American Economic Journal: Applied Economics 2017, 9(4): 30–57
https://doi.org/10.1257/app.20160055

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

By Ariaster B. Chimeli and Rodrigo R. Soares*

We provide evidence on the effect of market illegality on violence. Brazil was historically the main exporter of mahogany. Starting in the 1990s, trade was restricted and eventually prohibited. We build on previous evidence that mahogany trade persisted after prohibition and document relative increases in violence in areas with natural occurrence of mahogany. We show that as illegal activity receded in the late 2000s so did the relative increase in violence. We describe an experience of increase in violence following the transition of a market from legal to illegal and contribute to the evaluation of prohibition policies under limited enforcement. (*JEL* F14, K42, L73, O13, O17, O19, Q23)

Agents operating in illegal markets cannot resort to the justice system to uphold contracts, to guarantee property rights, or to resolve within firm disputes. It is often argued that in these contexts violence is used as a commitment and arbitration device. This argument plays a major role in the current debate on the War on Drugs and is thought to be also relevant to explain the violence usually associated with illegal logging, but skepticism is common (see, for example, Nadelmann 1989, *Economist* 2001, Keefer and Loayza 2010, and Hance 2010; for contrarian arguments, see Naylor 2009 or discussion in Donohue, Ewing, and Peloquin 2011). Weak states, unable to enforce the rule of law, may be prone to the development of illegal markets and to chronic violence without any causal relationship existing between the two. In addition, violence may be associated with drugs because of the psychopharmacological and economic compulsive effects they have on users

*Chimeli: Departamento de Economia/NEREUS, Universidade de São Paulo, Av. Prof. Luciano Gualberto 908, São Paulo, SP, 05508–010, Brazil (email: chimeli@usp.br); Soares: Columbia University, 420 W. 118th Street, New York, NY 10027, and Sao Paulo School of Economics-FGV (email: r.soares@columbia.edu). Excellent research assistance was provided by Bruno Vieira, Katie Cosby, Weijian Wang, and Tainá Pacheco. We thank Cristiane Passos from the Comissão Pastoral da Terra for providing the data on land conflicts. This paper benefited from comments from Raymundo Campos, Joyce Chen, Claudio Ferraz, Sebastian Galiani, James Grogan, Andy Keeler, Emily Owens, Imran Rasul, and seminar participants at Columbia University, ENCE-IBGE, FUCAPE, Iowa State University, Insper, IPEA-Rio, LSE, PSE, PUC-Chile, PUC-Rio, RAND, Universidad de Chile, USP, UFCE, Universidade Nova de Lisboa, Università di Bologna, Université de Cergy-Pontoise, UCLA, UC Riverside, University of Chicago, the CAF-UNDP-CISS Conference on Crime and Violence in Latin America, the 2010 Heartland Environmental and Resource Economics Workshop, the sixth HiCN Workshop, the 2011 NBER Summer Institute, the second ALCAPONE Meeting, the 2012 RES Meeting, the 2012 SBE Meeting, the twentieth Annual EAERE Conference, the first Maastricht Workshop on the Economics of Enforcement, the 2014 AEA Meeting, the 2014 EEA Meeting, and the 2014 LACEA Meeting. The authors declare that they have no relevant or material financial interests that relate to the research described in this paper.

[†]Go to https://doi.org/10.1257/app.20160055 to visit the article page for additional materials and author disclosure statement(s) or to comment in the online discussion forum.

(Goldstein 1985). Causal evidence on the effect of market illegality, per se, on violence is very limited. Randomized experiments in this setting seem virtually impossible, and institutional 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 identify the causal effect of the illegality on violence. Brazil was historically 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 2001. We show that mahogany extraction persisted and was associated with increased violence after prohibition. Our identification relies on the timing of implementation of restrictions to the mahogany trade and on the relevance of mahogany for a given region.

Chimeli and Boyd (2010) present evidence that large-scale mahogany trade persisted after prohibition through misclassification of mahogany exports as exports of the residual trade category "other tropical timber species." We rely on their results, which we reproduce and extend in the online Appendix, and ask whether the emergence of this illegal market was associated with increases in violence.

We use a difference-in-difference strategy and document relative increases in homicide rates after prohibition in areas with natural occurrence of mahogany (similar results, presented in the online Appendix, are obtained when we use propensity score and synthetic control methods). The increase in homicides in areas with natural occurrence of mahogany was particularly strong in states with higher shares of mahogany exports before prohibition and with higher suspected illegal mahogany activity after prohibition. In fact, the results are driven essentially by differences within the state of Pará, which accounted for more than 70 percent of mahogany exports before prohibition and was suspected to concentrate most of the illegal activity after prohibition. We also document that the differential increase in homicide rates in mahogany areas was disproportionally large for prime-aged (15–39) males and, among these, disproportionally concentrated on deaths occurring outside the home (less likely to be related to common violence among family members) and caused by firearms. Finally, as the Brazilian government increased efforts and greatly reduced the illegal mahogany activity in the late 2000s, the relative increase in violence in mahogany-occurring areas likewise receded. Both these patterns reinforce the idea that the rise in violence was associated with the functioning of the illegal mahogany market.

We are not able to pinpoint the specific nature of the increase in violence, which in principle could have had many concurrent proximate causes: competition among loggers, resolution of labor disputes within illegal firms, renegotiation of contracts, or conflict with local communities over environmental protection, just to name a few. Still, we provide robust evidence that the initial expansion of the illegal mahogany market was associated with substantial increases in violence and, similarly,

[1] Grogan, Barreto, and Veríssimo (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.

that its later contraction was followed by relative reductions in violence. It is also possible that our results capture violence associated with the initial expansion of the illegal market or with a race against time to extract as much as possible before the government cracked down on the illegal market, rather than the steady state level of violence that would have been observed in the long run.

Irrespectively, the result for the state of Pará, which constitutes the main focus of the analysis, implies that the illegal mahogany market generated a total of 5,172 deaths between 1999 and 2013. For the median municipality in the area (27,495 inhabitants), this amounted to 5 additional deaths per year. Depending on the source used to estimate the size of the mahogany market, this number points to one additional death per each US$187,000 to US$270,000 of illegal market size.

Our paper is closely related to the literature on illegal drugs and violence. There is a vast literature outside economics with case studies of the prevalence of crime and violence among drug users and sellers (see papers in De La Rosa, Lambert, and Gropper 1990). In economics, various papers focus on the effect of repressive efforts targeted at the illegal drugs trade, but do not deal explicitly with the problem of endogeneity and find mixed results (for example, Miron 1999, 2001 and Medina and Martínez 2003). Dell (2015) shows that plausibly exogenous increases in drug-trafficking repression in Mexico—identified from close elections between parties with different takes on drug policies—are associated with increased violence. Other papers look at the effect of illegal drugs' production on local violence. Angrist and Kugler (2008) show that the shift of coca production from Bolivia and Peru to Colombia in the mid-1990s was accompanied by increased violence in coca growing areas, while Mejía and Restrepo (2011) show that increases in the demand for Colombian coca due to changes in repressive policies abroad are associated with relative increases in violence in areas adequate for cultivation. Similarly, Dube, García-Ponce, and Thom (2016) present evidence that increases in the cultivation of marijuana and opium poppies driven by exogenous changes in the price of competing crops are associated with increases in killings by drug cartels in Mexico.

The small literature that deals directly with the relationship between market illegality and crime and violence is probably the most relevant to our paper. Adda, McConnell, and Rasul (2014) 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 toward nondrug related offenses). Owens (2014) uses state-level data and presents evidence suggesting that the criminalization of alcohol in the United States during the 1920s led to a change in the distribution of homicides toward ages 20 to 30, opening up the possibility that it was indeed associated with the emergence of organized crime and systemic violence (this change was partly offset by reductions in homicides in other age-groups due to reduced alcohol consumption, leading to a stable age-normalized pattern for overall homicides).

As Adda, McConnell, and Rasul (2014) and Owens (2014), we use an institutional change that can be seen as a natural experiment on the effect of illegality. But, differently from Adda, McConnell, and Rasul (2014), we analyze the shutdown of a market rather than changes in the criminal status of consumers in a specific location.

And, differently from both Adda, McConnell, and Rasul (2014) and Owens (2014), we analyze the incidence of violence in a market unrelated to "vice" goods (drugs, alcohol, prostitution, etc.) so that we immediately isolate systemic violence from violence that may be due to the consumption of the good itself or to characteristics of consumers (respectively, psychopharmacological and economic compulsive violence). Our focus on violence and illegal markets in the context of environmental regulations is also relevant by itself, given the common imposition of market prohibitions in this setting and the widely held perception that trade in illegal environmentally sensitive goods, particularly wood, is often associated with violence.[2] Despite abounding anecdotal evidence on this relationship, partly reviewed here in Section I, we know of no other study with plausible empirical identification linking environmental regulations directly to the incidence of violence.

