A Tale of Gold and Blood: The Consequences of Market Deregulation on Local Violence

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Abstract

We investigate how deregulating and disabling a decentralized structure for monitoring gold transactions in Brazil ultimately led to surging violence related to illegal mining in the country. With a difference-in-differences design and a unique database combining the geological occurrence of gold deposits and protected areas (where mining is forbidden), we demonstrate that municipalities more exposed to illegal gold mining experienced eight additional homicides per 100,000 people - or an increase of roughly 20% - after the deregulation. Moreover, data on crimes and deforestation suggest that illegal mining is indeed driving this large increase in violence.

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1 Introduction

A growing body of evidence indicates that the illegal exploration of natural resources is intimately connected with violence and environmental degradation (Chimeli and Soares, 2017; Parker and Vadheim, 2017; Idrobo, Mejía and Tribin, 2014). Efforts to curb this type of illegality typically rely on command-and-control regulatory approaches that require substantial state presence and monitoring capacity. In the context of the exploration of natural resources in developing countries, both may be lacking. In such cases, regulatory designs that decentralize the monitoring incentives throughout the production chain — in effect privatizing part of the monitoring costs — can in principle be of great help in limiting the pervasiveness of illegal activities. Despite their potentially important role, issues related to regulatory design have received very little attention in the literature on natural resources, illegal markets, and violence.

This paper illustrates the role of private market regulations in limiting illegality by exploring a natural experiment in the market for raw gold in the Brazilian Amazon. In Brazil, government-regulated local stores — the first-buyers — are the market entry points of raw gold produced by small miners. Before 2013, these first-buyers were accountable for screening sellers for mining permits and keeping documentation to prove the origin of the gold they purchased. Starting in 2013, however, a regulatory change exempted first-buyers from legal responsibility regarding the origin of the gold, greatly increasing their incentives to purchase illegal gold. Using various proxies for illegal gold mining, we show that this change led to increased gold exploration and major increases in violence in areas with gold reserves that could not be mined legally — namely Conservation Areas and Indigenous Territories — with no similar movements in areas with legal exploration of gold.

We rationalize our argument with a general equilibrium model, drawing partially from previous work on taxation and informality (Paula and Scheinkman, 2010). In our setting, first-buyers and gold miners can both choose whether to operate legally or illegally, depending on the level of private, decentralized monitoring that is induced by regulation. We add to this model elements from Castillo, Mejía and Restrepo (2020) to understand the connection between private monitoring downstream (first-buyers) and the level of illegal activity and violence upstream (miners). We show that reducing private monitoring ultimately makes it less costly for first-buyers to acquire illegal products, because the risk of punishment decreases.

In our context, this happened because exempting first-buyers from liability for buying illegal gold made them much less inclined to properly monitor its origin. At the same time, both legal and illegal gold become a single indistinguishable product once first-buyers re-sell them to melting facilities. This means that central government authorities have limited capacity to
track irregularities along the production chain without the help of first-buyers. Hence, exempting them from liability made it more profitable to buy illegal gold and disguise it as legal rather than just buy legal gold\(^1\).

Favoring illegal gold shifted demand and encouraged more small miners to operate illegally. More competition in illegal gold mining sites, however, leads to more disputes. In an environment with poorly defined property rights and low access to formal conflict resolution, those disputes become violent more often, especially when considering that gold has high value per gram and liquidity. These fights may break out for a number of reasons: conflict over territory, or to solve labor disagreements, or because miners are invading areas controlled by local communities, such as indigenous peoples. Whatever the case, the regulatory shock in 2013 is expected to have fostered violence in places more prone to illegal gold mining.

We test this hypothesis combining the timing of the deregulation with cross-sectional variation in the level of exposure to illegal gold mining across municipalities in the Brazilian Amazon. The latter is jointly determined by the geological occurrence of gold deposits and the location of Indigenous Territories and Conservation Areas, where mining is strictly forbidden and to which we will henceforth refer as protected areas. Importantly, although mining is not allowed in those areas, there is ample evidence that small — or wildcat — miners have been illegally extracting gold from them and selling it to first-buyers, both before and after 2013 (Ministério Público Federal, 2020). Therefore, the deregulation did not create illegal gold mining in the Brazilian Amazon, but rather made it much more profitable for first-buyers.

