	(5)
VARIABLES	mahog_states	with_state_t	with_interac_t	PA	PA_with_interac_t
treat1	6.179***	3.107***	3.121**	2.955	2.920
	[0.952]	[1.184]	[1.209]	[2.026]	[2.166]
treat2	18.04***	10.83***	10.07***	14.84***	15.13***
	[2.173]	[2.170]	[2.157]	[3.351]	[3.791]
Year	X	X	X	X	X
YearxState		X	X		
YearxControlsM			X		X
Observations	8,128	8,128	8,101	1,651	1,625
R-squared	0.898	0.911	0.928	0.874	0.887

Robust standard errors in brackets
*** p<0.01, ** p<0.05, * p<0.1

Table 4: Illegality of Mahogany Trade and Bovine Density, 1995-2007, Difference-in-Difference Results, Placebo Effects

VARIABLES	(1) bov_m_states	(2) bov_para
treat1	3.421**	4.227
	[1.596]	[2.679]
treat2	10.37***	16.43***
	[2.455]	[4.245]
pre	0.600	2.614*
	[1.106]	[1.481]
Observations	8,101	1,625
R-squared	0.928	0.887

Robust standard errors in brackets
*** p<0.01, ** p<0.05, * p<0.1

Table 5: Average Treatment Effect on the Treated Estimated using the Propensity Score - Municipalities in Mahogany Areas of Pará and Municipalities outside the Mahogany Area, but located in States with Some Occurrence of Mahogany, other than Pará - Outcomes Measured as Averages after 1999 or after 2002.

	Treatment Group: Municipalities with Mahogany in Pará Control Group: Municip. without Mahogany in States with Mahogany Occurrence	
	Post-1999/Pre-1999 5	Post-2002/Pre-1999 6
Before-after Diff-in-Diff without Matching*	10.711*** [2.435]	13.98*** [2.995]
Nearest Neighrbor Match; Outcome: Avg Bov Dens	6.930 [4.314]	9.839** [4.456]
Nearest Neighrbor Match; Outcome: Δ Avg Bov Dens	8.644*** [2.552]	11.55*** [2.962]
Inverse-Probability Weighted Regression; Outcome: Δ Avg Bov Dens; Controls: Pre-1999 Variables	9.682*** [2.400]	12.87*** [2.996]

Obs.: Propensity Score estimated from the equation presented in the Appendix Table XX. Details of the methodology explained in the text. *: First line corresponds to simple regression of the before-after change in cattle density on the dummy for municipalities in the mahogany area, using the same initial sample from the propensity score exercise (with robust standard errors).

Table A1: Mean-Differences Test for Nearest Neighbor Match on Pre-1999 Averages - Municipalities in Mahogany Areas of Pará Matched to Municipalities outside the Mahogany Area, but located in States with Some Occurrence of Mahogany

Variable	Unmatched/Matched	Mean		Diff. Treat x Control	
		Treated	Control	T	p>|t|
ln_gdp_pc	Unmatched	0,3505	0,3506	0,00	1,00
	Matched	0,3505	0,3347	0,16	0,87
% gdp agric	Unmatched	0,496	0,5076	-0,35	0,73
	Matched	0,496	0,5229	-0,58	0,56
% area plant	Unmatched	2,4739	4,2121	-1,79	0,07
	Matched	2,4739	2,0487	0,80	0,43
cattle density	Unmatched	23,527	21,07	0,63	0,53
	Matched	23,527	22,4	0,21	0,83
polit deaths	Unmatched	0,0124	0,0012	5,82	0,00
	Matched	0,0124	0,0076	0,79	0,44

Obs.: Variables are averages between 1995 and 1998 of gdp per capita (ln, 1996), fraction of gdp in agriculture (1996), % of area planted, mortality by heart and circulatory diseases, neoplasms, infectious diseases, traffic accidents, suicides, child mortality, assassinations related to land conflicts, and homicide rate.

Table A2: Propensity Score Probit Estimation, Municipalities in Mahogany Areas of Pará and Municipalities outside the Mahogany Area (but located in States with Some Occurrence of Mahogany), Averages between 1995-1998.

Dep. Var: Mahogany Area Dummy Vars	
ln_gdp_pc	-0.0484 [0.144]
% gdp agric	-0.0632 [0.404]
% area plant	-0.0501* [0.0275]
cattle density	0.00437 [0.00348]
polit deaths	21.25*** [7.038]
Observations	507

Obs: Robust standard-errors in brackets; *** p<0.01, ** p<0.05, * p<0.1. Dependent variable is a dummy indicating that a municipality is located in the mahogany occurrence area. Independent variables are averages between 1995 and 1998 of gdp per capita (ln, 1996), fraction of gdp in agriculture (1996), % of area planted, cattle density, and assassinations related to land conflicts, and homicide rate.