The data and the characteristics of mahogany trade allow us to see the illegal market in operation, to identify the area where violence should occur, and to link violence directly to the production side of the market. Our main contribution, therefore, is to isolate the relationship between transition into prohibition and the incidence of systemic violence. The results suggest that, when enforcement is absent, prohibition, per se, may be associated with increased violence. We document a rare example of an increase in violence following the transition of a market from legal to illegal and contribute to the evaluation of often-proposed market-prohibition policies when enforcement capabilities are limited.

The remainder of the paper is structured as follows. Section I provides a background of mahogany trade and policy in recent decades in Brazil and discusses the relationship between illegal logging and violence. Section II presents the data used in the paper. Section III describes our empirical strategy. Section IV presents the results on prohibition and violence. Finally, Section V concludes the paper.

I. Background

A. *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 of 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 by the local government in 2001 (see map of the area of natural occurrence of mahogany in Brazil in online Appendix A.1). The total Brazilian

[2] Market-prohibition policies with limited enforcement ability are not uncommon in the environmental protection context. For example, the United Nations Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) includes the possibility of prohibition of trade of certain species by signatory countries. Durst et al. (2001) also report a series of logging bans in the Asia-Pacific region, and the Montreal Protocol called for the banning of the use of chlorofluorocarbons (CFCs). Bulte and van Kooten (1999) discuss the case of the ban on ivory trade. Burgess et al. (2012) analyze, in the context of logging prohibition, the political economy of illegal deforestation in Indonesia.

production of mahogany between 1971 and 2001 is estimated to have been of the order of US$4 billion, with 75 percent corresponding to exports to the American and European high-end furniture and construction markets (Grogan, Barreto, and Veríssimo 2002).

Exploration of Brazilian mahogany was regulated in 1994 by the general principles of the federal decree #1282, which were further detailed in the 1995 ordinance #48 from the Brazilian Institute for the Environment and Natural Resources (Garrido Filha 2002). Under this regulatory framework, extraction of mahogany required a license and a forest management plan, specifying the availability of the species in the area covered by the license and a planned timeline for extraction.

Even under heavy regulation, exploration of mahogany led to increased concerns by domestic and international environmentalists who argued that continued extraction would soon lead to extinction. Although this statement has been disputed (Roozen 1998), a series of stricter regulations were introduced by the Brazilian government as a response. These included: a moratorium on the issuance of new forest management plans for mahogany extraction in July 1996; an export quota limiting international sales to 65,000 m^3 in 1998; the creation of a working group to audit forest management plans, which led to the suspension of 85 percent of all management plans in March 1999; an export quota limiting international sales to 30,000 m^3 in 2001; and the prohibition of extraction, transportation, and domestic or international trade of mahogany in October 2001. In addition, 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 supposedly requires careful monitoring of international trade by both the exporting and importing countries. This, in turn, may have reinforced the impetus for maintaining the more stringent outright prohibition already imposed by Brazilian authorities (IBAMA 1999; Grogan, Barreto, and Veríssimo 2002; and Lentini, Veríssimo, and Sobral 2003). Institutionally, the 2 main restrictions were those introduced in March 1999—when 85 percent of the operating licenses were suspended—and October 2001—when mahogany extraction was finally prohibited.[3]

Data from the US Department of Agriculture show that Brazil supplied 41 percent of all types of mahogany imports (including Asian and African species) to the US market between 1989 and 2001 (Bolivia and Peru followed with 25 percent and 15 percent, respectively). This accounted for 43 percent of the total value of US mahogany imports. The Brazilian mahogany share of the US market reached a peak of 68 percent in 1992. The importance of Brazilian mahogany to world markets is further reflected on the evolution of the total volume of US imports. As Brazilian authorities increased restrictions on the extraction of the species, the total volume of US imports likewise declined. Official US imports from around the world declined by 70 percent between 1989, when Brazil supplied 52 percent of the American market, and 2007, after the complete shutdown of Brazilian production.

[3] The 65,000 m^3 export quota imposed in 1998 was not binding, given the export levels observed in 1996 and 1997, and the 30,000 m^3 quota imposed in 2001 soon became obsolete, given the prohibition of mahogany trade in October 2001.

B. *Mahogany Prohibition and the Emergence of the Illegal Market*

Notwithstanding prohibition, a large amount of evidence points to continued exports of big-leaf mahogany from Brazil during the early 2000s, formally under the guise of the residual trade category "other tropical timber species." Accounts by Blundell and Rodan (2003), Barreto and Souza (2002), and Gerson (2000) describe how mahogany was systematically exported as other types of wood. Nellemann (2012) highlights that the mislabeling of protected species in export documentation is a widespread phenomenon in illegal logging around the globe. In the case of Brazil, apprehensions up to early 2010 provide additional anecdotal evidence that mahogany was systematically exported as "other tropical timber species" (e.g., Diário do Pará 2010).

Chimeli and Boyd (2010) analyze official export data from Brazil to the United States and the European Union to show that exports under the residual trade category "other tropical timber species" increased abruptly in 1999, from virtually 0 to volumes comparable to those of previous exports of big-leaf mahogany. They estimate structural breaks in the series for exports of "other tropical timber species" and verify that the estimated breaks closely match the main regulatory changes in the big-leaf mahogany market. In online Appendix A.3, we reproduce their results and expand on their analysis by testing whether the movements in exports of "other tropical timber species" could be due to substitution away from mahogany or to idiosyncratic changes in the market for tropical timber. We also analyze data on US imports of hardwood. We continue to find support to the hypothesis that the drastic jump in exports of "other tropical timber species" represents, in fact, smuggling of mahogany.

But how is mahogany smuggled through formal export channels? Selected timber species from the Amazon (mahogany, Brazilian cedar, ipe, and virola-balsa) have separate international trade codes that exporters are required to specify when they sell their product (Common Mercosur Nomenclature—NCM, chapter 44). In addition to these, there is an aggregate residual trade category 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).[4] Once mahogany is smuggled, the exporter is paid the invoice

[4] In addition, identification of mahogany by physical inspection is difficult and requires an expert with knowledge of mahogany, andiroba, cedar, and curupixá, species that can be easily mistaken for mahogany. As recently

value through regular export procedures, and the importer obtains a cargo complete with formal documentation.

Figure 1, panel A presents the monthly series of exports of "other tropical timber species" from Brazil between 1989 and 2013, together with 2 vertical lines indicating the main restrictions to mahogany trade. Exports of "other tropical timber species" jump by 3,500 percent in September 1999, just a few months after 85 percent of the mahogany management plans were suspended. The figure also shows a further increase in this residual category of timber exports after October 2001, when mahogany extraction and exports were finally prohibited.

In early 2008, exports of "other tropical timber species" start to fall drastically and continue in this trajectory until the end of the series. This is a consequence of increased monitoring and improved enforcement initiatives by the Brazilian government. In 2004, the federal government launched the Action Plan for the Prevention and Control of Deforestation in the Legal Amazon ("Plano de Ação para a Prevenção e o Controle do Desmatamento da Amazônia Legal," PPCDAm). This plan introduced two important innovations: use of remote-sensing technology for the monitoring of illegal deforestation and coordination across a wide number of government agencies to curb illegal deforestation. Assunção, Gandour, and Rocha (2015) report a substantial increase in the value of fines starting in 2004, a phenomenon that reflects the increased monitoring capabilities by authorities. Enforcement, however, remained weak until 2008. Data from the Federal Court of Accounts ("Tribunal de Contas da União") indicate that only 0.6 percent of the value of these fines was collected (Souza-Rodrigues 2015).

Enforcement only increased in a sustained way following Presidential Decree 6321 of December 2007, which established the legal basis for identifying municipalities with high deforestation rates and imposing harsher sanctions on their rural establishments (within the Amazon biome). The decree imposed a series of restrictions to rural establishments in priority municipalities: harsher registration, licensing and georeferencing requirements, revision of land titles to identify frauds, and, perhaps most importantly, restricted access to subsidized credit from federal agencies for any rural, industrial, or commercial activity.

In January 2008, the Ministry of Environment published the first list of priority municipalities in the Amazon region. Next, Presidential Decree 6514 (July 2008) reduced the number of appeal instances for environmental crimes and made easier the sale of confiscated assets. Assunção et al. (2013) estimate that this policy indeed restricted access to credit for rural establishments in the Amazon biome and led to a major reduction in deforestation between 2009 and 2011.

Figure 1, panel B presents the same data on exports of "other tropical timber species," but on a yearly basis, and is plotted together with exports of mahogany. 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."[5] In order

as 2011, there were studies being conducted on the identification of mahogany based on equipment using infrared light (Braga et al. 2011). These have as the main objective the development of technologies to facilitate detection and reduce the illegal trade of mahogany.

[5] Exports of mahogany are registered after 2001 because specimens extracted legally before prohibition could still be exported under certain circumstances.

