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The Use of Violence in Illegal Markets: Evidence from Mahogany Trade in the Brazilian Amazon

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The Use of Violence in Illegal Markets: Evidence from Mahogany Trade in the Brazilian Amazon*

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Abstract

Agents operating in illegal markets cannot resort to the justice system to guarantee property rights, to enforce contracts, or to seek protection from competitors' improper behaviors. In these contexts, violence is used to enforce previous agreements and to fight for market share. This relationship plays a major role in the debate on the pernicious effects of the illegality of drug trade. This paper explores a singular episode of transition of a market from legal to illegal to provide a first piece of evidence on the causal effect of illegality on systemic violence. Brazil has historically been the main world producer of big leaf mahogany (a tropical wood). Starting in the 1990s, policies restricting extraction and trade of mahogany, culminating with prohibition, were implemented. First, we present evidence that large scale mahogany trade persisted after prohibition, through misclassification of mahogany exports as "other tropical timber species." Second, we document relative increases in violence after prohibition in areas with: (i) higher share of mahogany exports before prohibition; (ii) higher suspected illegal mahogany activity after prohibition; and (iii) natural occurrence of mahogany. We believe this is one of the first documented experiences of increase in violence following the transition of a market from legal to illegal.

Keywords: illegal markets, violence, homicide, mahogany, Brazil
JEL codes: K42, O13, O17, Q58

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1. Introduction

Agents operating in illegal markets cannot resort to the justice system to uphold contracts, to guarantee property rights, or to seek protection from competitors' improper behaviors. Instead, in these contexts, violence is used to enforce previous agreements and to fight for market share (for a case study, see Mieczkowski, 1990). This relationship plays a major role in the current debate on the pernicious effects of the illegality of drug trade and the War on Drugs (see, for example, Nadelmann, 1989, Miron and Zwiebel, 1995, The Economist, 2001, and Keefer and Loayza, 2010). Historical episodes such as the American alcohol prohibition and the Opium Wars in China seem to support this view, but there is scant causal evidence on the effect of illegality on violence and skeptical views are common (see Naylor, 2009, or discussion in Fagan and Chin, 1990, and Donohue et al, 2011). Randomized experiments in this setting seem virtually impossible, while institutional changes leading to transitions of markets from legal to illegal – which could be used as natural experiments – are extremely rare.

This paper explores a singular episode of transition of a market from legal to illegal to provide a first piece of causal evidence on the increase in violence following the complete shutdown of a legal market. Brazil has historically been the main world producer of big leaf mahogany, an extremely valuable tropical wood.[1] From the end of the 1990s to the early 2000s, the Brazilian government implemented a series of policies progressively restricting the extraction and trade of mahogany, culminating with prohibition in late 2001. We analyze yearly data at the municipality level, using structural breaks and difference-in-differences estimation strategies, to show that mahogany extraction persisted and was associated with increased violence after prohibition. Our identification trusts on the timing of implementation of restrictions to the mahogany trade and on three pieces of information on the relevance of mahogany for a given region. We have data on the natural occurrence of mahogany in the Brazilian territory, on state level mahogany exports before prohibition, and on exports of "other tropical timber species" after prohibition. Combinations of these variables can be used to explore double differences on timing of change to illegality and relevance of mahogany for a

[1] Grogan et al (2002) claim that mahogany is one of the most valuable woods in the world, with the price per cubic meter for a high quality variety around US$ 1,200 in 2001. The area of natural occurrence of big leaf mahogany is restricted to Central America and to the South American region of the Amazon. The total Brazilian production of mahogany between 1971 and 2001 is estimated to have been of the order of US$ 4 billion, with 75% corresponding to exports to the US and Europe (Grogan et al, 2002).

given area, and also triple differences on timing of change, availability, and economic importance.

In particular, we first follow and extend the work of Chimeli and Boyd (2010) and present evidence that large scale mahogany trade persisted after prohibition, through misclassification of mahogany exports as exports of "other tropical timber species." Following, we document relative increases in homicide rates after prohibition in: (i) states with higher share of total mahogany exports before prohibition; (ii) states suspected of higher illegal mahogany activity after prohibition; and (iii) municipalities within the area of natural occurrence of mahogany. Our main results persist if the sample is restricted to states with some natural occurrence of mahogany or even only to the state of Pará, which accounts for more than 70% of exports in the pre-prohibition period. The increase in violence after prohibition does not seem to be determined by changes in socioeconomic conditions, agricultural activity, urbanization, public security expenditures, or overall mortality rates, and is not associated with pre-existing trends in homicide rates. In addition, we are able to characterize the typical victim of the increase in violence as prime-aged single males. We believe that the evidence presented here constitutes one of the first documented experiences of increase in violence following the transition of a market from legal to illegal.

Our paper is probably most closely related to the literature on illegal drugs and violence. There is a vast literature outside economics with case studies or descriptive analysis of the patterns and incidence of crime and violence among drug users and sellers (see papers in De La Rosa et al, 1990). In economics, Miron (1999 and 2001) explores time series and cross-country data on enforcement of alcohol and drug policies, and finds a positive correlation between enforcement and homicides. In the first case, the historical experience of the US is analyzed and identification comes from time series variation in enforcement, which is potentially endogenous to violence itself. In the second case, identification comes from cross-sectional country level variation with a reduced number of countries, so that omitted variables and outliers are potential concerns. Medina and Martínez (2003) use variation in drug prohibition enforcement across Colombian municipalities between 1991 and 1998 and find no systematic relationship between enforcement and crime, though again endogeneity may be an issue. Mejía and Restrepo (2011) show that increases in the demand for Colombian coca due to

external shocks (changes in repressive policies abroad) are associated with relative increases in violence in areas adequate for coca cultivation.

A number of recent papers tries to deal directly with the relationship between market illegality and crime and violence. Adda et al (2010) explore an episode of decriminalization of cannabis possession in a London borough between 2001 and 2002. They find that decriminalization was associated with increases in drug related offenses and reductions in other types of offenses (as police shifted resources towards non-drug related crimes). Owens (2011a) uses state level data and presents evidence that increases in violence in the 1920s US were mostly driven by demographic trends, bearing almost no relationship with the criminalization of alcohol markets. Still, Owens (2011b) shows that criminalization of alcohol led to a change in the distribution of homicides towards ages 20 to 30, suggesting that indeed it was associated with the emergence of organized crime and systemic violence (partly offset by the reduction in homicides in other age-groups due to reduced consumption).

As Adda et al (2010) and Owens (2011a and 2011b), we use an institutional change that can be seen as a natural experiment on the effect of illegality. But, differently from Adda et al (2010), we analyze the complete shutdown of a market, rather than changes in the criminal status of consumers in a specific location. And, differently from Owens (2011a and 2011b), we analyze the incidence of violence in a market unrelated to "vice" goods (drugs, alcohol, prostitution, etc), so that we immediately isolate what is sometimes termed "systemic" violence, as opposed to violence that may arise due to the consumption of the good itself or to intrinsic characteristics of consumers. Our municipality data and the characteristics of mahogany allow us to be much more precise about the locations where violence should be occurring and to link it explicitly to the production side of the market. Therefore, our setting is more adequate for the analysis of the overall effect of prohibition on the incidence of systemic violence. The results suggest that prohibition, per se, is associated with increased violence.

The remainder of the paper is structured as follows. Section 2 presents a background of mahogany trade and policy in recent decades in Brazil. Section 3 presents the data used in the paper. Section 4 describes our empirical strategy. Section 5 presents the results related to mahogany trade after prohibition. Section 6 presents the results on prohibition of mahogany trade and violence. Finally, section 7 concludes the paper.

2. Background

2.1 Mahogany Policy in Brazil

Big leaf mahogany (*Swietenia macrophylla King*) is a native species of the Americas, originally ranging from Mexico to the Amazon region in South America. The durability, color and malleability of the timber from this tree are the main reasons for the high prices it fetches in international markets and have led to its intense exploration over the years. Most of the remaining big leaf mahogany trees are located in the Amazon forest, and Brazil was the largest exporter of the species prior to prohibition of production and trade by the local government in 2001. Brazilian production was mainly exported to the United States and European high-end furniture and construction markets.

Exploration of Brazilian mahogany in the 1980s and 1990s, even under heavy regulation, contributed to increased concerns by domestic and international environmentalists who argued that continued extraction would soon lead to extinction. Although this statement has been disputed,[2] a series of stricter regulations were introduced by the Brazilian government starting in the early 1990s to curb extraction. These included: (i) export quotas limiting international sales to 150,000 m^3, 65,000 m^3 and 30,000 m^3 in 1990, 1998 and 2001 respectively; (ii) moratorium on the issuance of new forest management plans to back up mahogany extraction starting in July 1996; (iii) creation of a working group to audit forest management plans (required for mahogany extraction to take place), which led to the suspension of 85% of all management plans in March 1999; and (iv) prohibition of extraction, transportation and domestic or international trade of mahogany in October 2001. Finally, big leaf mahogany was listed on appendix II of the United Nations Convention of International Trade of Endangered Species of Wild Fauna and Flora (CITES) in November 2002 (this regulation came into force in November 2003). Inclusion of a species in appendix II of CITES requires careful monitoring of international trade by both the exporting and importing countries. This, in turn, might have reinforced the impetus for maintaining the more stringent outright prohibition already imposed by Brazilian authorities.[3] Institutionally, the two main restrictions were those introduced in March 1999 – when 85% of the management licenses were suspended – and October 2001 – when mahogany extraction was finally prohibited.

[2] See Roozen (1998) and cited references.
[3] See IBAMA (1999), Grogan et al (2002), and Lentine et al (2003).

Despite tightened regulations, mounting evidence points to the continuing smuggling of big leaf mahogany formally exported under the guise of "other tropical timber species." In a recent article, Chimeli and Boyd (2010) analyze official export data to show that Brazilian exports under the trade category "other tropical timber species" jumped by 1,800% in a single month in 1999 and were sustained at volumes comparable to those of former exports of big leaf mahogany. They estimate structural breaks in the series for "other tropical timber species" and verify that these regime changes closely match regulatory changes in the big leaf mahogany market. An especially strong structural break takes place following the suspension of 85% of all forest management plans in March 1999. They also explore alternative explanations for the jumps in exports of "other tropical timber species," but only to find further evidence that these correspond to smuggling of mahogany through formal export channels.[4]

But how can mahogany be smuggled out of the country through formal export channels? Selected timber species from the Amazon (mahogany, Brazilian cedar, ipe, virola-balsa, and louro) have separate international trade codes that exporters have to specify when they sell their product (Common Mercosur Nomenclature – NCM, chapter 44). In addition to these, there is an aggregate residual trade code that encompasses "other tropical timber species" (NCM 4407.29.90).