We employ a standard Difference-in-Differences design and define the treated group as municipalities with gold deposits inside protected areas, i.e. those more prone to illegal gold mining. Our main control group is municipalities with all gold deposits outside protected areas. In this context, identification stems from both the timing of the regulatory shock and the plausibly exogenous distribution of mineral reserves with respect to protected areas within each municipality. Based on this strategy, we expect the treated group to experience a disproportionate increase in both illegal mining and violence after the deregulation.

We find that municipalities more exposed to illegal gold mining had roughly eight additional homicides per 100,000 people - or close to a 20% increase - after the regulatory change in 2013, compared with less exposed locations. To put results in perspective, the additional violence generated by the deregulation amounts to roughly four and three times the average homicide rate in Asia and Europe respectively (UNODC, 2020).

Our estimates are robust to the inclusion of multiple controls for urbanization, economic

\(^1\)Indeed, as described in details by Brazilian authorities (Ministério Público Federal, 2020), first-buyers have become de facto gold-launderers, buying illegal gold and then re-selling it legally.
growth, GDP composition, and state-specific trends that could be both resulting from gold mining and driving violence. Furthermore, estimates are conditional on exposure to gold mining in general, legal or illegal. Hence, our results are not driven by the mere presence of gold-mining operations, but only that of illegal ones.

We also provide evidence that the estimated effect is coming from illegal gold mining specifically and not from disputes for illegal mining sites of other valuable minerals. Moreover, we show that our results are not driven by a more general type of violence associated with land conflicts, such as in the case of land grabbers invading protected areas.

Finally, we verify what happens with the level of illegal gold mining in exposed locations, since it is the driving force behind increasing violence. This is challenging, however, because data on illegal activities is usually nonexistent. We circumvent this limitation by looking at indirect signs of illegal mining inside protected areas with gold deposits. Specifically, we use geocoded data on both deforestation associated to wildcat mining and sanctions against mining-related environmental crimes. Indeed, we find evidence that illegal miners might not be expanding the borders of existing sites, but rather intensifying activities or venturing into new, unexplored areas. These results are in line with our theoretical framework, which predicts that more miners would try their fortune in illegal gold mining after the deregulation in 2013.

Our paper contributes to the broad literature on the adverse effects of the presence of natural resources on development (Angrist and Kugler, 2008; Dal Bó and Dal Bó, 2011; Dube and Vargas, 2013; Berman et al., 2017; Stoop, Verpoorten and van der Windt, 2019). More specifically, our findings speak to the growing literature about violence and conflicts in markets with poorly enforced property rights (Chimeli and Soares, 2017; Fetzer and Marden, 2017; Bandiera, 2003; Dell, 2015; Castillo, Mejía and Restrepo, 2020; Alston, Libecap and Mueller, 2000). We add to this body of evidence by showing that the design of monitoring strategies matter and can be quite effective in curbing negative outcomes arising from the illegal exploration of natural resources in developing nations. Indeed, even small changes to incentives for private agents to monitor each other can ultimately defeat the purpose of decentralized monitoring.

We also provide a new theoretical framework for violence in illegal markets that takes into account the role of different players in the production chain. This is related to previous papers about Value-added Taxes (VAT) as a tool to reduce informality (Paula and Scheinkman, 2010; Pomeranz, 2015). In their context, VAT encourages formal players to be more conscious about transacting with informal ones and ultimately pushes the former to squeeze away the latter. In our case, we demonstrate that an analogous mechanism of decentralized monitoring is helpful to deter both illegality and violence.
As for the empirical setting, our paper is closely related to Idrobo, Mejía and Tribin (2014). The latter shows how illegal gold mining partially drove increasing violence in Colombia during the gold prices’ boom after the financial crisis of 2008. In their case, emphasis lies on the importance of securing property rights to avoid violence. Our paper adds to their findings by providing evidence that the mere existence of regulation guaranteeing property rights is not enough if enforcement strategies are poorly designed.