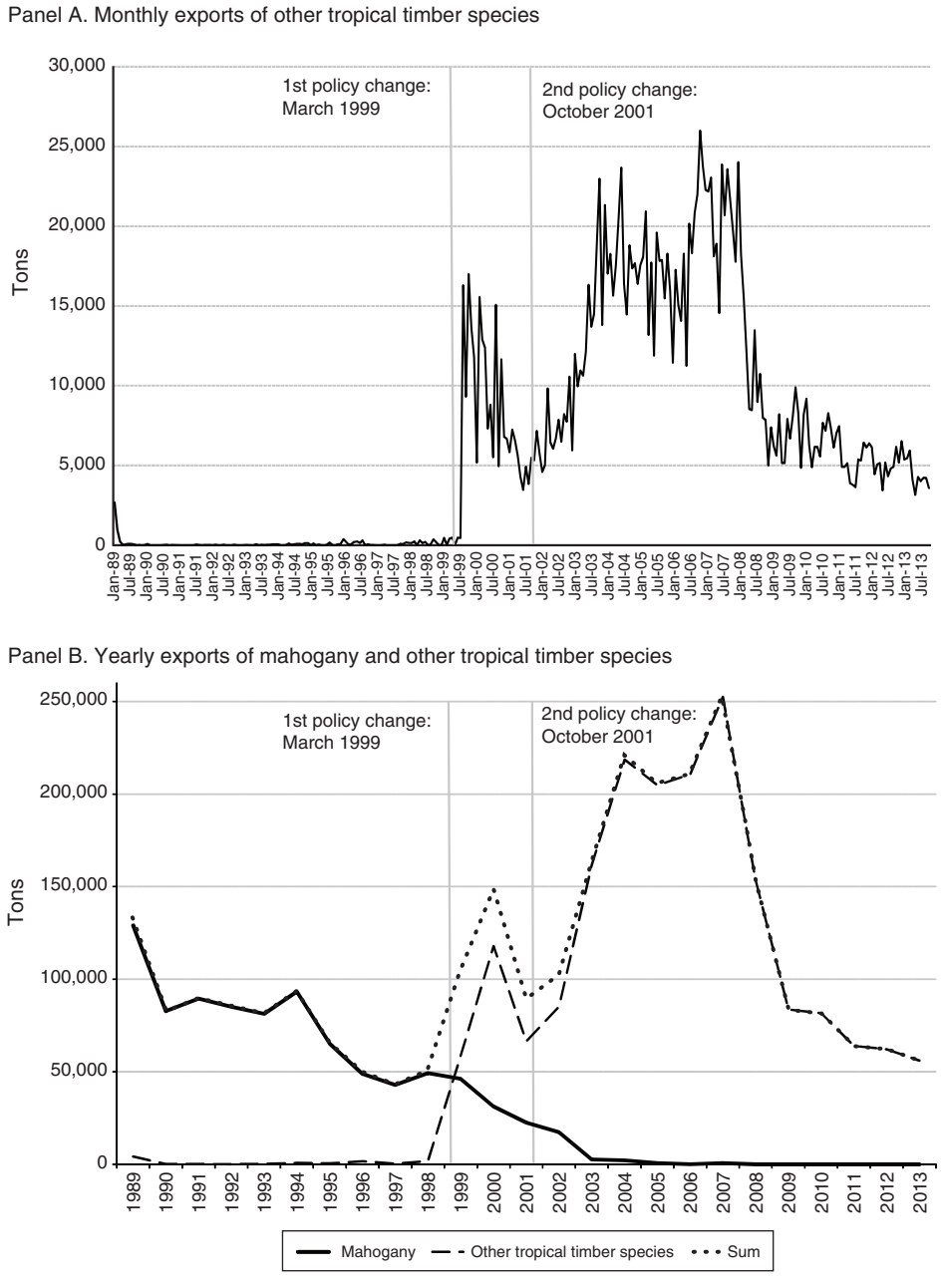


FIGURE 1. EXPORTS OF MAHOGANY AND THE RESIDUAL CATEGORY OTHER TROPICAL TIMBER SPECIES, BRAZIL 1989–2013

to illustrate this point, the figure also presents the sum of the two series, which displays a more stable pattern. The aggregate series suggests that legal mahogany exports were replaced by illegal exports under the guise of "other tropical timber species."

If exports of "other tropical timber species" represent disguised mahogany in their entirety, Figure 1, panel B would actually indicate a temporary increase in

exports immediately following prohibition. Though apparently counterintuitive, this is in line with the idea that quantity regulations may be optimal—as compared to taxation or prohibition—when private enforcement by competitors play an important role in detecting and denouncing violations.[6] This point is developed in detail by Glaeser and Shleifer (2001) and is directly applicable to our setting, where monitoring by the state immediately after the introduction of stricter regulations was very limited. Without—or with a sufficiently small number of—legal market agents, private enforcement may lose its grip, and the illegal market may instead expand and become more competitive.

A recent report on illegal logging by the United Nations and the INTERPOL claims that misreporting of species is prevalent and, in some instances, reaches volumes "up to 30 times greater than official volumes reported" (Nellemann 2012, p. 13). In this perspective, the relative magnitudes of official mahogany exports before prohibition and of exports of "other tropical timber species" after prohibition do not seem surprising. The more stringent regulations imposed in the end of the 1990s may have been enough to create the incentives for this particular illegal arrangement to develop. Nevertheless, our argument does not require that all exports of "other tropical timber species" after 1999 are disguised mahogany exports, only that a substantial part of it is.[7]

Grogran, Barreto, and Veríssimo (2002) estimate the value of mahogany exports between 1971 and 2001 to have been around US$4 billion. This value averages to US$129 million per year, corresponding to 1.2 percent of the aggregate GDP of the state of Pará in 2000 (which accounted for more than 70 percent of exports before prohibition). This number highlights the relevance of this potential market to the local economy.

C. *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. Reuter (2009), for example, argues that these markets are typically organized in such a way that "firms" are small and short-lived and tend to interact more through competition than collusion. These would be consequences of the 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

[6] Discussions of other contexts in which stringent regulations may backfire can be found in Bulte and van Kooten (1999).

[7] If we consider the sum of mahogany and "other tropical timber species" as indicating entirely mahogany exports, the increase in supply portrayed in Figure 1 also led to a reduction in price. This is what should happen if the international demand for mahogany did not experience large shifts during the period. There is a reduction in implicit prices (from value of exports) concomitant with the increase in supply after 1999. From the average changes in quantities and implicit prices, assuming a stable demand, we calculate a price elasticity of −2.22 (using average implicit prices and quantities during the periods before and after the major restrictions to extraction were introduced, pre-1999 and 1999–2007). Once the illegal exporting arrangement was set up, we cannot rule out the possibility that it would also be used to export other timber extracted illegally. Still, the quantities and implicit prices from the export data are broadly consistent with increased supply of a commodity with characteristics of a luxury good (high price elasticity), such as mahogany.

competitors but also 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, 2003, Hance 2010, and Nellemann 2012). It is easy to find reports that discuss illegal logging as intrinsically related to the widespread use of violence. News from private media outlets, nongovernmental organizations, and state agencies document time and again the use of violence in the illegal mahogany market and give indications of its scale.

In the Brazilian Amazon, protected timber species are stolen from private land, indigenous and conservation areas, and public land (*Terras Indígenas no Brasil* 2002, Soares 2003, Greenpeace Notícia 2004, Mendes 2005, and Comissão Pastoral da Terra 2011). Intimidation-driven deals with indigenous tribe leaders are also commonly reported (Mendes 2004). In the process of extracting mahogany, loggers are said to resort to illegally obtained weapons and to threaten execution of whoever may offer any resistance (Soares 2003). Threats and murders of rural workers, nongovernmental 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 gunshots 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 (Greenpeace Notícia 2004). The investigative commission for biopiracy from the Brazilian House of Representatives also documented death threats to staff members of the Brazilian Institute for the Environment and Natural Resources (IBAMA) in Pará (Câmara dos Deputados 2005). According to Mendes (2005), organized crime in the region commands a small army of men ready to perform acts of sabotage and intimidation and to murder rural workers, union leaders, and human rights militants. Influential politicians, indigenous tribe leaders, and public officials from federal and local governments have also been accused of involvement with the illegal trade (Mendes 2005). In these settings, reports of violent episodes associated with deals gone sour or with unsuccessful renegotiations of agreements are common.

The so-called "mahogany mafia," which operated during the most dynamic period of the illegal market, seems to have had considerable depth. A federal police officer compared their market in 2002 to that for narcotics, stating that "we are not dealing with small transgressors, but a mafia….They use violence, move large fortunes, and coerce the small guys" (O Estado de São Paulo 2002). According to a public prosecutor in the state of Pará, they built clandestine roads, bridges, and airstrips, assembled a "war arsenal," exploited slave labor, had a large number of trucks, and even owned a ferryboat and airplanes (Ministério Público do Estado do Pará 2002).