Exporters (or hired export companies) have to produce an invoice specifying the quantity and value of the transaction and have to fill out two export forms ("Registro de Exportação," or Export Registry, and "Declaração de Despacho de Exportação," or Declaration of Export Dispatch). Both these forms specify the NCM code of the exported good, and this is the point at which exporters have the opportunity to list mahogany as another species. Finally, an outsourced customs dispatcher is then responsible for presenting the cargo at the port.

While import tariffs are common in Brazil, the same is not true for export taxes. As a result, the likelihood of inspection at the port ("yellow light" or "red light" levels of monitoring) is much lower for exports than for imports. This gives exporters an opportunity to smuggle mahogany as a different species (which is subject to less stringent regulations).[5] Once

[4] Theoretical discussions of contexts in which more stringent regulations may backfire can be found in Bulte and Van Kooten (1999) and Becker et al (2006). Glaeser and Shleifer (2001) provide a more general discussion of the relative advantages and disadvantages of quantity regulations.

[5] In addition, identification of mahogany by physical inspection is extremely difficult and requires an expert with knowledge of mahogany and, additionally, of andiroba, cedar, and curupixá, species that can be easily mistaken by

mahogany is smuggled, the exporter is paid the invoice value through regular export procedures and the importer obtains a cargo complete with formal documentation.

Figure 1 presents the aggregate series for Brazil of mahogany and "other tropical timber species" exports, between 1989 and 2007. It is clear that the declining trend of mahogany exports after the introduction of restrictions is accompanied by a rising trend in exports of "other tropical timber species."[6] In order to illustrate this point, the figure also presents the sum of the two series, which displays a more stable pattern. The aggregate series do suggest that legal mahogany exports were replaced by illegal exports under the guise of "other tropical timber species." Prior accounts by Blundell and Rodan (2003), Barreto and Souza (2001), and Gerson (2000) describe this same phenomenon. Apprehensions from as recently as early 2010 provide additional anecdotal evidence that Brazilian mahogany was systematically exported as species falling under the general category "other tropical timber species" (see, for example, Diário do Pará, 2010).

The existing evidence suggests that regulations that significantly reduced exports of big leaf mahogany and finally culminated into outright prohibition created an active illegal market. Grogran et al (2002) estimate the total value of mahogany exports between 1971 and 2001 to be around US$ 4 billion. This value averages US$ 129 million per year, corresponding to 1.2% of the aggregate GDP of the state of Pará in 2000 (Pará accounted for more than 70% of total mahogany exports before prohibition). This highlights the relevance of this potential market to the local economy. Furthermore, the peculiar characteristics of the smuggling of Brazilian mahogany allow us to track down this illegal activity. This provides us with a unique opportunity to test the hypothesis that illegal markets are associated with increased violence.

2.2 Violence and the Illegal Mahogany Market

The role of violence in markets operating outside the scope of the legal system has received some theoretical attention. Donohue and Levitt (1998), for example, analyze the efficiency of allocations in these markets, arguing that it is directly related to the cost of fighting and the uncertainty regarding final outcomes of a fight. Reuter (1985 and 2009) argues that

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it. As recently as 2011, there are studies being conducted on the identification of mahogany based on equipment using infrared light (O Globo, 2011). These have as main objective the development of technologies to facilitate detection and reduce the illegal trade of mahogany.

[6] Some export of mahogany after prohibition in 2001 is registered, since exports from specimens extracted before prohibition were allowed under certain circumstances.

these markets are typically organized in such a way that "firms" are small and short-lived, and tend to interact much more through competition than collusion. These would be consequences of lack of access to external credit markets, of the attention drawn by large firms, and of the difficulty and high risk of using violence to maintain centralized control, all of which would imply negative returns to firm size. He also argues that, in illegal markets, violence characterizes not only interactions between competitors, but within organizations, from labor disputes to reputation building and managerial successions.

In relation to the particular case of violence in connection with illegal logging, anecdotal evidence abounds both in Brazil and elsewhere (see, for example, Greenpeace, 2001 and 2004, and Hance, 2010). It is easy to find reports that discuss illegal logging as intrinsically related to the widespread use of violence.[7] News from private media outlets, non-governmental organizations, and official media document time and again the use of violence in the illegal mahogany market and give indications of the scale of this criminal activity.

In the Brazilian Amazon, protected timber species are stolen from private land (Comissão Pastoral da Terra, 2011), indigenous and conservation areas (Soares, 2003, O Liberal, 2002, and Universo Online, 2004), and public land (Soares, 2003, Universo Online, 2004, and Mendes, 2005). Intimidation driven deals with indigenous tribe leaders are also commonly reported (Mendes, 2004). Whereas illegal extraction of mahogany already occurred before prohibition in association with fraudulent forest management plans, Mendes (2005) documents an increase in organized crime in Pará following prohibition.

In the process of extracting mahogany, loggers are said to resort to illegally obtained weapons and "threat execution of whoever may offer any resistance" (Soares, 2003). Threats and murders of rural workers, non-governmental organization leaders, and government officials attempting to disrupt the functioning of the illegal mahogany market have been widely publicized. For example, Adilson Prestes, a landless rural worker, was murdered by gun shots in the town of Novo Progresso, Pará, on July 3, 2004, allegedly for having denounced to local authorities extraction of mahogany in public and indigenous lands and a clandestine cemetery (Universo Online, 2004). At the other end of the political spectrum, a former president (2001-2002) of the Brazilian Institute for the Environment and Natural Resources (IBAMA) received

[7] For example, Hance's (2010) interview article on Indonesia is titled "Violence a part of the illegal timber trade, says kidnapped activist."

death threats because of his role in the prohibition of mahogany extraction and trade (O Liberal, 2002). The investigative commission for bio-piracy of the Brazilian House of Representatives also documented death threats to two other IBAMA staff members in Pará (Câmara dos Deputados, 2005). According to Mendes (2005), organized crime in the region has two main activities: intensive exploration of mahogany and other species in public and protected land, and illegal sales of public land. In this process, loggers command a small army of men ready to perform acts of sabotage, intimidation, and murder of rural workers, union leaders, and human rights militants.

Reports from the media suggest a significant depth of the so-called "mahogany mafia," and a Federal Police officer has compared its market to that for narcotics (O Estado de São Paulo, 2002). While describing individuals involved in this trade, the same officer states that "we are not dealing with small transgressors, but a mafia (…). They use violence, move large fortunes and coerce the small guys." Allegations of this nature led to a formal arraignment by a prosecutor in the state of Pará. According to its report, the "mahogany mafia" – who illegally extracted the timber to be sold in international markets – built clandestine roads, bridges, and airstrips, assembled a "war arsenal," exploited slave labor, and owned 38 vehicles (mainly trucks), a ferry boat, and airplanes (Ministério Público do Estado do Pará, 2002). Influential politicians, indigenous tribe leaders, and public officials from federal and local governments have also been accused of involvement in the illegal mahogany market (Mendes, 2005).

In the following sections, we first test for structural breaks in the Brazilian exports of "other tropical timber species." We then compare the estimated breaks with the dates when Brazilian authorities imposed restrictions on the mahogany market. These regime changes can serve as benchmarks to test the effect of prohibition on violence.

3. Data

Mahogany Variables

In order to conduct our exercise, we need some indicator of the relevance of mahogany in certain areas of the country. We use different pieces of information to construct such indicator. First, Grogan et al (2002), based on Lamb (1966) and on field work conducted by the authors, provide a map indicating the area of natural occurrence of mahogany in the Brazilian territory (the same map is presented by Lentini et al, 2003, and is reproduced here in Appendix

A.1). 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.[8]

Given the difficulty of access in the Brazilian Amazon, where the mahogany occurrence area is concentrated, the former variable may not be a very precise indicator of the actual relevance of mahogany in a certain region. For remote areas, with costly transportation, natural occurrence may not be enough to warrant profitable exploration. So we also construct variables trying to capture the economic relevance of mahogany in different regions. We have state level information on the total exports of mahogany (in kilograms) before prohibition, starting from 1989. Based on this information, we create a variable indicating the state share in total exports of mahogany before 1999. Exports can be done by a state that does not produce mahogany, in case an exporting company buys wood from a producing state. Still, more than 90% of mahogany exports come from the region of natural occurrence of mahogany, with more than 70% coming from the state of Pará, which is typically identified as the main producer and the area where most of the illegal logging takes place (see, for example, Greenpeace, 2001).

Finally, we also use information on exports of "other tropical timber species" by state, from 1989 and 2007. We use this information to present evidence on the continuing exploration and trade of mahogany after prohibition and as a proxy for the extent of illegal logging taking place in different states.

The data on exports of mahogany and other type of tropical timber 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 two export categories we analyze in this paper are monthly exports in Kg of mahogany and "other tropical timber species" for all exporting states of Brazil, from January 1989 to March 2010. To construct these series we took into account a change in export codes that took place in 1996.

[8] For the state of Pará, the main producer of mahogany before prohibition, Greenpeace (2001) presents a map indicating locations of legal mahogany logging and locations where investigations uncovered illegal mahogany extraction. It is reassuring that these locations are all within the area of natural occurrence of mahogany indicated by our variable and imply an overall distribution of mahogany activity very similar to that suggested by the map from Groggan et al (2002).

The precise strategy used to match the codes before and after 1996 is described in detail in Appendix A.2.

Outcome Variable

Our outcome variable, used as an indicator for the incidence of violence, is the homicide rate per 100,000 inhabitants. This variable is available yearly at the municipality level from the Brazilian Ministry of Health integrated system of information (www.datasus.gov.br). Homicide rates are thought to have higher reporting than other types of violence (Soares, 2004), and the unified system of public health from the Brazilian government warrants a certain uniformity in definition across regions. The homicide data are available yearly since the early 1980s.[9]

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 and maybe determined by the prohibition of mahogany trade, and which may also affect the incidence of violence.