Indeed, our paper is a cautionary tale for policies aiming at reducing disputes over property rights. In Brazil, the creation of Indigenous Territories and Conservation Areas had presumably solved such conflicts (Fetzer and Marden, 2017) by assigning clear property rights over large swaths of land in the Brazilian Amazon. The fact that we find increasing violence in those same locations suggests that defining property rights does not work in a vacuum and it cannot rely only on direct government monitoring. It is likely that laws delimiting protected areas need to be complemented by proper incentives for players not to explore them illegally or, alternatively, to actively safeguard them.

This is an important implication not only for this context, but also for designing all kinds of policies aimed at discouraging production processes with high social and environmental costs, such as in Parker and Vadheim (2017). For example, certification of origin initiatives are supposed to assure consumers that they are buying food, wood, or jewelry with socially and environmentally responsible sourcing. Some certifications ensure goods are not being supplied by farmers who invade Conservation Areas; others attest that loggers are not cutting down endangered trees; and others still certify that minerals are not coming from war or conflict zones. In these cases, our results suggest that making first-buyers truly liable for the verification procedure is crucial.

The rest of the paper is organized as follows. The next section provides additional background about gold mining in the Brazilian Amazon. Section 3 presents the conceptual framework and the testable implications. Sections 4 and 5 outline the data and the empirical strategy. Sections 6 and 7 present the main results, as well as robustness checks. Section 8 concludes.

2 Gold Mining and Violence in the Brazilian Amazon

2.1 Mining and selling gold prior to 2013

Gold has had an important role in Brazil since the country’s first large deposits were found in the seventeenth century. Such discovery, followed by a large migration wave to the mining sites,
allowed Brazil to become one of the largest producers of gold in the world between the 17th and 18th centuries (Porto, Palermo and Pires, 2002). More recently, although the country went down in this ranking since then, it was still the world’s 10th largest producer in 2017, holding a 2.6% market share.

Nowadays, the frontier of gold exploration in Brazil is in the Amazon region, comprising nine federal states\(^2\) that in 2017 accounted for one third of the country’s gold production. The influx of people rushing for gold in this relatively remote, forest-covered region did not only bring the benefits of increasing income. It also produced deforestation, water pollution, and increasing violence.

Violence is typically associated to small-scale mining — or *garimpo*, in Portuguese. Conflict arises from either territorial, power, or even labor disputes among miners — *garimpeiros* — or between them and local communities, such as indigenous peoples. The reason for these disputes to become violent is that most *garimpeiros* operate illegally either inside protected areas; or without a proper permit. Without well-defined property rights over their mining operations, *garimpeiros* have little access to formal justice to solve their conflicts and thus often resort to weapons and violence instead.

This situation is aggravated by the growing number of *garimpos* in the region and their increasing capitalization\(^3\), which raises the stakes. According to data on legal gold production, *garimpo’s* output was 74% higher in the 2013-2017 period compared with 2008-2012, as opposed to a 29% increase for large gold mining companies in the same period.

These two types of player — *garimpeiros* and large mining companies — account for most of the gold production in Brazil. Each of them, however, operates under quite different regulatory regimes. In particular, *garimpeiros* apply for a special mining permit called *Permissão de Lavra Garimpeira* (PLG), which is easier to get and, more importantly, does not require a preliminary Prospective Study (Pesquisa Mineral)\(^4\).

Formally, the Prospective Study consists in estimating the potential size and productivity of new mineral deposits. This step is important because they enable authorities to verify whether the actual production of a deposit matches its estimated productivity (Ministério Público Federal, 2020). This matching is possible because miners must show a valid permit at the moment of sale to inform authorities about the origin of their product. With both the Prospective Study and

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\(^2\) Acre, Amapá, Amazonas, Maranhão, Mato Grosso, Pará, Roraima, Rondônia, and Tocantins.