II. Data

A. *Mahogany Variables*

Lentini, Veríssimo, and Sobral (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 the political division of Brazil into municipalities and create a dummy variable equal to one 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 online Appendix A.1.[8] This variable is our main indicator of mahogany relevance. It has the advantages of being measured at the municipality level and determined by preexisting conditions.

Given the limited transportation network in the Brazilian Amazon, where the mahogany area is concentrated, natural occurrence may not be a sufficient indicator of the economic relevance of mahogany in a certain region since it may not be enough to warrant profitable exploration. So we also construct variables trying to capture the economic relevance of mahogany for the various states. We use state-level information on 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. Finally, we also use information on exports of "other tropical timber species" by state from 1989 to 2013. These data provide evidence on the continuing exploration and trade of mahogany after prohibition and can be used as a proxy for the extent of illegal logging.

The data on exports of mahogany and other 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 series are monthly exports in kilograms for all exporting states between January 1989 and December 2013. The precise strategy used to match the trade codes across years is described in detail in online Appendix A.2.

B. *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's 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 certain uniformity in definition across regions. The homicide data are available yearly since the 1980s, but reporting is an increasing problem as we move back into the early years of the series. Information on other types of violence in Brazil is processed by state-level police forces. The states from the northern region of the country, where the mahogany area is located, do not have systematic data collection at the municipality level for these types of variables. This prevents the use of indicators of less extreme forms of violence, generated outside the health system, in our analysis.

[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 Lentini, Veríssimo, and Sobral (2003).

C. *Other Variables*

Other variables used in the paper account for relevant municipality characteristics that may be correlated with the mahogany occurrence and also with the evolution of violence. We have municipality-level information on: total area planted, from the municipal agricultural surveys from IBGE; mortality by cause of death, from the Brazilian Ministry of Health; 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 (only up to 2007); and GDP per capita and share of GDP in agriculture, from the Brazilian national accounts (available only for 1996 and between 1999 and 2010).

D. *Sample and Descriptive Statistics*

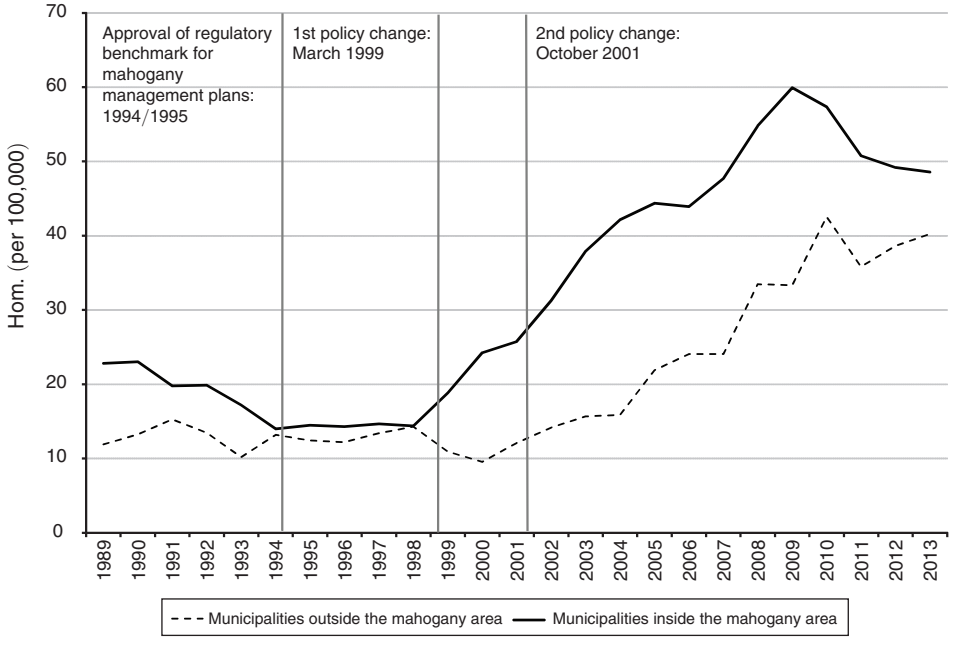
Our main analysis focuses on the period between 1995 and 2013 and, initially, on states that have some part of their territory covered by the area of natural occurrence of mahogany. Following, we restrict attention to the state of Pará, where most of the mahogany activity took place before prohibition and where we observed the bulk of the responses of violence. We start in 1995 because the regulatory benchmark of the mahogany management plans was completed only in that year, and in addition, a large number of new municipalities were created in Brazil during the early 1990s.

We use municipalities as a unit of analysis and restrict the sample to municipalities that already existed in 1995. Some municipalities were created between 1995 and 2013, but these are very small population-wise and, since our regressions are weighted by population, ignoring them makes virtually no difference for the results (the municipalities that already existed in 1995 account for more than 93 percent of the total population for mahogany-occurring states throughout the sample period, and more than 96 percent of the population for the state of Pará). The main advantage of using municipalities instead of a more aggregate unit of analysis is that it allows a more precise definition of the mahogany occurrence area.[9]

For descriptive purposes and to anticipate the main driving force behind our results, panel A in Figure 2 plots the yearly homicide rate for the state of Pará between 1989 and 2013, disaggregated by areas with and without the occurrence of mahogany. The figure also indicates the 3 key institutional changes during this period: the approval of the regulatory benchmark for the legal operation of mahogany management plans in the end of 1994 and beginning of 1995, the suspension of

[9] Nevertheless, in online Appendix A.4, we reproduce the main results of the paper using minimum comparable areas instead of municipalities as units of analysis. Results remain virtually identical to those presented in the main tables of the paper. A minimum comparable area in Brazil is a definition that aggregates different municipalities and allows the comparison of the same geographic area over time. The problem with this alternative in our setting is that the geocoding currently available only allows us to build minimum comparable areas going back to a slightly more aggregate version of the 1990 political division. Since a large number of municipalities were created between 1990 and 1995, this implies a large loss in terms of number of observations and also in the precision of our definition of the area of natural occurrence of mahogany (the number of cross-sectional observations is reduced from 628 to 437 for all states with some area of natural occurrence of mahogany, and from 128 to 94 for the state of Pará). Therefore, we choose to go with municipalities as units of analysis. In the end, results are not really sensitive to this choice.

Panel A. Homicides in mahogany and non-mahogany areas



Panel B. Homicide differential across mahogany and non-mahogany areas and exports of other tropical timber species

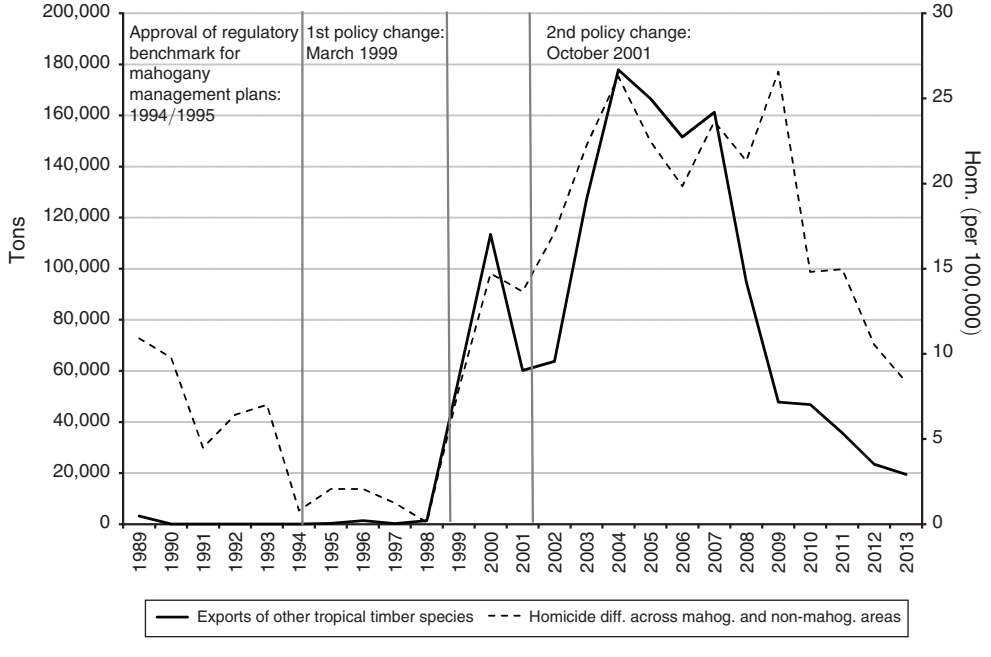


Figure 2. Homicide Rates in Mahogany and Non-mahogany Areas, Pará, 1995–2013

85 percent of the operating licenses in March 1999, and the prohibition of extraction and trade in October 2001.