Few variables are available yearly at the municipality level, so we also use several state level controls in our analysis. Most of the state level variables come from the Brazilian National Household Survey ("Pesquisa Nacional por Amostra de Domicílios") and were tabulated by the Institute for Applied Economic Research ("Instituto de Pesquisa Econômica Aplicada," available from www.ipeadata.gov.br), a think tank from the Brazilian government. These include: poverty rate, ratio of income per capita of the top 10% of the income distribution to the bottom 40%, percentage of households with more than 2 members per room, enrollment rate between ages 7 and 14, percentage of informal workers in the labor force, percentage of population living in households with access to treated water, percentage of population living in households with toilet connected to the public sewerage system, illiteracy rate in the population above 15, percentage of the labor force occupied in agriculture and fishing, and unemployment rate. Other state level data include household electricity consumption per capita from the Brazilian Census Bureau ("Instituto Brasileiro de Geografia e Estatística," or IBGE) statistical yearbook

[9] The main police forces in Brazil are run by states. For the vast majority of Northern states (those in the mahogany area), institutional development is quite weak and there are no consistent municipality level series for crime rates available from the police forces. So our only alternative is to look at homicide rates based on mortality data.

and government expenditures on public security per capita (from the Brazilian Ministry of Finance).

At the municipality level, we have total area planted (from the municipal agricultural surveys from IBGE) and mortality data by cause of death (from the Brazilian Ministry of Health). We also use municipality level data on number of political deaths associated with land conflicts (collected by the "Comissão Pastoral da Terra," a catholic organization that monitors and tries to mediate land related conflicts in Brazil).

Variables constructed from the PNAD are available, under a consistent methodology, since 1992, but for the years 1994 and 2000, when the survey did not take place. Household electricity consumption is not available for the year 1997, while the other state level variables are available for all years between 1992 and 2007. Within this time interval, the municipality data (area planted and mortality) are available for all years.

Given the availability of data, the creation of a large number of municipalities in Brazil in the early 1990s, and the fact that the policies we want to analyze were introduced only in the end of the 1990s, we restrict our sample to the period between 1995 and 2007. Still, regressions including all controls lose part of the observations within this time interval.

Tables 1 and 2 and Figure 2 present descriptive statistics for the three samples of municipalities that will be used throughout the paper: the entire country of Brazil, only states with some natural occurrence of mahogany, and only the state of Pará. Table 1 presents averages of homicide rates, access to treated water, and gdp per capita for municipalities outside and inside the mahogany occurrence areas, for the entire country.[10] Table 2 presents the same descriptive statistics, but first only for municipalities in states with some natural occurrence of mahogany, and then only for municipalities in the state of Pará.[11] Table 1 makes clear that mahogany regions are typically poorer and with less access to public goods than other regions of Brazil. Also, mahogany regions start with lower homicide rates, but surpass the countrywide rates by 2007. Table 2 shows that the differences in socioeconomic characteristics

[10] We do have data on gdp per capita for some years, but do not use it in our later empirical exercises since it would imply a substantial loss in terms of number of observations. Still, results are very similar when we control for gdp per capita, even with the loss in number of observations (available from the authors upon request).

[11] To keep a consistent sample and a balanced panel in the later analysis, we concentrate on municipalities that already existed in 1995 (there were some municipalities created during the period of our analysis). Results and descriptive statistics are identical if we also include municipalities created during the period.

become much milder when we look at more homogeneous areas, either states with some mahogany occurrence or only the state of Pará.

Figure 2 plots the homicide rates series from Tables 1 and 2. The patterns mentioned before become even clearer, and the dates of the main interventions in the prohibition of mahogany do seem to be associated with relative increases in homicide rates in mahogany occurring areas. Particularly striking is the pattern observed in the state of Pará, where the evolution of homicides was almost identical between mahogany and non-mahogany occurring areas before prohibition, but a gap opens up immediately after the first major restriction to logging in 1999. Tables 1 and 2 and Figure 2 suggest that prohibition may indeed have had an effect on violence, but they also highlight the challenges implicit in our empirical exercise.

4. Empirical Strategy

4.1 Illegal Mahogany Trade after Prohibition: Structural Break Estimation

We first provide evidence that exports of mahogany continued after prohibition, through misclassification of mahogany exports as exports of "other tropical timber species." In order to do so, we show that the historical series of exports of "other tropical timber species" experienced huge increases in quantity (kilograms) following the introduction of the most severe restrictions on mahogany extraction and trade. To develop this argument formally, we follow Bai and Perron (1998) and test for endogenous structural breaks in the series and check whether the dates identified by the model match the timing of introduction of restrictions in the mahogany market. This same exercise was conducted for the aggregate monthly series for Brazil by Chimeli and Boyd (2010). Here we extend their analysis by formally controlling for exports of some selected species, in an attempt to account for widespread movements in the markets for tropical woods and substitution from mahogany to other varieties. We also perform the same tests with yearly series (which tend to be less noisy than monthly series).

Consider a step function with *m* structural breaks determining *m+1* distinct regimes:

$$y_t = \delta_j + x_t'\beta + u_t \quad \text{with} \quad t = T_{j-1}+1,\cdots,T_j \quad \text{and} \quad j = 1,\cdots,m, \qquad (1)$$

where y_t is the observed dependent variable, δ_j are regime specific averages (regime specific coefficients of regression of y_t on a vector of 1's), x_t and β are covariates and associated

coefficients, u_t is the possibly autocorrelated and heteroskedastic disturbance at time t, and T_1,..., T_m are the break points to be estimated.

Estimation of these breakpoints initially requires calculation of the minimum sum of squared residuals for each admissible partition of the time domain:[12]

$$S_T(T_1,\cdots,T_m)=\min_{\delta}\sum_{i=1}^{m+1}\sum_{t=T_{i-1}+1}^{T_i}(y_t-\delta_i-x_t'\beta)^2. \quad (2)$$

Next, Bai and Perron (1998) use a dynamic programming algorithm to compute the minimum $S_T(T_1, \ldots, T_m)$ over all admissible partitions, yielding the estimated breakpoints

$$(\hat{T}_1,\cdots,\hat{T}_m)=\arg\min_{T_1,\cdots,T_m} S_T(T_1,\cdots,T_m). \quad (3)$$

Finally, to determine the number of breaks in the series, we employ a set of statistics derived by Bai and Perron (1998) to first test the null hypothesis of no breaks versus the alternative of $m = b$ breaks, and then to test the null hypothesis of l breaks against $l+1$ breaks.

We also conduct the same exercises controlling for exports of cedar, ipe and virola-balsa. Cedar and ipe are imperfect substitutes for mahogany, mainly due to their durability, and jumps in their exports could reflect systematic changes in demand for timber from the Amazon as a response to mahogany prohibition. Virola-balsa is a softer type of timber with very different uses from mahogany. We include it to capture overall movements in the international markets that might also be correlated with jumps in exports of "other tropical timber species."

4.2 Mahogany Prohibition and Violence: Differences-in-Differences

The dimensions of variation we explore to identify the causal effect of prohibition on violence are the timing of the institutional changes and the differential relevance of mahogany across different areas of the country. In principle, if the increase in homicide rates after prohibition is larger in mahogany occurring or producing 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, rather than from differential timing of treatment. Areas with no mahogany related activity should experience no significant changes in the incidence of violence due to

[12] By admissible partition of the time domain, we mean partitions T_1,..., T_m such that each regime lasts for no less than a given pre-determined time length h greater than the number of regressors in the model.

prohibition (apart from general equilibrium effects, which are likely to be small), while areas with some type of mahogany activity should experience increases in violence.

Given the institutional discussion from section 2 and the evidence to be presented in the next section, we focus on two particular years as key moments in the increasing trend towards mahogany trade prohibition. 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 all following years, corresponding to the final prohibition of mahogany trade instituted on October 2001.[13]

Our benchmark specification is the following:

$$Homicide_{it} = \alpha + \beta_1.(D_{1999\leq t\leq 2001} \times Mahog\_Var_i) + \beta_2.(D_{t\geq 2002} \times Mahog\_Var_i) + z_{it}'\gamma + \vartheta_i + \mu_t + \varepsilon_{it}, \quad (4)$$

where $Homicide_{it}$ indicates the homicide rate 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; $Mahog\_Var_i$ is some variable indicating the relevance of mahogany in municipality i (to be discussed in the next paragraph); z_{it} is a vector of control variables; ϑ_i is a municipality fixed-effect; μ_t is a year fixed-effect; ε_{it} is a random term; and α, β_1, β_2, and γ are parameters. Under the usual assumptions, $E[\varepsilon_{it} | D_{t\geq 1999}, D_{t\geq 2002}, Mahog\_Var_i, z_{it}, \vartheta_i, \mu_t] = 0$, and OLS estimation of the above equation provides unbiased estimates of the β's. In this hypothetical setting, the random term ε_{it} is not correlated with the independent variables, so OLS estimates of the β's indeed provide the parameters of interest: the causal impact of mahogany trade restrictions on homicide rates.

We use three pieces of data to identify the relevance of mahogany in a given area ($Mahog\_Var_i$). First, we use information on the area of natural occurrence of mahogany. From that, we create a dummy variable equal to 1 for municipalities that are in the mahogany occurring area. But natural occurrence of mahogany may not be enough for its trade to be an important activity, given that it may not be economically profitable to explore mahogany in remote and difficult to access areas. So we also use information on mahogany exports before

[13] We present here only results including both treatment variables simultaneously. Results tend to be stronger when we consider only one treatment (either from 1999 or from 2002 onwards). These results are available from the authors upon request.

prohibition and exports of "other tropical timber species" after prohibition. This information is available only at the state level, so we create two variables: one indicating the share of the state in aggregate mahogany exports between 1989 and 1998 (before prohibition), and another indicating the total amount of yearly "suspected mahogany exports," both before and after prohibition. The second variable is constructed simply by adding the series of mahogany and "other tropical timber species" exports, on the assumption that the latter represented illegal mahogany exports. The first variable gives a measure of the importance of mahogany to the local economy before prohibition, while the second gives an estimate of mahogany activity which includes the illegal period (in reality, we only use the post-prohibition period as treatment, but the pre-prohibition period is also useful in some of our robustness exercises).