\(^3\) Federal prosecutors and the police estimate that the initial capital expenditures to start a *garimpo* have reached a range of R$60,000 (roughly US$12,000 in 2020) to two million Brazilian Reais (roughly US$400,000).

\(^4\) The reason for this more permissive regulation traces back to the notion of what was a *garimpeiro* in the 1980’s, i.e., a small and poorly equipped individual who barely makes a living out of mining. Because of this vulnerable position, *garimpos* were seen as a short-term enterprise that could not wait for long government approval processes.
the actual production of mines, authorities can, in principle, determine whether a mining site is producing much more than what was estimated. This helps track down miners who might be using legal operations as fronts for laundering minerals that come from places where mining is strictly forbidden by Brazilian law, such as protected areas. Moreover, this would also prevent tax evasion, which is likely the primary motivation for this permit system.

For big mining companies, this mechanism works coherently, because they are required to provide the Prospective Study. Garimpeiros, however, are not required to provide that study by the time they apply for a PLG permit. Without an estimated output, authorities can never ascertain whether garimpeiros are producing a suspiciously large amount of minerals. This is crucial to understand why garimpeiros are much more likely to illegally explore areas where mining is not allowed, both before and after the regulatory change in 2013. A common practice, for example, is to work illegally inside protected areas and then make it look like the minerals actually came from mining sites with valid permits by the time they are sold to local gold stores — the first-buyers (Ministério Público Federal, 2020).

These first-buyers are small establishments called Pontos de Compra de Ouro (PCOs) and are the typical buyers of raw gold in the Amazon. In fact, Garimpeiros can only sell gold to these stores, who then transfer it to melting facilities that produce gold bars for the financial system. Despite usually being located near big mining sites, PCOs are controlled by large financial institutions and are regulated by the Brazilian Central Bank.

As entry-points of raw gold in the market, PCOs are essential front-line monitoring agents, especially because they are responsible for checking and storing proofs of legal origin for the gold they buy (e.g., a valid PLG permit). Notably, this documentation is kept by PCOs physically in-store, with no electronic accountability system whatsoever.

Importantly, because PCOs were legally required to check for valid permits and other documents, they were clearly liable in case they purchased illegal gold. Hence, the risk of government sanction worked to deter PCOs from blindly accepting gold from garimpeiros. This, however, changed radically in 2013.

### 2.2 Deregulation of the raw gold market in 2013

In 2013, a group of congressmen performed a political maneuver to amend some norms regulating gold transactions. Curiously, they appended these modifications to another bill being

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5I.e., analogous to the case of money laundering via legitimate businesses.

6Based on the 1998 Anti-Money-Laundering Law (Lei 9.613/1998), all parties participating in operations with illicit money and goods can be prosecuted and punished if they fail to report potential violations.
discussed in Congress that had nothing to do with the mining sector. These amendments specifically affected the acquisition of gold by PCOs from garimpeiros. Seemingly innocuous, the new regulation was approved as part of Law 12.844/2013 (Congresso Nacional do Brasil, 2013) and turned out to be quite relevant in weakening the government’s capacity to combat illegal gold mining (Ministério Público Federal, 2020).

There were two main changes. First, starting in 2013, PCOs were allowed to buy gold from garimpeiros under the principle of Good Faith, i.e., first-buyers could simply assume, without liability, that garimpeiros were not lying about the true origin of the raw gold they were selling. PCOs were still required to collect and keep copies of garimpeiros’ IDs and PLG permits, but needed not to put much effort into checking their validity. In practice, PCOs were nearly exempted of responsibility for buying illegal gold and thus were much less likely to search and report irregularities.

Consequently, combating illegal gold mining became more costly after 2013 because monitoring was now more dependent on central government’s efforts. Authorities either would have to search for fraud in PCOs’ in-store archives, or they would have to run expensive crackdowns against illegal garimpeiros in the vast Amazon forest. As neither of these alternatives are easy to implement and as PCOs became less encouraged to help monitoring, the risk of being punished for illegal gold mining decreased for garimpeiros as well.