The homicide rate in mahogany areas starts slightly above that in other areas in 1989, but the two converge to roughly the same level and remain stable throughout the period during which the regulated market was in operation. Following the start of the progressive shutdown of the regulated market in 1999, the relative increase in violence within mahogany areas is clear. The dates of the main restrictions to mahogany exploration are associated with relative increases in homicide rates in mahogany-occurring areas. It is also important to notice that the evolution of homicides is very similar across mahogany and non-mahogany areas between 1994 and 1999, but a gap opens up immediately after the introduction of the first major restriction to logging.[10]

Panel B in Figure 2 plots the difference in homicide rates across mahogany and non-mahogany areas of the state of Pará together with the state exports of "other tropical timber species." The co-movement of the two variables is obvious. The difference in homicides rises together with the initial increase in exports and then rises further after prohibition in 2002 when exports also experience a substantial increase. After 2008, when exports of "other tropical timber species" start falling, so does the differential homicide rate across mahogany and non-mahogany areas, with a delay of maybe 1 to 2 years. Figure 2 suggests that prohibition indeed had an effect on violence and justifies our decision to focus most of the analysis on the interval between 1995 and 2013.

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.[11] Treatment and control groups are more homogeneous within Pará, which is also a particularly relevant state because it accounts for more than 70 percent 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 we start with both samples and then restrict the robustness analysis to the state of Pará.

Table 1 presents descriptive statistics for municipalities inside and outside the area of natural occurrence of mahogany for the two samples. The table presents numbers on the average homicide rate, GDP per capita, and fraction of GDP in agriculture, between 1995 and 1998 and between 1999 and 2013. The first period corresponds to the operation of the regulated market, while the second one refers to

[10] The increase in violence in non-mahogany areas of Pará starting in the early 2000s is part of a broader phenomenon taking place in Brazil: poorer states and, more generally, medium and small municipalities as well as rural areas, which historically were relatively safe, experienced major increases in violence during this period (see, for example, Cerqueira 2014 and Justus, Scorzafave, and Sant'Anna 2016). This is a countrywide trend, whose origins are still debated, so we believe its rationalization is beyond the scope of this paper. Our focus is on the differential increase in violence across mahogany and non-mahogany areas. It is nevertheless true that the increase in violence in non-mahogany areas of Pará was somewhat larger than that observed in other similar regions of the country, so there is the possibility of spillovers in violence across mahogany and non-mahogany areas; in which case, our results would underestimate the effect of illegality.

[11] Qualitative results are very similar when we consider all municipalities in Brazil.

Table 1—Descriptive Statistics, Selected Variables for the 1995–1998, 1999–2013 Periods

	Outside the mahogany area ($N = 465$)			Inside the mahogany area ($N = 163$)		
	Homicide rate	GDP per capita	% GDP in agriculture	Homicide rate	GDP per capita	% GDP in agriculture
Panel A. Municipalities in states with mahogany occurrence						
Pre-1999	15.04	3.06	31.1%	22.82	2.55	31.4%
	(15.70)	(2.99)	(0.28)	(19.93)	(1.68)	(0.23)
Post-1999	24.19	4.51	15.3%	34.43	4.63	20.4%
	(19.34)	(3.99)	(0.16)	(24.56)	(3.59)	(0.16)
	Outside the mahogany area ($N = 84$)			Inside the mahogany area ($N = 44$)		
	Homicide rate	GDP per capita	% GDP in agriculture	Homicide rate	GDP per capita	% GDP in agriculture
Panel B. Municipalities in Pará						
Pre-1999	13.13	2.77	29.7%	14.67	1.93	37.9%
	(12.04)	(2.41)	(0.30)	(14.04)	(1.87)	(0.24)
Post-1999	25.31	3.31	11.1%	44.13	4.58	20.7%
	(22.54)	(3.03)	(0.12)	(28.97)	(5.53)	(0.16)

Notes: Averages are weighted by municipality population (standard errors are in parentheses). Variables are homicide rate per 100,000 inhabitants, GDP per capita in 2000 R$ (in thousands), and percentage of GDP in agriculture. Pre-1999 is the average from 1995 to 1998 for homicide rate, 1996 for GDP per capita, and fraction of GDP in agriculture; post-1999 is the average between 1999 and 2013.

the period of restrictions to trade and prohibition and the appearance of the illegal market. The objective of the table is to characterize the differences between municipalities located inside and outside the mahogany area and to highlight the main challenges implicit in our empirical exercise.

The table makes clear that mahogany regions were initially poorer and more dependent on agriculture, irrespectively of whether one considers all mahogany producing states or only Pará. Within mahogany-occurring states, mahogany areas were somewhat more violent before 1999, but this difference opened up widely afterward. Interestingly, mahogany areas seem to have experienced socioeconomic improvements at faster rates than other areas, eventually surpassing them in GDP per capita. All these patterns are particularly clear in the state of Pará. In this case, initial homicide rates are very similar across mahogany and non-mahogany areas, but become very different afterward.

III. Empirical Strategy

The variation we explore to identify the causal effect of prohibition on violence combines the timing of the institutional changes and the distinct relevance of mahogany across different areas. In principle, if the increase in homicides 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 comes from the heterogeneous response of different areas to prohibition.

Given the institutional discussion from Section I and the evidence to be presented in the next section, we focus on three years as key moments in the regulatory changes. First, we create a dummy variable equal to 1 for the interval between 1999

and 2001, capturing the first major step toward prohibition (suspension of 85 percent of the operating licenses for management plans). Following, we create a second dummy variable equal to 1 between 2002 and 2008, corresponding to the prohibition of mahogany instituted in October 2001. And finally, we create a third dummy equal to 1 starting in 2009, identifying the years of increased monitoring from the Brazilian government and reductions in exports of "other tropical timber species." In the paper, we present only the results from this difference-in-difference strategy. But, in online Appendix A.5, we discuss the results obtained when we use propensity score and synthetic control methods. Each of these strategies has advantages and disadvantages, so the overall stability of results lends additional credibility to our conclusion.

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

$$
\begin{aligned}
(1) \qquad Homicide_{it} \;=\; & \alpha + \beta_1 \cdot (D_{1999\leq t\leq 2001} \times Mahog\_Var_i) \\
& + \beta_2 \cdot (D_{2002\leq t\leq 2008} \times Mahog\_Var_i) \\
& + \beta_3 \cdot (D_{t\geq 2009} \times Mahog\_Var_i) + z_{it}'\gamma + \theta_i + \mu_{st} + \varepsilon_{it},
\end{aligned}
$$

where $Homicide_{it}$ indicates the homicide rate for municipality i in year t (in some specifications, for a particular age and demographic group); $D_{1999\leq t\leq 2001}$ is a dummy variable equal to 1 for the years between 1999 and 2001; $D_{2002\leq t\leq 2008}$ is a dummy variable equal to 1 between 2002 and 2008; $D_{t\geq 2009}$ is a dummy equal to 1 for 2009 and all following years; $Mahog\_Var_i$ is a variable indicating the relevance of mahogany in municipality i; 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, β_3, and γ are parameters. Under the usual assumptions, $E[\varepsilon_{it} | D_{1999\leq t\leq 2001}, D_{2002\leq t\leq 2008}, D_{t\geq 2009}, Mahog\_Var_i, z_{it}, \theta_i, \mu_{st}] = 0$, and OLS estimation of the above equation provides unbiased estimates of the βs.

The relevance of mahogany for a given area ($Mahog\_Var_i$) is captured by the dummy variable indicating whether a municipality is located in the area of natural occurrence of mahogany. In some robustness exercises, we also use information on mahogany exports before prohibition and exports of "other tropical timber species" after prohibition as indicators of the relevance of mahogany activity. 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 yearly "suspected mahogany exports" 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 in the illegal period. These variables vary only at the state level, but they can be interacted with the dummy indicating areas of occurrence of mahogany to create triple differences. The triple differences compare not only areas with natural occurrences of mahogany to other areas but also within areas of natural occurrences of mahogany, those in states where mahogany was an

important economic activity to those in states where it was not (triple differences in timing of prohibition, natural mahogany occurrence, and relative importance of mahogany activity).

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 the incidence of violence, through reduced income and worsened labor market opportunities or through changes in the pattern of agricultural activity and violence in the agricultural frontier. To partly address these concerns, we allow for state-specific time dummies, so that any systematic difference across states due to policy or socioeconomic changes are immediately controlled for.

In some specifications, we also allow for flexible time trends as functions of municipalities' initial characteristics. Since most of the variables that we observe at the municipality level could in principle be endogenous to the restrictions to mahogany trade, we opt to control for interactions of their baseline (1995 or 1996) values with time dummies, instead of directly controlling for their contemporaneous values.[12] The variables for which initial values are interacted with time dummies are the following: area planted, GDP per capita (ln), and share of GDP in agriculture; mortality from infectious diseases, neoplasms, heart and circulatory conditions, suicides, traffic accidents, and before age five; and number of deaths due to land conflicts. This specification also includes an interaction between the baseline homicide rate and time dummies to allow for differential dynamics of violence according to the initial level of homicides.