These variables capture export activity, but not necessarily extraction, since non-mahogany producing states can also be exporters (though, in reality, this is a rare event). Since each of the suggested variables has advantages and disadvantages, we use all of them as treatments in our analysis. In addition, we go one step further and create treatment variables that are the product of one of the export variables (state share in mahogany exports before prohibition or "suspected mahogany exports" after prohibition) and the dummy variable for mahogany occurrence area. These treatments correspond to triple differences in timing of prohibition, natural mahogany occurrence, and relative importance of mahogany activity (either before prohibition or supposed illegal activity afterwards). We have therefore five treatment variables that we use throughout the paper, two of them trusting only on state level variation (export related variables) and three trusting on municipality level variation (mahogany occurrence area and triple differences using interactions of area with exports).

In our context, there are two potential problems with the difference-in-differences strategy: omitted variables and differential dynamic behavior of homicide rates. First, there may be other changes taking places simultaneously with prohibition of mahogany trade. In particular, prohibition has economic impacts that may indirectly affect the incidence of violence. We try to control for three dimensions that may be of concern: (i) prohibition of mahogany may reduce income in certain areas and reduce labor market opportunities, so we control for a large set of state level socioeconomic characteristics (unemployment rate, percentage of informal workers, fraction of household with more than 2 members per room, and inequality); (ii) prohibition may be related to changes in the pattern of agricultural activity

and this may also be intrinsically related to violence in the agricultural frontier, so we control for fraction of municipality area planted and fraction of state population occupied in agriculture; and (iii) some of the mahogany areas are remote regions of the country, that may be going through modernization changes and increased urbanization, so we control for state level access to various public goods and indicators of urbanization (enrollment rate between ages 7 and 14, percentage of population living in households with access to treated water, percentage of population living in households with toilet connected to the public sewerage system, illiteracy rate in the population above 15, and household electricity consumption per capita).

As discussed in the previous section, most of these variables are available only at the state level, while only area planted is available at the municipality level. To partly address this limitation, in some robustness exercises we resort to the type of data that we do have yearly at the municipality level: mortality records. We use as additional controls in some specifications mortality rates for infectious diseases, neoplasms, heart and circulatory conditions, suicides, traffic accidents, and also overall mortality before age 5. Infectious diseases, neoplasms, and heart and circulatory conditions are intended to capture broad mortality trends at the municipality level, and also possibly changes in registration. Suicides and traffic accidents should control for changes associated with modernization and urbanization, while mortality under age five (and also possibly infectious diseases) can be seen as a control for local living conditions and economic development.

Finally, when controlling for mortality patterns, we also include the number of political deaths associated with land conflict. Lack of well defined property rights in the Brazilian agricultural frontier is commonly associated with violent land disputes (see Alston et al, 2000, and Altson and Mueller, 2010). Since part of this agricultural frontier is located in the Brazilian Amazon, overlapping some of the mahogany area, one might be worried about confounding effects of land conflict in our estimation.

We conduct our analysis for different samples and using different sets of controls. Part of the analysis restricts the sample to municipalities in states with natural occurrence of mahogany, and then only to municipalities in the state of Pará. Treatment and control groups are more homogeneous within these specific areas (see Tables 1 and 2), and the state of Pará is particularly relevant because it accounts for more than 70% of mahogany exports before

prohibition. But, on the other hand, contamination of the control group is more likely over smaller areas and state level controls are not very useful in this case. So, given the relative strengths of the different samples, we keep all of them throughout the paper.

The second issue raised relates to the possibility of differential dynamic behavior of homicides in mahogany occurring areas, even before the imposition of restrictions on logging and trade. Figure 2 suggests that this was not the case, but we explore this possibility by assessing whether there is any evidence of differential preexisting trends in homicide in areas associated with mahogany production.

There are some remaining methodological issues that we deal with in our estimation: (i) as the variance of homicide rates is directly related to population size, we weight all regressions by population size; and (ii) as the difference-in-differences strategy may lead to underestimation of standard errors due to autocorrelation in the residuals, we cluster standard errors at either the state or municipality level (depending on the treatment variable), allowing for an arbitrary structure of correlation over time (as suggested by Bertrand et al, 2004).

5. Results: Illegal Mahogany Trade after Prohibition

The analysis in this section is closely related to a growing body of literature on detection of illegal activities, exemplified by Fisman and Wei (2004), Fisman et al (2009), and Della Vigna and La Ferrara (2010). Table 3 presents the estimated structural breaks for exports of "other tropical timber species" and Figure 3 plots the corresponding data. The results on the left portion of the table are based on monthly exports, while the right portion uses total annual exports. Whereas the number of observations is much larger when we use monthly information, higher frequency data can be more volatile and mask longer run movements in the series. We therefore report our results for both series.

We also report our estimates when we control for exports of cedar, ipe and virola-balsa. As mentioned before, cedar and ipe are imperfect substitutes for mahogany, and jumps in their exports could reflect systematic changes in demand for timber from the Amazon as a response to mahogany prohibition. Virola-balsa is a softer type of timber with very different uses than mahogany. We include it as a control to capture potential overall movements in the international trade of timber from the Amazon, independent from the mahogany market. When analyzing the annual series, we drop the variable for ipe from our set of controls, since

the minimum time interval between two structural breaks in Bai and Perron (1998) has to be greater than the number of regressors in the model. This means that, with the annual data, the inclusion of three controls plus the constant would force the structural breaks to be at least five years apart.

The table presents estimated break dates in bold (month of the year in parenthesis), followed by their corresponding confidence intervals. Since Bai and Perron's (1998) algorithm uses integers for dates, confidence intervals formed by time spans smaller than the time unit of the series are not reported and appear as NA. The first structural break for our monthly series occurs on August 1999, following suspension of 85% of all forest management plans used to back up extraction of big leaf mahogany. The suspended management plans were located in the state of Pará and affected the largest producers of mahogany, who effectively lost their ability to formally extract and sell this resource. The structural break taking place on August 1999 corresponds to an increase of 1,800% in the Brazilian exports of "other tropical timber species" in one single month.[14] When we focus on the annual series, the first structural break occurs in 1998 and reflects the increase in exports taking place on August of the following year, as described above.

The second structural break that appears in our four models occurs sometime between 2001 and 2003. This break is consistent with two institutional changes affecting the mahogany market: i) prohibition of extraction, transportation and trade of big leaf mahogany imposed by Brazilian authorities in the end of 2001, and ii) inclusion of big leaf mahogany in Appendix II of CITES, which might have signaled that prohibition was likely to be maintained. We therefore find support to the hypothesis that the drastic contraction of the formal mahogany market in 1999 and prohibition in late 2001 have contributed to the flourishing of an illegal market in the main producing states.[15,16]

[14] Most of the exports of "other tropical timber species" came from the state of Pará, the largest producer of mahogany. Estimating structural breaks for exports of "other tropical timber species" from Pará produces identical point estimates and minor variations in the confidence intervals for the monthly series. Estimates of break dates for the states where mahogany naturally occurs are available from the authors upon request.

[15] When analyzing total Brazilian exports of "other tropical timber species" to the European Union and the United States for the time span ranging from January 1989 to December 2006, Chimeli and Boyd (2010) estimate structural breaks in August 1999 and sometime in the time span ranging from September 2002 to April 2004, depending on the consumer market and taking into account confidence intervals.

[16] If we ignore the problem alluded to above and estimate the model with annual series using our entire set of controls (three controls for the different types of timber plus the intercept), we artificially estimate the first break in 1997, five years before the second break in 2002. However, visual inspection of the series for "other tropical

6. Results: Mahogany Prohibition and Violence

Table 4 presents the results for our benchmark specification. The table displays the coefficients estimated with the specification from equation 4, without the inclusion of any control, when the five different treatments are considered: (i) mahogany occurring region interacted with treatment years; (ii) pre-prohibition state share of mahogany exports interacted with treatment years; (iii) mahogany occurring region interacted with pre-prohibition share of exports and with treatment years; (iv) state "suspected mahogany exports" interacted with treatment years; and (v) mahogany occurring region interacted with "suspected mahogany exports" and with treatment years.

The results show a significant effect of the second treatment variable, associated with the shutdown of the legal mahogany market, in all specifications. The coefficient on the first policy change (*treat 1999*) is also quantitatively much smaller than that on the second one (*treat 2002*). Areas in the region of natural occurrence of mahogany, states with higher share of mahogany exports before prohibition, and states with higher "suspected mahogany exports" after prohibition all experienced relative increases in homicide rates after 2001. In addition, the triple difference estimates from columns 3 and 5 lead to coefficients substantially higher than their respective double difference counterparts (columns 2 and 4). This suggests that the most pernicious effects of prohibition were observed in areas that had natural occurrence of mahogany and where mahogany commercial activity was relevant (either legally before prohibition or illegally after prohibition). This pattern is consistent with the logic behind our identification strategy and the anecdotal evidence discussed in section 2.

In Table 5, we include state and municipal controls. For each treatment variable, we present columns with only the state controls added and then with the state and municipal controls. If anything, results are typically stronger when the additional controls are included and, in several cases, the first treatment variable (*treat 1999*), which was not significant, becomes statistically significant. The fact that point estimates are not reduced when we include the controls indicates that the changes in homicide we are detecting are not related to changes

timber species" suggests that no unusual changes took place in 1997. Dropping the series for cedar instead of ipe in the estimation with the annual series produces results analogous to those presented in the table, with one structural break in 1998 and another in 2003, and no estimated confidence intervals in either case.

in state level economic activity, socioeconomic conditions, urbanization, nor to municipality changes in the pattern of agricultural activity.

Following, we restrict the sample in two different ways to deal with potential concerns related to the comparability of treatment and control groups. First, we look at states with some natural occurrence of mahogany, so that we end up with only 7 states. In Table 6, we present results without controls and with both state and municipality controls. Some of these results should be interpreted with caution, given that the export variables vary only at the state level. This implies that, for columns 3, 4, 7, and 8, we have only 7 cross-sectional units of variation in the treatment (we still cluster standard errors at the state level in these cases, but there are potentially serious concerns related to the small number of clusters). In any case, point estimates are slightly smaller than those obtained before, but qualitative results remain almost identical. Even within mahogany occurring states, mahogany occurring areas experience significant increases in violence when compared to other areas.