The second main change in Law 12.844/2013 allowed for people other than garimpeiros to sell gold to PCOs. The only requirement was for them to be somehow providers of services and goods for garimpeiros, such as airplane pilots, suppliers of food and fuel etc. Just as garimpeiros, these other agents would only need to present an ID and a valid mining permit at the moment of sale.

Because the law was very vague in this point, the pool of potential sellers of gold expanded substantially, which consequently made it harder for authorities to look for illegal transactions. Furthermore, a variety of criminals, such as drug dealers, learned that they could use gold transactions with PCOs to launder their money with lower probability of getting tracked.

In sum, the changes enacted in 2013 disabled the decentralized monitoring structure that helped control the origin of gold produced by garimpeiros. It left law enforcement agents with thousands of miners to monitor instead of a handful of PCOs. In the next section, we present the

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7The amendment was included during a legislative session that was debating an entirely different matter. The original bill under discussion was based on an executive act — called Medida Provisória — that was meant to change some agricultural subsidies. Strong lobby from the National Association of Gold Producers and Buyers (ANORO, in Portuguese), however, led to the inclusion of important changes in the regulation of gold transactions as well (Ministério Público Federal, 2020).

theoretical framework explaining how this led to more violence caused by illegal gold mining.

3 Conceptual framework

The underlying argument supported by Brazilian authorities is that exempting PCOs from liability for acquiring illegal gold ultimately encouraged them to doing so more often (Ministério Público Federal, 2020). In this section, we model this as a change in the risk of legal punishment for PCOs who buy illegal gold. Then, we investigate how it could trickle upstream and disturb the equilibrium both in the level of illegal gold mining and violence associated with it.

3.1 Setup

Let the gold industry be composed by two markets: the upstream market, i.e., garimpeiros mining legal and illegal gold deposits; and the downstream market, i.e., the PCOs buying gold from garimpeiros and selling it to the financial sector.

3.1.1 Downstream Market

The PCOs decide how much legal or illegal gold (\(Y_L\) or \(Y_I\)) they will buy from garimpeiros given prices (\(p\), \(P_L\) and \(P_I\)) and the expected sanctions for buying illegal gold (\(\mu \in [0, 1]\) and \(\gamma\)). Therefore, the PCOs solve the following problem:

\[
\max_{Y_L, Y_I} \quad p(Y_L^{\alpha} Y_I^{1-\alpha}) - p_L Y_L - [\mu (p_I + \gamma) Y_I + (1 - \mu) p_I Y_I] \tag{1}
\]

The final consumer — the financial sector — pays a price \(p\) per unit of gold and does not observe whether the gold’s origin is illicit. Hence, the PCO acts as a firm producing one single type of gold with either legal or illegal inputs. The production function has a Cobb-Douglas form with constant returns to scale (0 < \(\alpha\) < 1). As for inputs, legal gold has a certain cost of \(p_L Y_L\); whereas illegal gold has an expected cost: with a probability \(\mu \in [0, 1]\), the PCO is caught in an illegal transaction and pays a fine \(\gamma\) in addition to the unit price. Alternatively, with probability \((1 - \mu)\), no irregularities are found, and the PCO only pays \(p_I\).

Solving Problem 1 yields the following equilibrium prices. The higher the expected sanc-
tions ($\mu \gamma$), the less PCOs are willing to pay for illegal gold.

\begin{align*}
  p_I &= p(1 - \alpha) \left( \frac{Y_L}{Y_I} \right)^{\alpha} - \mu \gamma \\
  p_L &= p\alpha \left( \frac{Y_L}{Y_I} \right)^{\alpha - 1}
\end{align*}

3.1.2 Upstream Market

Each garimpeiro $g$ in a municipality $m$ first decides whether to operate illegally or not. If she decides to work illegally, she must invest in weapons to gain control of gold deposits before starting operations. Alternatively, if operating legally, she simply maximizes profits. Figure 7 in the Appendix details this decision process. Next, we solve the Illegal Miners’ problem by backward induction.