So municipalities are allowed to have arbitrarily different dynamics of violence as a function of the large set of initial characteristics mentioned in the previous paragraph. This allows for different dynamics of crime according to: socioeconomic conditions (GDP per capita, mortality from infectious diseases, and mortality before age five); potential violence associated with the agricultural frontier (fraction of area planted, share of GDP in agriculture, and assassinations due to land conflicts); broader mortality and demographic trends (mortality from neoplasms and mortality from heart and circulatory conditions); and changes associated with modernization and urbanization (suicides and mortality due to traffic accidents).

In our context, controlling for differential trends in the agricultural frontier is particularly important. Ill-defined property rights in the Brazilian agricultural frontier, which is partly located in the Amazon region, are commonly associated with violent land disputes (see Alston, Libecap, and Mueller 2000 and Altson and Mueller 2010). It is important, therefore, to understand to what extent the violence associated with illegal extraction of mahogany is also related to irregular occupations from agricultural activities (following the initial extraction of mahogany).

[12] If we control for contemporaneous values of these municipality characteristics, instead of including interactions of initial values with time dummies, results remain very similar both qualitatively and quantitatively (results not shown, but available upon request). We do not present this result due to the potential problem of "bad controls" (Angrist and Pischke 2009).

To deal with remaining concerns related to the difference-in-difference specification, we go one-step further and explicitly analyze the hypothesis of parallel trends across treatment and control groups, first by conducting a placebo test involving the pre-prohibition period and, following, by including municipality-specific linear trends as additional controls. We also discuss how GDP per capita and the fraction of GDP in agriculture evolved during this period across mahogany and non-mahogany areas, and whether it seems plausible that changes in socioeconomic conditions and agricultural activity could be the driving forces behind the increase in violence.

There are a few remaining methodological issues that should be mentioned explicitly: the variance of homicide rates is directly related to population size, so we weight all regressions by population size; and difference-in-difference strategies may underestimate standard errors due to autocorrelation in the residuals, so we cluster standard errors at the municipality level, allowing for an arbitrary structure of correlation over time (as suggested by Bertrand, Duflo, and Mullainathan 2004).

IV. Results

A. *Benchmark Results*

Table 2 presents our main results for the sample including all states with some area of natural occurrence of mahogany. Column 1 includes no control variable, column 2 introduces state-specific time dummies, and column 3 includes interactions of time dummies with baseline values of all of our controls (area planted, GDP per capita, and share of GDP in agriculture; mortality from infectious diseases, neoplasms, heart and circulatory conditions, suicides, traffic accidents, and before age 5; and number of deaths due to land conflicts) plus the homicide rate.

These first 3 columns show a significant effect on violence of both the suspension of 85 percent of the management plans (*treat 1999*) and the shutdown of the legal mahogany market (*treat 2002*). The coefficient on the variable indicating the period of increased monitoring by the Brazilian government (*treat 2009*) is nonsignificant in column 1 and significant, but somewhat smaller in magnitude than that associated with prohibition, in column 3. The coefficient on the first policy change (*treat 1999*) is always smaller than that on the second one (*treat 2002*), but both are estimated very precisely (with the exception of the first treatment in column 1, where there are no controls). Areas in the region of natural occurrences of mahogany experienced a relative increase in homicide rates between 1999 and 2001, and then again more intensely after 2002.

It is also worth noting that in column 2, when we include our state-specific time dummies, results become substantially stronger than in column 1, both in terms of point estimates and statistical significance. In column 3 of Table 2, when we include the broad set of interactions of initial conditions and time dummies, there is only a small change in point estimates. So the difference in the behavior of homicide rates across mahogany and non-mahogany areas does not seem to be driven by differential trends across states or municipalities.

The relatively large point estimate for the coefficient on the last treatment variable (*treat 2009*) can be somewhat misleading. Figure 2, for example, suggests that

Table 2—Illegality of Mahogany Trade and Homicides, 1995–2013, Difference-in-Difference Benchmark Results

	Municipalities in states with mahogany occurrence					
					Triple-diff:	
Variables	(1)	(2)	(3)	Treatments interacted with linear trends (4)	State percent in exp. before 1999 (5)	Suspect. state exp. after 1999 (6)
treat 1999	4.520	8.078	5.946	5.669	17.13	0.0994
	[2.627]	[2.841]	[2.031]	[2.586]	[6.078]	[0.0370]
treat 1999 × trend				2.409		
				[1.398]		
treat 2002	7.034	15.03	12.68	15.11	31.13	0.139
	[3.491]	[3.633]	[3.650]	[3.321]	[7.517]	[0.0303]
treat 2002 × trend				−0.0275		
				[0.556]		
treat 2009	−1.478	9.514	10.81	14.29	22.52	0.371
	[4.521]	[4.207]	[4.173]	[5.369]	[9.228]	[0.146]
treat 2009 × trend				−2.387		
				[1.023]		
State FE × year FE		X	X	X	X	X
Baseline charact. × year FE			X			
Observations	11,932	11,932	11,533	11,932	11,932	11,932
R^2	0.645	0.709	0.772	0.710	0.712	0.711

Notes: Robust standard errors are in brackets (clustering at municipality). Dependent variable is the homicide rate (per 100,000 inhabitants). All regressions include a constant, municipality, and year dummies, and are weighted by population. Treatment variables are dummies = 1 between 1999–2001, between 2002–2008, and after 2008 interacted with: dummy of mahogany-occurring area (columns 1–4); state share in total pre-1999 mahogany exports × dummy of mahogany occurring area (column 5); sum of state exports of mahogany and "other tropical timber species" (which we call "suspected state exports after 1999") × dummy of mahogany occurring area (column 6). Columns 2 to 6 control for state-specific time dummies. Column 3 controls for interactions of year dummies with baseline (1995) values of the following municipality characteristics: percent of area planted, mortality by heart and circulatory diseases, neoplasms, infectious diseases, traffic accidents, suicides, child mortality, assassinations related to land conflicts (rate), per capita GDP (ln), fraction of GDP in agriculture (the latter 2 measured in 1996), and homicide rate.

the difference in homicides across mahogany and non-mahogany areas starts at a very high level in 2009 but drops sharply afterward. In order to document this pattern more rigorously, in column 4, we allow the treatments to affect both the level and the trend of the dependent variable (we interact each treatment with a linear time trend equal to zero in the first year of treatment). The results suggest that: the initial suspension of 85 percent of the management plans was associated with a discrete increase in homicide rates and a mild increase in trend; prohibition further increased the level of homicides without affecting the previous trend; and in 2009, homicide rates started from the same level inherited from the prohibition period but dropped fast in the following years (at a rate of 2.4 per 100,000 per year afterward).

In columns 5 and 6 of Table 2, we present the results of our triple difference estimates, which indicate that increases in violence were particularly strong in states with a higher share of mahogany exports before prohibition and with higher "suspected mahogany exports" after prohibition (the coefficients displayed in the table correspond already to the cumulative effect of the combination of mahogany area

Table 3—Illegality of Mahogany Trade and Homicides, 1995–2013, Difference-in-Difference Results for Pará and Other States Separately

	Municipalities in Pará			Municipalities in states with mahogany occurrence excluding Pará			
Variables	(1)	(2)	Treatments interacted with linear trends (3)	(4)	(5)	(6)	Treatments interacted with linear trends (7)
treat 1999	12.68	11.00	9.642	0.346	1.600	2.734	0.0811
	[4.458]	[3.214]	[4.154]	[3.457]	[2.206]	[2.001]	[1.900]
treat 1999 × trend			3.041				1.519
			[2.179]				[1.330]
treat 2002	22.59	18.71	20.93	−1.993	4.392	4.466	6.924
	[5.520]	[4.966]	[4.963]	[3.077]	[2.241]	[1.694]	[2.809]
treat 2002 × trend			0.553				−0.844
			[0.886]				[0.452]
treat 2009	16.49	20.89	25.60	−12.48	−0.299	2.819	−1.628
	[6.771]	[6.959]	[8.555]	[2.876]	[2.796]	[2.604]	[2.278]
treat 2009 × trend			−4.555				0.665
			[1.517]				[0.716]
State FE × year FE					X	X	X
Baseline charact. × year FE		X				X	
Observations	2,432	2,033	2,432	9,500	9,500	9,500	9,500
R^2	0.731	0.864	0.735	0.651	0.694	0.745	0.694

Notes: Robust standard errors are in brackets (clustering at municipality). Dependent variable is the homicide rate (per 100,000 inhabitants). All regressions include a constant, municipality, and year dummies, and are weighted by population. Treatment variables are dummies = 1 between 1999–2001, between 2002–2008, and after 2008 interacted with dummy of mahogany-occurring area. Columns 5 to 7 control for state specific time dummies. Columns 2 and 6 control for interactions of year dummies with baseline (1995) values of the following municipality characteristics: percent of area planted, mortality by heart and circulatory diseases, neoplasms, infectious diseases, traffic accidents, suicides, child mortality, assassinations related to land conflicts (rate), per capita GDP (ln), fraction of GDP in agriculture (the latter 2 measured in 1996), and homicide rate.

with either of these two dimensions). This suggests that the strongest effect of prohibition was observed in areas with natural occurrences of mahogany and where mahogany activity was more 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 before.