In Table 7 we go one step further and restrict the sample only to the state of Pará. Given that Pará accounted for most of the mahogany production before prohibition, and that a major part of the illegal activity is thought to take place there, it deserves particular attention. In addition, Table 2 and Figure 2 showed that there is much less municipality heterogeneity within Pará than across Brazil as a whole, so that this exercise may help diminish concerns related to heterogeneity between treatment and control. Given that we are restricting the analysis to a single state, all we can do is compare municipalities inside and outside the area of natural occurrence of mahogany, before and after the institutional changes. We run this specification with and without the control for municipality area planted. These results are comparable to columns 1 from Table 4, and columns 1 and 2 from Table 5. Results are of similar magnitude but typically larger than those obtained before, with both treatments appearing as positive and statistically significant. So our previous results do not seem to be driven by unobserved heterogeneity across control and treatment groups. Looking only at the state of Pará, we are still able to detect a statistically significant increase in homicide rates in mahogany occurring areas when compared to other areas. If anything, differences are starker within Pará than across Brazil as a whole.

The only remaining limitation might be that we do not have enough municipality controls, and municipalities associated with mahogany could be going through other changes

around this same period. In order to address this potential concern, we conduct two additional exercises. First, we control for a broad set of mortality rates, which we do observe yearly at the municipality level. These mortality rates capture changes in overall mortality patterns across areas (heart and circulatory diseases, neoplasms, and infectious diseases), changes in socioeconomic conditions (mortality before age five and, to some extent, also infectious diseases), and changes in urbanization or modernization (traffic accidents and suicides).[17] In addition, we also control for deaths associated with land conflicts, to disentangle the violence we are identifying from that related to land control in the agricultural frontier.

Following, we deal with the possibility that the treatment variables are capturing distinct dynamics of violence in mahogany regions. If this was the case, one would expect these dynamics to be present already before the restrictions on mahogany exploration and trade were imposed. To assess this possibility, we introduce variables trying to account for pre-intervention trends in homicide rates.[18] The pre-1999 placebos used vary according to the treatment variable: (i) a dummy for 1997-1998 interacted with the treatment variables (mahogany occurring areas, pre-1999 share of mahogany exports, and the interaction of these two) for the first three cases, (ii) an interaction of "suspected mahogany exports" with a pre-1999 dummy for the fourth treatment, and (iii) an interaction of these two variables with mahogany occurring areas for the last treatment.

Results from these last two robustness tests are presented in Tables 8 and 9, for all treatments and all samples considered before. In Table 8, the inclusion of mortality controls leads to results that are, in most cases, quantitatively similar to those obtained when we did not include any control. As in those results, the first treatment (*treat 1999*) is not statistically significant, while the second (*treat 2002*) is.

In Table 9, none of the pre-intervention placebos appear as statistically significant. The vast majority of estimated coefficients on pre-intervention variables is very small in magnitude, while the effects of the treatments are again similar to those estimated before. So there is no

[17] One may imagine that a certain fraction of "extremely successful" murders go unnoticed, or at least are not registered by the health system as such. If so, it seems plausible that some of these might be registered as deaths due to traffic accidents, suicides, or even heart attacks. In this case, our strategy will underestimate the effect of prohibition on homicides.

[18] We conduct the preexisting trends exercises with the specification without controls since it has a more complete sample in terms of year coverage. The results are identical when we include the controls, but since in this case the data have less coverage across years, we think it is actually a weaker test.

evidence that our treatment variables are capturing differential dynamic behavior of homicide rates that were already present before the introduction of restrictions to mahogany trade, or that they reflect other changes taking place at the municipality level. In this respect, notice that columns 5 and 10 of Table 9 represent particularly strong tests of our hypothesis: they imply that, in mahogany occurring areas, state level "suspected mahogany exports" are significantly correlated with homicide rates after prohibition, but not before. This rules out not only pre-existing trends, but also alternative stories that would associate violence intrinsically to mahogany exploration.

Our final exercise presents one additional piece of evidence to lend support to the specific story outlined in section 2. In order to shed some light on the nature of the increase in violence detected here, we break down homicide rates by demographic characteristics: gender, age, and marital status. For brevity, we consider only our simplest treatment variable (interaction of mahogany areas with treatment years) and run our benchmark specification with the three different samples. Results are presented in Table 10, where first we break down homicide rates by gender and then, considering only males, break it down again by age group and marital status (in the latter case, since we do not have population by marital status, we simply divide homicide rates by the entire male population). Qualitative results are identical across the three samples: the increase in violence we are detecting is fundamentally driven by violence against prime-aged single men. Since this is also the group most likely to be involved in illegal activities and, more generally, crime, we believe this result lends additional support to the specific hypothesis raised in the paper. For example, looking at the state of Pará only, the increase in homicide rates is 19 times larger for men than for women, 9 times larger for prime-aged men than for other age groups, and 7 times larger for single men than for married men.[19]

To conclude our discussion of the results, we turn to the quantitative aspect of the estimated coefficients. For ease of computation and visual comparison, consider the coefficients in columns 1, 6, and 11 from Table 9. These can be immediately read as the increases in homicide rates per 100,000 inhabitants after mahogany prohibition, when each of the three samples is considered (the other treatments would require slightly more cumbersome calculations to deliver a concrete quantitative analysis). Comparing with the 1998

[19] These also represent relative increases in homicide rates for prime-aged single men (taking the 1998 homicide level as the reference point).

average homicide rate in each respective sample, these estimated coefficients correspond to increases of roughly 40% when considering the sample with the entire country or with mahogany occurring states, and of 114% when considering only the state of Pará. For the median municipality in the mahogany occurring areas of Pará (around 18,500 inhabitants), this effect corresponds to 2.8 additional homicides every year. From 1995 to 2007, the effect for Pará adds up to 1,998 additional deaths due to illegal mahogany activity.

Despite seeming exaggeratedly large, the coefficient for Pará is in fact quite reasonable when put in perspective of the recent experience of the state: it explains 93% of the differential increase in homicide rates between mahogany and non-mahogany occurring areas, illustrated before in Figure 2(c). The fact is that the state had relatively low incidence of violence in 1995, but by 2007 it had become a very violent area. Since the mahogany market is estimated to correspond roughly to 1% of its yearly GDP, it seems plausible that most of this spike in violence was due to increased illegal logging and the context of violence that followed.

7. Concluding Remarks

This paper presents evidence of the increase in violence in Brazilian regions with natural occurrence or trade of mahogany, following the introduction of increasingly restrictive regulations and eventual prohibition of mahogany exploration. Much has been said in the popular press and the academic literature about the intrinsic association between market illegality and the use of violence. Still, there is very little if any direct causal evidence on this relationship. We present what we believe is the first piece of evidence on the increase in violence following the complete shutdown of a legal market. The increase in homicides we document is not related to changes in socioeconomic conditions, pre-existing trends in violence, or pernicious or degrading effects of the consumption of the good itself. Our evidence points to a causal effect of market illegality, per se, on the incidence of systemic violence.

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Appendix

A.1 Area of Natural Occurrence of Mahogany in the Brazilian Territory, reproduced from Grogan et al (2002)

A.2 Construction of Export Series

Between January 1989 and December 1995, the Brazilian government used the Brazilian Merchandise Nomenclature (NBM) to code products internationally traded. In January 1996, Brazil started adopting the Mercosur Merchandise Nomenclature (NCM) also used by Argentina, Paraguay and Uruguay. Since most merchandise codes were either consolidated or expanded in the new classification system, MDIC then compiled a list to convert NBM into NCM codes. We used this list to construct our series.

International trade data were reported using both systems in 1996 and we used monthly data for this year to check for possible discrepancies associated with the two classification systems. The case of mahogany exports was straightforward (4407.24.10 in the NCM system corresponds to 4407.23.0102 and 4407.23.0201 in the NBM system) with no discrepancies in 1996. As for other tropical species, exports according to the NCM system (4407.29.90) do not match the summation of the corresponding NBM codes in 1996 (4407.21.0100, 4407.21.0200, 4407.21.9900, 4407.22.0100, 4407.22.0200, 4407.22.9900, 4407.23.0199 and 4407.23.0299). Exports of other tropical species in 1996 according to the NCM system were nil for all Brazilian states, whereas they were positive for parts of the year according to the NBM system. The states that had positive exports were Amazonas, Mato Grosso and Pará, all of them in the Amazon region and with parts of their territory overlapping the area where big leaf mahogany naturally occurs. Their joint exports totaled 1,595,578 Kg in 1996, corresponding to about 2.4% of the annual average for these states between 1989 and 2007. Visual inspection of the data suggests structural breaks in the exports of other tropical species starting in 1999. Since we build our series using the summation of NBM codes prior to 1997, we err on the safe side and make the test for structural breaks more stringent.

We used the same approach to build the series for cedar, ipe and virola-balsa. Cedar's codes are 4408.39.10 from 1996 through 2007 (NCM) and 4407.99.0199, 4407.99.0201 and 4407.99.0399 from 1989 through 1996 (NBM). By using 1996 as a validation year, we build the series using only code 4407.99.0201 for the earlier period. Ipe's codes are 4407.29.20 (NCM), and 4407.99.0199, 4407.99.0208 and 4407.99.0303 (NBM). We use only the last two NBM codes to build our ipe series. Virola-Balsa's codes are 4407.24.90 (NCM) and 4407.23.0199, 4407.23.0299, 4407.99.0102, 4407.99.0205, 4407.99.0301 and 4407.99.0399 (NBM). We ignore NBM codes 4407.24.90 and 4407.99.0399 in the construction of our virola-balsa series.

Table 1: Descriptive Statistics, Brazilian Municipalities

Year	Municipalities outside Mahogany Occurrence Area (N=4,811)			Municipalities inside Mahogany Occurrence Area (N=163)		
	homicides (per 100,000)	access water (%)	gdp p.c. (1,000s in 2000 R$)	homicides (per 100,000)	access water (%)	gdp p.c. (1,000s in 2000 R$)
1995	23.92	0.78	.	18.21	0.64	.
1996	24.90	0.82	6.11	18.81	0.70	2.54
1997	25.84	0.82	.	20.84	0.69	.
1998	26.34	0.83	.	23.16	0.72	.
1999	26.64	0.84	6.78	21.54	0.72	3.45
2000	27.09	.	6.80	25.55	.	3.54
2001	28.19	0.86	6.76	27.82	0.71	3.61
2002	28.72	0.87	7.20	30.95	0.75	3.79
2003	29.13	0.88	7.18	31.14	0.74	3.98
2004	27.12	0.88	7.49	31.65	0.68	4.34
2005	25.87	0.89	7.52	31.56	0.72	4.35
2006	26.36	0.90	7.71	33.75	0.75	4.32
2007	25.24	0.91	8.24	30.83	0.76	4.66

Obs.: Averages weighted by state population. Variables are homicide rates per 100,000 inhabitants, percentage of individuals living in households with access to treated water (measured at state level), and gdp per capita in 2000 R$ (thousands).