**Illegal Miners** maximize gold production in conquered deposits:

\begin{equation}
  \max_{y_{g,m,I}} p_I y_{g,m,I} - c(y_{g,m,I}) - k
\end{equation}

Such that $y_{g,m,I}$ is the illegal gold output; $c(.)$ is a twice differentiable cost function, increasing and convex; $k$ are fixed costs. Defining the inverse derivative $c^{-1}(\cdot) = q(\cdot)$, we reach the following equilibrium output and profits:

\begin{align*}
  y^*_{g,m,I} &= q(p_I) \\
  \Pi^*_g &= p_I q(p_I) - c(q(p_I)) - k
\end{align*}

By backward induction, illegal garimpeiros first choose how much to invest on weapons $w_{g,m}$. This investment will factor into a contest success function to produce the level of violence in disputes for mining sites, analogously as in Castillo, Mejia and Restrepo (2020). Each garimpeiro $g$ holds a portion of total weapons investment given by $s_{g,m} = \frac{w_{g,m}}{\sum_{g' \in N_{m,I}} w_{g',m}}$, where $N_{m,I}$ is the number of illegal miners. Defining the operational profits as $\Pi^o_{g,m} = p_I y_{g,m} - c(y_{g,m})$, the weapon-investing problem is:

\begin{equation}
  \max_{w_{g,m}} \{ \Pi^o_{g,m} s_{g,m} - k - w_{g,m} \}
\end{equation}

Combining the solution of this problem with Equation 6 gives the equilibrium investment in weapons $w^*_{g,m}$ as a function of prices, costs, and the number of illegal miners in each municip-
ity. Then, we obtain the equilibrium level of violence by adding weapons’ expenditures of all *garimpeiros* in each municipality, yielding:

$$v_m^* = \{p_Iq(p_I) - c(q(p_I))\} \frac{N_{m,I} - 1}{N_{m,I}}$$

Equation 8 shows that violence is increasing in the number of illegal *garimpeiros* ($N_{m,I}$). Intuitively, as more people crowd an illegal mining site, more violent conflict for property rights is expected\(^9\).

**Legal Miners** choose how much gold to produce to maximize profits given the probability of successfully obtaining a mining permit ($1 - \beta$) and fees to operate legally ($\tau$)\(^10\). Their maximization problem is as follows:

$$\max_{y_{g,m,L}} (1 - \beta) \{p_L y_{g,m,L} - c(y_{g,m,L}) - \tau y_{g,m,L}\} - k$$

Problem 9 yields similar first order conditions as in Equations 5 and 6, except for the additional costs associated with permits:

$$y_{g,m,L}^* = q(p_L - \tau)$$

$$\Pi_{g,m,L}^* = (1 - \beta) \{p_L q(p_L - \tau) - c(q(p_L - \tau)) - \tau q(p_L - \tau)\} - k$$

### 3.2 Market Clearing Conditions

In equilibrium, *upstream* and *downstream* markets must clear. Hence, total production of legal and illegal gold must be equal to what *PCOs* sold to final consumers. For conciseness, market clearing conditions are in Equations 23 and 24 in the Appendix.

Combining these conditions with equilibrium prices in Equations 2 and 3, we reach the optimal illegal gold price as a function of exogenous parameters. Then, to find the optimal number of illegal miners in Equation 12, we compute the profit threshold that makes *garimpeiros* indifferent between operating legally or not.

$$N_{m,I}^* = \sqrt{\frac{\{p_I^* q(p_I^*) - c(q(p_I^*))\}}{(1 - \beta) \{q(1 - \tau) - c(q(1 - \tau)) - \tau q(1 - \tau)\}}}$$

\(^9\)Please refer to Appendix B.2 for the complete derivation of the weapon-investing problem and the *garimpeiro*’s optimal profits from illegal mining.