We save the discussion on the quantitative implications of the estimated coefficients for later, but notice for now that the numbers from columns 5 and 6 are not directly comparable to those in other columns, since the scales of the treatment variables are different.

Table 3 reproduces the main specifications from Table 2 splitting the sample between Pará and other states with areas of natural occurrence of mahogany. Pará accounted for more than 70 percent of mahogany exports before prohibition, and most of the illegal activity is presumed to take place there, so it deserves particular attention. In addition, Table 1 and Figure 2 show that there was initially much less municipality heterogeneity in homicide rates within Pará than across other mahogany-occurring states, so this exercise may help diminish concerns related to heterogeneity between treatment and control. The first three columns in the table refer to Pará only, while the remainder

of the columns refer to other mahogany-occurring states (in the case of Pará, we are dealing with a single state, so we do not need state-specific time dummies).

Qualitative results for Pará are very similar to those from Table 2, but quantitative results are substantially stronger. Since municipalities in Pará are more homogeneous than in the extended sample, this suggests that, if anything, heterogeneity across treatment and control seems to be biasing our estimated coefficients toward zero. Column 3 also reproduces, for the case of Pará, the same dynamics of evolution of homicides over the three treatment periods as discussed in Table 2.

When we look at other mahogany-occurring states in columns 4 to 7, results are much weaker and, in most cases, not statistically significant. There is some increase in violence during the prohibition period (between 2002 and 2008), but no other detectable effect. Even for this case, the quantitative effect is one-third of that estimated for Pará. Given the prominent role of Pará in mahogany extraction before prohibition and the suspicions surrounding its continued role in illegal mahogany activity, this result is reassuring. For this reason, we focus the analysis in the remainder of our empirical exercises on Pará.[13] Overall, the results indicate that the relative increase in violence in mahogany areas after 1999 is not related to socioeconomic changes taking place at the state level or to differential dynamics of municipalities with different initial conditions.

For the interested reader, online Appendix Table A.4.1 presents results without population weights and computing standard errors using the Driscoll-Kraay formula, which is robust to arbitrary forms of spatial correlation (Driscoll and Kraay 1998). Both quantitative and qualitative results remain similar to those from Table 3.

We conclude our discussion of the benchmark results analyzing their quantitative implications. To look at a more homogeneous set of municipalities and concentrate on the state that is driving the results and accounts for most of the mahogany activity (Pará), consider the coefficients in column 2 from Table 3. These can be immediately read as changes in homicide rates per 100,000 inhabitants after the mahogany restrictions, indicating average increases of, respectively, 11.0 per 100,000 inhabitants between 1999 and 2001, 18.9 after 2002, and 20.9 after 2009. Comparing with the pre-1999 average homicide rate in mahogany areas of Pará, these estimated coefficients correspond to increases of the order of 100 percent or more. Though apparently large, these numbers have to be seen in light of the experience of the state of Pará during this period, where the overall increase in homicide rates was well above 100 percent (see Figure 2). Just the difference in homicide rates across mahogany and non-mahogany areas of Pará, which was very small in 1995, reached over 160 percent at its peak (2004). Our estimated coefficients explain roughly the entire differential increase in homicide rates across areas with and without mahogany when averaged over the entire period between 1998 and 2013 (to be precise, the coefficients explain 101 percent of the average increase). Since the mahogany market is estimated to correspond roughly to 1 percent of the state GDP, it seems

[13] As mentioned before, if we estimate regressions analogous to those from Table 3, but controlling for the contemporaneous levels of the independent variables, rather than interacting their initial values with time dummies, qualitative and quantitative results remain similar. We opt to not present these results due to the potential problem of "bad controls" in these specifications (Angrist and Pischke 2009).

plausible that most of this relative increase in violence was due to increased illegal logging and the context of violence that followed.

To give a more concrete meaning to the estimated coefficient, consider the median municipality in the mahogany-occurring area of Pará (27,495 inhabitants). The estimated impact of prohibition during the 2002–2008 period, for example, amounts to 5 additional homicides per year. From 1999 to 2013, the effect in Pará adds up to 5,171 additional deaths due to illegal mahogany activity.

Bearing in mind the historical size of the mahogany market—US$129 million per year between 1971 and 2001 (Groggan, Barreto, and Veríssimo 2002)—and Pará's 70 percent share in it, the estimated coefficient for the prohibition period implies 1 additional death per each US$262,000 of illegal market. As an alternative reference point, considering the average level of suspected mahogany exports during the most active period (US$89 million per year between 2002–2008, in 2000 values), the analogous number amounts to 1 death per US$181,000 of illegal market size. To our knowledge, this is the first time that numbers linking violent deaths directly to the size of an illegal market are estimated.

B. *Differential Trends and Other Concurrent Socioeconomic Changes*

Despite the evidence from Figure 2 and the consistency of results across the different specifications in Tables 2 and 3, one might still be concerned that the treatment variables are capturing distinct preexisting dynamics of violence in mahogany regions. Notice that this would have to be the case conditional on the state-specific time dummies and interactions of initial conditions (including the homicide rate) and time dummies already included in previous specifications.

If this were the case, these distinct dynamics should be present already before the restrictions to mahogany exploration and trade were imposed. To assess this possibility, we introduce a variable that accounts for preintervention trends, or a placebo intervention, in homicide rates. We include a dummy for 1997–1998 interacted with the dummy indicating mahogany areas. This exercise tries to detect whether homicides in mahogany areas were already increasing a couple of years before the restrictions to extraction were imposed. The results are presented in column 1 of Table 4. The preintervention placebo is very small and not statistically significant. There is no evidence that our treatment variables are capturing differential dynamic behavior of homicide rates that were present before the introduction of restrictions to mahogany trade. In column 2 of Table 4, we estimate an additional specification that includes municipality-specific linear trends. This specification is very demanding on the data but is of little consequence in terms of estimated coefficients. Point estimates remain with similar magnitude and strongly significant when we include municipality-specific trends.

In order to rule out some competing socioeconomic explanations for the relative increase in crime in mahogany areas, it is also useful to analyze explicitly how GDP per capita and agricultural activity were evolving in these areas during the same period. This helps shed light on whether the increase in violence was driven by lower economic growth and potentially worse labor market opportunities or to expansions of agricultural activity, which might both be associated with mahogany prohibition. The

Table 4—Illegality of Mahogany Trade and Homicides, Testing for Parallel Trends and Other Effects of Regulatory Change, Municipalities in Pará, Difference-in-Difference

	Effect on homicides and parallel trends, 1995–2013		Other economic changes, data restricted to 1996, 1999–2010					
	Testing for pre-trend	Municipality linear trend	Dependent variable: Homicide		Dependent variable: GDP per capita		Dependent variable: Percent GDP in agric.	
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
treat 1999	13.55	14.07	10.44	8.577	0.322	0.256	0.0515	0.0823
	[6.021]	[4.345]	[3.384]	[5.018]	[0.134]	[0.145]	[0.0594]	[0.0594]
treat 2002	23.45	25.96	20.35	16.16	0.461	0.312	0.0182	0.0874
	[6.262]	[5.820]	[4.989]	[7.363]	[0.166]	[0.174]	[0.0648]	[0.0607]
treat 2009	17.35	22.24	20.94	14.65	0.431	0.207	−0.00712	0.0967
	[7.062]	[6.144]	[8.091]	[7.293]	[0.164]	[0.192]	[0.0725]	[0.0644]
Placebo	1.728							
	[4.374]							
Municipality specific trend		X		X		X		X
Observations	2,432	2,432	1,664	1,664	1,664	1,664	1,664	1,664
R^2	0.731	0.801	0.776	0.855	0.942	0.966	0.851	0.916

Notes: Robust standard errors are in brackets (clustering at municipality). Dependent variable is the homicide rate (per 100,000 inhabitants) in columns 1–4, the log of GDP per capita in columns 5–6, and the share of GDP in agriculture in columns 7–8 (the latter 2 only available for 1996, 1999–2010). All regressions include a constant, municipality, and year dummies, and are weighted by population. Treatment variables are dummies = 1 between 1999–2001, between 2002–2008, and after 2008 interacted with the dummy of the mahogany-occurring area. Pre-1999 placebo is a dummy for 1997–1998 interacted with mahogany occurring area. Columns 2, 4, 6, and 8 include, as additional controls, interactions of municipality dummies with a linear time trend.

last four columns in Table 4 explore this point. Since GDP data at the municipality level is only available for 1996 and 1999–2010, in columns 3 and 4, we run analogous specifications for the homicide rate restricting the sample to this same period. Results for homicide rates remain qualitatively similar to those obtained before. For GDP per capita, there seems to be some catch up for mahogany areas, concentrated mainly in the early 2000s. This general pattern was already apparent in the descriptive statistics from Table 1, but it loses strength as municipality-specific trends are included in column 6. For the fraction of GDP in agriculture, there seems to be no statistically significant difference in behavior across mahogany and non-mahogany areas. Overall, the results indicate that it seems unlikely that deteriorations in socioeconomic conditions or changes in the pattern of agricultural activity could explain the relative increase in violence observed in mahogany-occurring areas during this period.