Table 2: Descriptive Statistics, Brazilian Municipalities

year	Panel A: STATES WITH SOME MAHOGANY OCCURRENCE					
	Municipalities outside Mahogany Occurrence Area (N=465)			Municipalities inside Mahogany Occurrence Area (N=163)		
	homicides (per 100,000)	access water (%)	gdp p.c. (1,000s in 2000 R$)	homicides (per 100,000)	access water (%)	gdp p.c. (1,000s in 2000 R$)
1995	13.26	0.50	.	18.21	0.64	.
1996	13.59	0.57	3.06	18.81	0.70	2.54
1997	14.76	0.57	.	20.84	0.69	.
1998	15.62	0.59	.	23.16	0.72	.
1999	13.70	0.61	3.63	21.54	0.72	3.45
2000	15.43	.	3.85	25.55	.	3.54
2001	16.74	0.64	3.89	27.82	0.71	3.61
2002	17.02	0.69	4.12	30.95	0.75	3.79
2003	18.77	0.69	4.30	31.14	0.74	3.98
2004	17.68	0.63	4.76	31.65	0.68	4.34
2005	20.98	0.66	4.66	31.56	0.72	4.35
2006	22.32	0.71	4.69	33.75	0.75	4.32
2007	22.93	0.72	4.99	30.83	0.76	4.66
	Panel B: STATE OF PARÁ					
	Municipalities outside Mahogany Occurrence Area (N=83)			Municipalities inside Mahogany Occurrence Area (N=45)		
year	homicides (per 100,000)	access water (%)	gdp p.c. (1,000s in 2000 R$)	homicides (per 100,000)	access water (%)	gdp p.c. (1,000s in 2000 R$)
1995	12.96	0.53	.	12.10	0.53	.
1996	12.37	0.61	2.77	12.82	0.61	1.88
1997	13.41	0.60	.	13.69	0.60	.
1998	14.00	0.58	.	12.18	0.58	.
1999	9.36	0.64	3.07	15.53	0.64	2.83
2000	10.78	.	3.15	21.09	.	3.07
2001	13.13	0.67	3.33	21.73	0.67	3.13
2002	15.51	0.70	3.40	27.60	0.70	3.20
2003	17.72	0.69	3.35	30.90	0.69	3.31
2004	17.47	0.60	3.58	36.53	0.60	3.67
2005	24.21	0.61	3.50	37.79	0.61	3.66
2006	25.50	0.65	3.65	40.25	0.65	3.91
2007	25.86	0.69	3.85	43.35	0.69	4.16

Obs.: Averages weighted by municipality population. Variables are homicide rates per 100,000 inhabitants, percentage of individuals living in households with access to treated water (measured at state level), and gdp per capita in 2000 R$ (thousands). Top panel includes only municipalities in states with some natural occurrence of mahogany, and bottom panel includes only municipalities in the state of Pará.

Table 3: Breakpoints in Brazilian exports of "other tropical species"

Monthly exports			Annual exports		
No Controls			No Controls		
Break Dates	95% Confidence Interval		Break Dates	95% Confidence Interval	
1999(8)	NA	NA	**1998**	NA	NA
2003(6)	2003(4)	2003(8)	**2002**	2001	2003
With Controls (Cedar, Ipe and Virola-Balsa)			With Controls (Cedar and Virola-Balsa)		
Break Dates	95% Confidence Interval		Break Dates	95% Confidence Interval	
1999(8)	NA	NA	**1998**	NA	NA
2003(6)	2003(5)	2003(9)	**2002**	2001	2003

Obs.: Variable is export of other tropical timber species. Series cover the period from 1989 to 2007. Table reports the results of the Bai and Perron (1998) structural break test, with estimated break dates and respective confidence intervals.

Table 4: Illegality of Mahogany Trade and Homicides, Brazilian Municipalities, 1995-2007, Difference-in-differences

Sample:	All States				
Treatment:	Mahog Area x Treat Years	Pre-1999 Mahog Exp x Treat Years	Mahog Area x Pre-1999 Mahog Exp x Treat Years	Suspected Mahog Exp x Treat Years	Mahog Area x Suspected Mahog Exp x Treat Years
	1	2	3	4	5
treat 1999	2.821	-2.168	6.874	-0.0250	0.0465
	[2.176]	[2.658]	[4.634]	[0.0225]	[0.0312]
treat 2002	9.761**	15.63**	30.41***	0.0760**	0.148***
	[3.925]	[5.760]	[8.534]	[0.0303]	[0.0403]
Observations	64,662	64,662	64,662	64,662	64,662
R-squared	0.734	0.735	0.735	0.736	0.735

Obs.: Robust standard-errors in brackets (clustering at state for columns 2 and 4, and at municipality for the others); *** p<0.01, ** p<0.05, * p<0.1. Dependent variable is the homicide rate (per 100,000 inhabitants). All regressions include a constant, municipality and year dummies, and are weighted by population. 27 states. Treatment variables are dummies=1 between 1999-2001 and after 2002 interacted with: dummy of mahogany occurring area; state share in total pre-1999 mahogany exports; sum of state exports of mahogany and "other tropical timber species" (which we call "virtual exports of mahogany"); and interactions of the latter two with mahogany occurring area.

Table 5: Illegality of Mahogany Trade and Homicides, Controls Included, Brazilian Municipalities, 1995-2007, Difference-in-differences

Sample:	All States									
Treatment:	Mahog Area x Treat Years		Pre-1999 Mahog Exp x Treat Years		Mahog Area x Pre-1999 Mahog Exp x Treat Years		Suspected Mahog Exp x Treat Years		Mahog Area x Suspected Mahog Exp x Treat Years	
	1	2	3	4	5	6	7	8	9	10
treat 1999	7.486**	6.228***	1.369	2.102	9.087**	8.875**	-0.000236	0.00786	0.0612**	0.0620**
	[2.945]	[2.272]	[2.739]	[2.179]	[4.020]	[3.708]	[0.0243]	[0.0169]	[0.0261]	[0.0251]
treat 2002	17.22***	12.33***	21.56***	16.13***	35.22***	30.57***	0.112***	0.0805***	0.164***	0.145***
	[4.033]	[2.886]	[5.105]	[3.029]	[7.453]	[6.995]	[0.0274]	[0.0158]	[0.0333]	[0.0329]
state controls	X	X	X	X	X	X	X	X	X	X
municip control		X		X		X		X		X
Observations	54,713	54,138	54,713	54,138	54,713	54,138	54,713	54,138	54,713	54,138
R-squared	0.748	0.786	0.749	0.787	0.748	0.787	0.749	0.787	0.748	0.787

Obs.: Robust standard-errors in brackets (clustering at state for columns 2 and 4, and at municipality for the others); *** p<0.01, ** p<0.05, * p<0.1. Dependent variable is the homicide rate (per 100,000 inhabitants). State controls are: ratio of top 10% to bottom 40% of income distrib, poverty rates, % of household with more than 2 members per room, primary enrollment rate btwn 7 and 14, informality in labor force, % pop with access to water, % pop with access to sewage, % labor force in agriculture, unemployment, illiteracy, electricity consumption p.c. (ln). Municipality control is % of area planted. All regressions include a constant, municipality and year dummies, and are weighted by population. 27 states. Treatment variables are dummies=1 between 1999-2001 and after 2002 interacted with: dummy of mahogany occurring area; state share in total pre-1999 mahogany exports; sum of state exports of mahogany and "other tropical timber species" (which we call "virtual exports of mahogany"); and interactions of the latter two with mahogany occurring area.

Table 6: Illegality of Mahogany Trade and Homicides, Municipalities in Mahogany Occurring States, 1995-2007, Difference-in-differences

Sample:	Mahogany Occurring States									
Treatment:	Mahog Area x Treat Years		Pre-1999 Mahog Exp x Treat Years		Mahog Area x Pre-1999 Mahog Exp x Treat Years		Suspected Mahog Exp x Treat Years		Mahog Area x Suspected Mahog Exp x Treat Years	
	1	2	3	4	5	6	7	8	9	10
treat 1999	4.089*	3.403	-2.705	-3.287	8.218*	5.891*	-0.0231	-0.0336	0.0462	0.0353
	[2.212]	[2.112]	[1.932]	[2.183]	[4.622]	[3.422]	[0.0134]	[0.0190]	[0.0307]	[0.0252]
treat 2002	6.071*	10.20***	10.20**	9.855**	25.12***	25.64***	0.0512**	0.0510**	0.115***	0.117***
	[3.149]	[3.266]	[3.342]	[3.693]	[7.750]	[7.230]	[0.0169]	[0.0171]	[0.0363]	[0.0332]
state controls		X		X		X		X		X
municip control		X		X		X		X		X
Observations	8,164	6,876	8,164	6,876	8,164	6,876	8,164	6,876	8,164	6,876
R-squared	0.701	0.724	0.707	0.722	0.710	0.729	0.709	0.723	0.710	0.729

Obs.: Robust standard-errors in brackets (clustering at state for columns 2 and 4, and at municipality for the others); *** p<0.01, ** p<0.05, * p<0.1. Dependent variable is the homicide rate (per 100,000 inhabitants). State controls are: ratio of top 10% to bottom 40% of income distrib, poverty rates, % of household with more than 2 members per room, primary enrollment rate btwn 7 and 14, informality in labor force, % pop with access to water, % pop with access to sewage, % labor force in agriculture, unemployment, illiteracy, electricity consumption p.c. (ln). Municipality control is % of area planted. All regressions include a constant, municipality and year dummies, and are weighted by population. Only 7 (mahogany occurring) states. Treatment variables are dummies=1 between 1999-2001 and after 2002 interacted with: dummy of mahogany occurring area; state share in total pre-1999 mahogany exports; sum of state exports of mahogany and "other tropical timber species" (which we call "virtual exports of mahogany"); and interactions of the latter two with mahogany occurring area.