As a final test to the parallel trends assumption, we run specifications that include only the initial and final periods, where the initial period is 1995 and the final period varies from 1996 to 2013. This exercise allows us to detect the specific timing of the differential behavior of homicides across mahogany and non-mahogany-occurring areas. The 18 coefficients estimated sequentially in this procedure, with their respective standard errors, are plotted in Figure 3 against the final period included in each regression. The dynamics of homicides across mahogany and non-mahogany areas are virtually identical up 1999, when homicide rates start rising in mahogany areas.

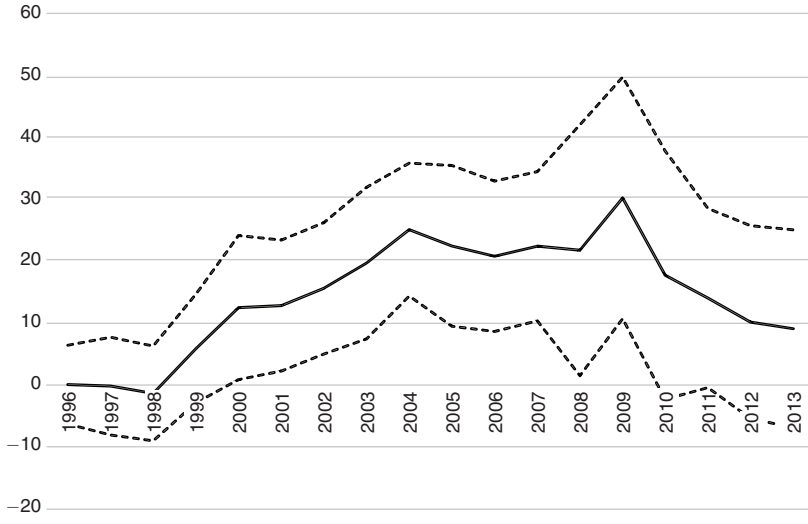


FIGURE 3. TIMING OF THE EFFECT, PARÁ, 1996–2013

The difference in homicide rates across mahogany and non-mahogany areas starts being statistically significant in 2000 and remains so until 2009. By 2010, the difference in homicide rates across the 2 areas starts to fall and ceases to be statistically significant. This difference continues to fall and remains nonsignificant up to 2013, when our dataset stops. It is not surprising that the profile of the relative increase in homicide rates in mahogany areas seems to follow the introduction of the restrictions to extraction and to match closely the profile of exports of "other tropical timber species" discussed in Figure 2. As exports start to fall after 2008, so does the difference in homicide rates between mahogany and non-mahogany areas. This pattern was already present in the results from column 3 of Table 3.

C. *Characterizing the Victims of Violence*

Table 5 presents another piece of evidence that lends support to the specific story outlined in Section I. In order to shed light on the nature of the increase in violence, we break down our dependent variable by characteristics that are thought to come closer to describing criminal violence, rather than domestic violence, family disputes, or violence among acquaintances. We first restrict the analysis to male homicides, then to homicides of prime-aged males (15–39), and then, within this group, to homicides of single men, to homicides for which the death occurred outside the home, and to homicides by firearms. Some of these characterizations of homicides are available only starting in 1996, so in order to report comparable results, we look at data between 1996 and 2013 (and reproduce our benchmark results for this time frame in the first column, for purposes of comparison). In the last two columns in the table, we also analyze whether the restrictions to mahogany seem to have affected deaths due to land conflicts. Deaths registered as due to land conflicts are very rare, so we use both the rate per 100,000 and a dummy indicating occurrence as dependent variables. We only have this particular information up to 2007.

Table 5— Illegality of Mahogany Trade and Homicides, Characterization of Victims and Homicides, Municipalities in Pará, 1996–2013, Difference-in-Differences

	All	Male homicides		Male homicides, ages 15–39			Deaths from land conflicts	
Variables	1996–2013 (1)	All ages (2)	Ages 15–39 (3)	Single (4)	Death occurred outside the home (5)	Homicide by firearm (6)	Rate (per 100,000) (7)	Occurrence dummy (8)
treat 1999	11.36	22.59	37.37	22.35	32.87	26.20	−0.00592	−0.0260
	[3.346]	[6.041]	[11.63]	[8.771]	[9.858]	[7.650]	[0.00376]	[0.0384]
treat 2002	21.27	38.17	67.87	52.66	63.23	41.01	−0.000448	0.00145
	[5.269]	[10.32]	[19.30]	[17.57]	[17.75]	[16.35]	[0.00501]	[0.0806]
treat 2009	15.16	25.40	30.33	26.12	26.56	2.028		
	[6.885]	[13.86]	[26.39]	[23.80]	[25.86]	[27.53]		
1996 level of dependent variable	14.29	24.09	35.72	34.09	25.33	20.78	0.01	0.11
Proportional effect in 2002–2008	148%	158%	190%	154%	250%	197%	−3%	1%
Observations	2,304	2,304	2,304	2,304	2,304	2,304	1,664	1,664
R^2	0.753	0.754	0.733	0.734	0.734	0.694	0.167	0.356

Notes: Robust standard errors are in brackets (clustering at municipality). Dependent variable is the homicide rate (per 100,000 inhabitants) by demographic group. In columns 4–6, the denominator of the homicide rate for each subgroup is the total male population aged 15–39. All regressions include a constant, municipality, and year dummies, and are weighted by population. Treatment variables are dummies = 1 between 1999–2001, between 2002–2008, and after 2008 interacted with the dummy of the mahogany-occurring area.

Table 5 indicates that the increase in violence in mahogany-occurring areas is fundamentally driven by violence against prime-aged men. Point estimates in column 2, for example, are almost two times higher than the analogous coefficients from column 1. Numbers from column 3, for the period of increasing violence (up to 2008), are more than 3 times larger than those from column 1. When we break down the homicides of prime-aged men into the categories mentioned before and look at the main prohibition period, we see that 78 percent of the increase in violence is related to homicides of single men, 93 percent to homicides for which the death occurred outside the home, and 60 percent to homicides by firearms. Underreporting of this particular information in death registries is likely to make these lower-bound estimates. Lastly, institutional changes in the mahogany market do not seem to be drivers of deaths due to land conflicts (small and nonsignificant coefficients in columns 7 and 8), a fact that lends further support to the idea that we are capturing deaths directly related to mahogany extraction, and not to ensuing conflict between ranchers and local communities over use of land.

The table also presents the proportional effects of the estimated coefficients (compared to the baseline value of the dependent variable), since underlying homicide levels are also very different across these categories. The table shows that the increase in homicides was more than proportionally concentrated on prime-aged men and, among these, more than proportionally associated with deaths occurring outside the home and by firearms. Despite the limitations intrinsic to the data, this result points to effects disproportionally associated with characteristics less likely to be associated with domestic or family-related violence, and more likely to be associated with criminal violence.

V. Concluding Remarks

This paper presents evidence of the increase in violence in Brazilian regions with natural occurrences 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 intrinsic association between market illegality and the use of violence. Still, there is very little direct causal evidence on this relationship. We present a unique piece of evidence on the increase in violence following the complete shutdown of a legal market and the subsequent appearance of an active illegal market. The increase in homicides we document is not related to changes in socioeconomic conditions, preexisting trends in violence, or intrinsic characteristics of the good being traded or of its consumers. We also show that, as the government improved its monitoring capabilities and started being able to effectively enforce prohibition, the illegal market shrank and the violence associated with it subsided and returned to trend.

Different markets are embedded in different institutional settings and the relationship between illegality and violence is likely to vary across contexts. For example, corruption and high monitoring costs may make it difficult to enforce the prohibition of narcotics, whereas the existence of low cost substitutes for chlorofluorocarbons (CFCs) may have contributed to the largely successful—although not perfect—worldwide ban on the substance. With these caveats in mind, our analysis provides one piece of evidence pointing to a causal effect of market illegality, per se, on the incidence of systemic violence and exemplifies how enforcement capacity interferes in this relationship.

Our results also serve as a cautionary tale for policymakers 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." Violence is an important social cost to be accounted for in the cost-benefit analysis of market control policies. In the absence of adequate enforcement capabilities, addressing unwanted externalities with overly restrictive regulations may end up exacerbating social losses.

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