Table 7: Illegality of Mahogany Trade and Homicides, Municipalities in the State of Pará, 1995-2007, Difference-in-differences

Sample:	Pará	
Treatment:	Mahog Area x Treat Years	
	1	2
treat 1999	8.877**	8.725**
	[3.545]	[3.715]
treat 2002	15.53***	17.67***
	[5.723]	[5.647]
municip control		X
Observations	1,664	1,629
R-squared	0.727	0.731

Obs.: Robust standard-errors in brackets (clustering at municipality); *** p<0.01, ** p<0.05, * p<0.1. Dependent variable is the homicide rate (per 100,000 inhabitants). Municipality control is % of area planted. All regressions include a constant, municipality and year dummies, and are weighted by population. Only state of Pará. Treatment variable are dummies=1 between 1999-2001 and after 2002 interacted with dummy of mahogany occurring area.

Table 8: Illegality of Mahogany Trade and Homicides, Controlling for Mortality Patterns, Brazilian Municipalities, 1995-2007, Difference-in-differences

Sample:	All States					Mahogany Occurring States					Pará
Treatment:	Mahog Area x Treat Years	Pre-1999 Mahog Exp x Treat Years	Mahog Area x Pre-1999 Mahog Exp x Treat Years	Suspected Mahog Exp x Treat Years	Mahog Area x Suspected Mahog Exp x Treat Years	Mahog Area x Treat Years	Pre-1999 Mahog Exp x Treat Years	Mahog Area x Pre-1999 Mahog Exp x Treat Years	Suspected Mahog Exp x Treat Years	Mahog Area x Suspected Mahog Exp x Treat Years	Mahog Area x Treat Years
	1	2	3	4	5	6	7	8	9	10	11
treat 1999	4.098*	1.550	6.245*	0.00385	0.0424*	1.966	-1.448	3.830	-0.0154	0.0206	4.335
	[2.093]	[2.306]	[3.623]	[0.0180]	[0.0249]	[1.655]	[1.887]	[3.561]	[0.0171]	[0.0255]	[3.556]
treat 2002	9.248***	14.80***	25.99***	0.0742***	0.124***	7.456**	9.282**	21.02***	0.0501**	0.0964***	12.00**
	[2.967]	[3.123]	[7.191]	[0.0155]	[0.0336]	[3.079]	[3.289]	[7.653]	[0.0153]	[0.0352]	[5.261]
mortality controls	X	X	X	X	X	X	X	X	X	X	X
state and/or muni controls	X	X	X	X	X	X	X	X	X	X	X
Observations	54,118	54,118	54,118	54,118	54,118	6,856	6,856	6,856	6,856	6,856	1,609
R-squared	0.807	0.808	0.808	0.808	0.808	0.750	0.749	0.754	0.750	0.754	0.775

Obs.: Robust standard-errors in brackets (clustering at state for columns 2, 4, 7, and 9, and at municipality for the others); *** p<0.01, ** p<0.05, * p<0.1. Dependent variable is the homicide rate (per 100,000 inhabitants). State controls are: ratio of top 10% to bottom 40% of income distrib, poverty rates, % of household with more than 2 members per room, primary enrollment rate btwn 7 and 14, informality in labor force, % pop with access to water, % pop with access to sewage, % labor force in agriculture, unemployment, illiteracy, electricity consumption p.c. (ln). Municipality control is % of area planted. Mortality controls (at municipality level are): heart and circulatory diseases, neoplasms, infectious diseases, traffic accidents, suicides, mortality before age 5, and number of murders related to land conflicts. All regressions include a constant, municipality and year dummies, and are weighted by population. Various samples. Treatment variables are dummies=1 between 1999-2001 and after 2002 interacted with: dummy of mahogany occurring area; state share in total pre-1999 mahogany exports; sum of state exports of mahogany and "other tropical timber species" (which we call "virtual exports of mahogany"); and interactions of the latter two with mahogany occurring area.

Table 9: Illegality of Mahogany Trade and Homicides, Testing for Pre-Existing Trends, Brazilian Municipalities, 1995-2007, Difference-in-differences

Sample:	All States					Mahogany Occurring States					Pará
Treatment:	Mahog Area x Treat Years	Pre-1999 Mahog Exp x Treat Years	Mahog Area x Pre-1999 Mahog Exp x Treat Years	Suspected Mahog Exp x Treat Years	Mahog Area x Suspected Mahog Exp x Treat Years	Mahog Area x Treat Years	Pre-1999 Mahog Exp x Treat Years	Mahog Area x Pre-1999 Mahog Exp x Treat Years	Suspected Mahog Exp x Treat Years	Mahog Area x Suspected Mahog Exp x Treat Years	Mahog Area x Treat Years
	1	2	3	4	5	6	7	8	9	10	11
treat 1999	3.743	-2.433	6.424	-0.0831	0.0329	5.122*	-3.408	7.522	-0.0274	-0.00933	8.494**
	[3.350]	[3.440]	[5.323]	[0.117]	[0.0330]	[3.022]	[3.108]	[4.630]	[0.0370]	[0.0311]	[3.704]
treat 2002	10.68**	15.36**	29.96***	0.0367	0.139***	7.106**	9.495***	24.43***	0.0482	0.0776**	15.15***
	[4.908]	[5.812]	[9.178]	[0.0776]	[0.0418]	[3.352]	[2.484]	[7.264]	[0.0323]	[0.0361]	[5.567]
pre-existing	1.852	-0.527	-0.887	-0.184	-0.0429	2.079	-1.408	-1.375	-0.0137	-0.176	-0.755
trend	[3.147]	[1.881]	[4.235]	[0.323]	[0.103]	[2.458]	[2.706]	[2.629]	[0.107]	[0.109]	[2.310]
Observations	64,662	64,662	64,662	64,662	64,662	8,164	8,164	8,164	8,164	8,164	1,664
R-squared	0.734	0.735	0.735	0.736	0.735	0.701	0.707	0.710	0.709	0.710	0.727

Obs.: Robust standard-errors in brackets (clustering at state for columns 2 and 4, and at municipality for the others); *** p<0.01, ** p<0.05, * p<0.1. Dependent variable is the homicide rate (per 100,000 inhabitants). All regressions include a constant, municipality and year dummies, and are weighted by population. 27 states. Treatment variables are dummies=1 between 1999-2001 and after 2002 interacted with: dummy of mahogany occurring area; state share in total pre-1999 mahogany exports; sum of state exports of mahogany and "other tropical timber species" (which we call "virtual exports of mahogany"); and interactions of the latter two with mahogany occurring area. Pre-1999 placebos vary according to the treatment variable: (i) a dummy for 1997-1998 interacted with the treatment variables (mahogany occurring areas, pre-1999 share of mahogany exports, and the interaction of these two) for the first three cases, (ii) an interaction of "virtual exports of mahogany" with a pre-1999 dummy for the fourth treatment, and (iii) an interaction of these two variables with mahogany occurring areas for the last treatment.

Table 10: Illegality of Mahogany Trade and Homicides, Characterization of Victims, Brazilian States, 1995-2007, Difference-in-differences

Treatment in all cases: Mahog Area x Treat Years

Panel A Sample: All States

	Gender		Male by Age Group		Male by Marital Status	
	male	female	15-49	other	single	married
treat 1999	4.553	0.441	7.968	1.521	3.308	1.176*
	[3.872]	[0.612]	[6.606]	[1.043]	[3.230]	[0.605]
treat 2002	17.98**	0.534	29.76**	3.457**	15.44**	1.849**
	[7.429]	[0.554]	[12.27]	[1.456]	[6.229]	[0.737]

Panel B Sample: Mahogany Occurring States

	Gender		Male by Age Group		Male by Marital Status	
	male	female	15-49	other	single	married
treat 1999	7.454*	0.748	12.16*	1.892	7.148**	1.251**
	[4.168]	[0.613]	[6.996]	[1.230]	[3.504]	[0.624]
treat 2002	11.20*	0.331	18.13*	2.575*	11.49**	1.323*
	[6.063]	[0.502]	[10.03]	[1.443]	[5.342]	[0.722]

Panel C Sample: Pará

	Gender		Male by Age Group		Male by Marital Status	
	male	female	15-49	other	single	married
treat 1999	16.13**	1.300	25.36**	6.181***	13.05**	3.186**
	[6.766]	[0.869]	[11.74]	[1.463]	[5.449]	[1.349]
treat 2002	28.00**	1.479**	48.93**	5.803***	25.85**	3.587**
	[11.20]	[0.728]	[19.53]	[2.044]	[10.29]	[1.459]

Obs.: Robust standard-errors in brackets (clustering at municipality); *** p<0.01, ** p<0.05, * p<0.1. Dependent variable is the homicide rate (per 100,000 inhabitants) by demographic group. All regressions include a constant, municipality and year dummies, and are weighted by population. 27 states. Treatment variables are dummies=1 between 1999-2001 and after 2002 interacted with dummy of mahogany occurring area.

Figure 1: Exports of Mahogany and Other Tropical Timber Species (in Kgs), Brazil, 1989-2007

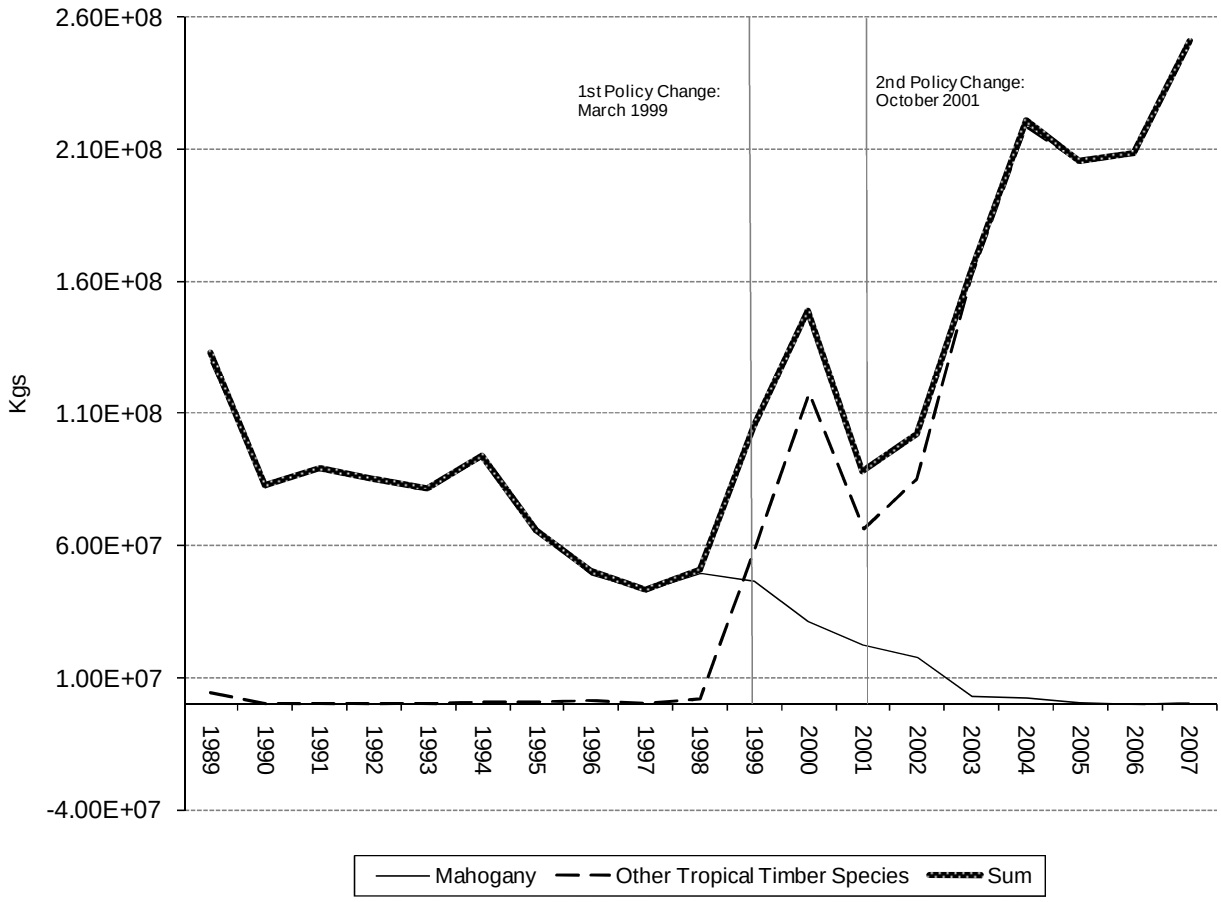
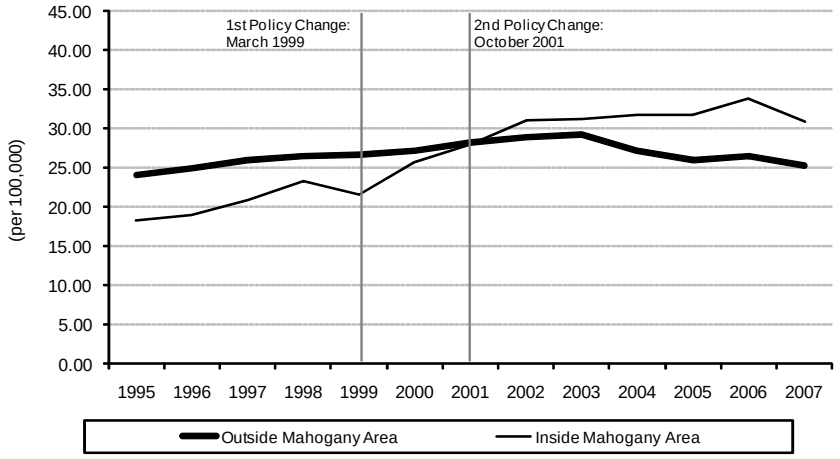
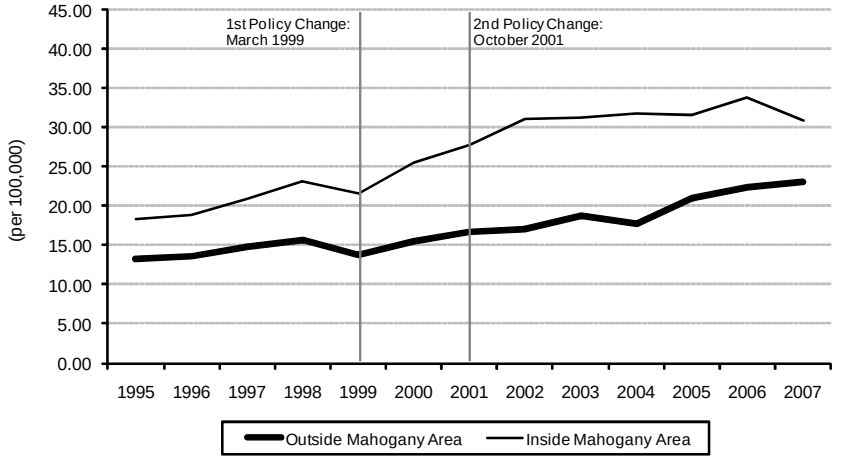


Figure 2: Evolution of Homicide Rates (per 100,000) in Brazil, Various Areas, 1995-2007

(a) Brazilian Municipalities, 1995-2007



(b) Municipalities in States with Mahogany Occurrence, 1995-2007



(c) Municipalities in the State of Pará, 1995-2007

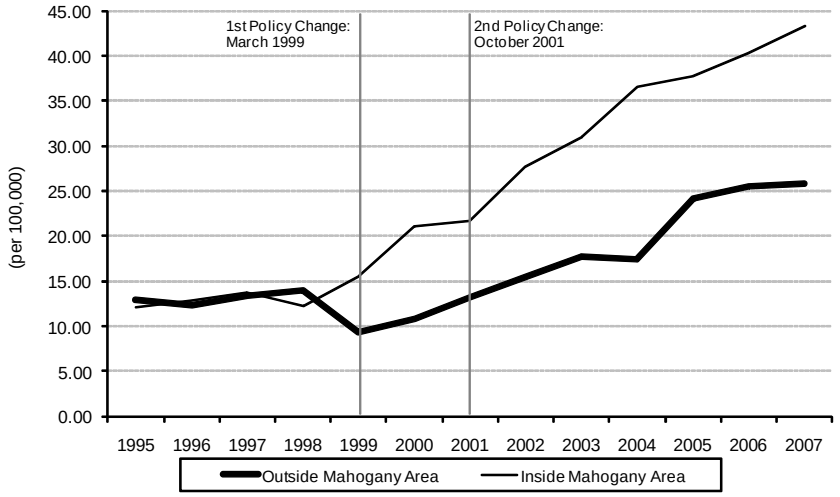
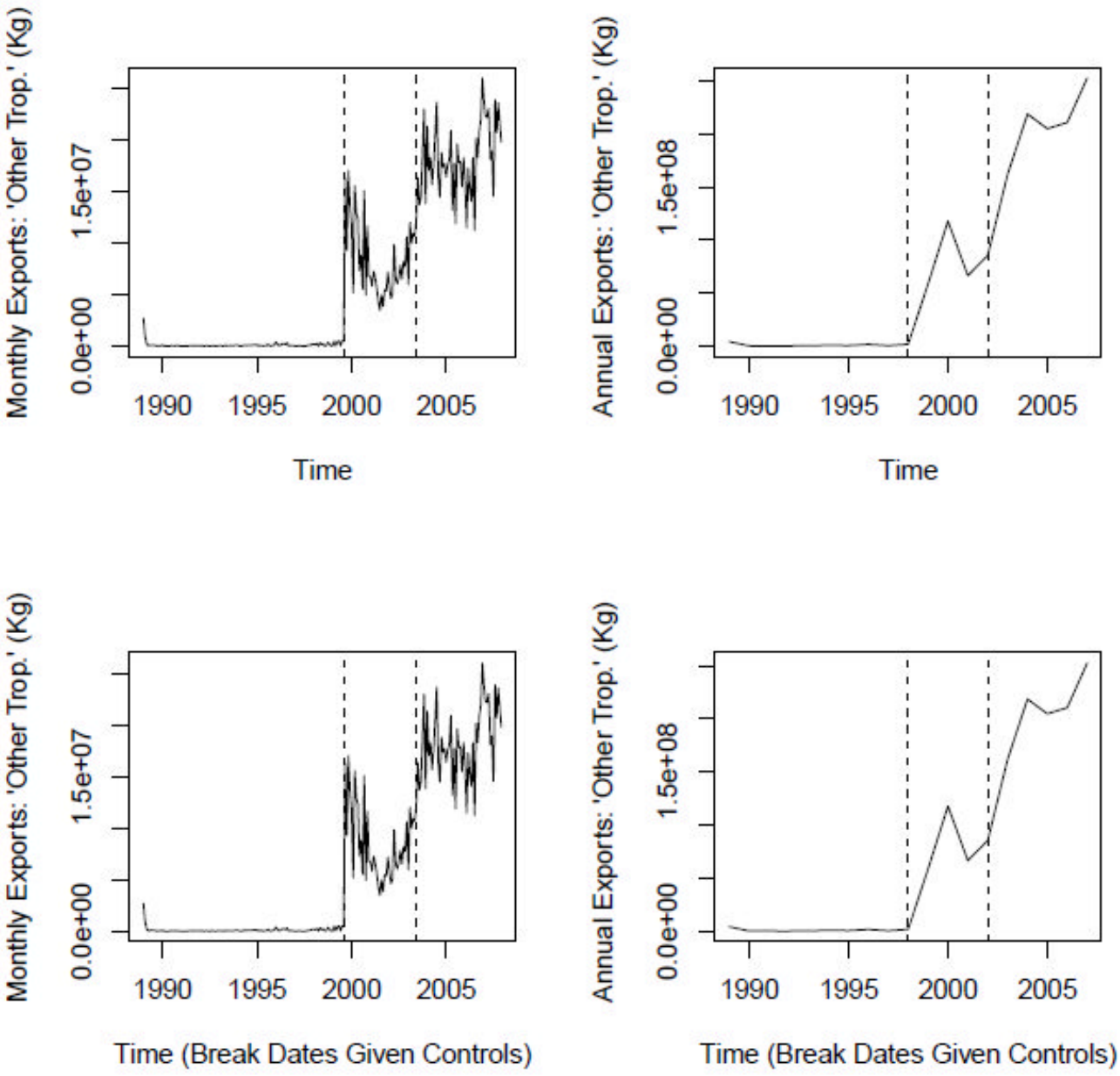


Figure 3: Exports of “Other Tropical Timber Species” from Brazil, 1989-2007 – Monthly and Annual Data



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