\(^10\)This could include fees for either permit renewal or submitting environmental reports for example.
3.3 Changes in Monitoring Level and Violence

Finally, to understand how the monitoring parameter $\mu$ affects the equilibrium number of illegal miners and violence, we depart from Equations 12 and 8, respectively, and study the sign of the partial derivatives below\textsuperscript{11}.

\begin{align*}
\frac{\partial y^*_m}{\partial \mu} &< 0 \\
\frac{\partial N^*_m}{\partial \mu} &< 0
\end{align*}

Because of the negative sign, decreasing monitoring via PCOs thus leads to an increase in both the size of illegal gold mining (number of illegal miners) and violence in illegal mining sites.

4 Data and descriptives

Our main hypothesis is that exempting PCOs from liability causes the government’s monitoring capacity to decrease, leading to a higher equilibrium level of illegal gold mining and violence. To verify this, we draw from multiple sources and combine spatial information about gold deposits, protected areas, homicides, mining-related environmental crimes, and deforestation.

4.1 Gold deposits

We use large and publicly available data on all known mineral deposits in Brazil provided by the Brazilian Geological Service (Serviço Geológico do Brasil, 2021). Each observation is a geocoded point corresponding to the approximate location of the deposit, its composition, the date it was uploaded in the system, among other characteristics. Since many of these deposits have not yet been explored, however, there is no estimate about the amount of mineral in each observation.

Figure 1 shows the spatial distribution of mineral deposits in Brazil. Even though gold deposits are fairly distributed across the country, they are over-represented in the Amazon states (green borders). Around 57% of all gold deposits in Brazil are in the Amazon, compared with only 14% for all other minerals.

This spatial concentration of gold in the Amazon is also present in official statistics about gold production and permits issued. Output from big mining companies in this region has ac-

\textsuperscript{11}Details of this derivation are in Appendix B.4.
counted for 25% of the Brazilian industrial gold production from 2006 to 2017. This does not include gold extracted by *garimpeiros,* who have produced roughly 15% of all Brazilian gold in that same period. Unfortunately, there are no micro-level data on gold produced in *garimpos.* Nevertheless, tax data\textsuperscript{12} suggests that more than 90% of it comes from the Amazon region.

We also know that there has been increasing willingness to mine gold in the Amazon, especially among *garimpeiros.* In the legal market, we observe a sharp increase in the number of *PLG* permits requested per year in the region, especially beginning in 2013.\textsuperscript{13}

### 4.2 Indigenous Territories and Conservation Areas

As much as we can have a sense about the size of the gold market by looking at official numbers, we still need to circumvent the lack of data on illegal gold mining. To do this, we will focus on a prevalent kind of illegal mining that happens inside territories in which such activity is strictly regulated.

\textsuperscript{12} *Garimpeiros* are supposed to pay a federal tax when selling gold to local stores. This allows us to have a rough idea of market shares based on the amount of tax paid. Of course, this is likely under-reported due to illegal gold transactions.

\textsuperscript{13} More details in Figure 6 in Appendix A.
forbidden.

The two main clear-cut cases are Indigenous Territories and Conservation Areas — both quite widespread in the Amazon region. On the one hand, mining in Indigenous Territories is forbidden by the Brazilian Constitution until Congress regulates this activity with a specific law. Since 1988, this has never happened, and thus all miners working inside these areas are doing so illegally. On the other hand, Conservation Areas are protected by Law 9.985/2000, and no economic activity is allowed inside them\(^\text{14}\).

The procedure to create protected areas in Brazil is quite formalized. Indigenous Territories’ borders are established by Fundação Nacional do Índio (FUNAI) — the federal agency of indigenous affairs — after exhaustive anthropological surveys and presidential approval. As for Conservation Areas, they were mainly delimited in the beginning of the 2000’s to halt the advance of deforestation, as well as to protect areas of ecological value. Hence, it does not seem to be the case that protected area’s locations are endogenous to the spatial distribution of mineral deposits.

Nonetheless, mineral deposits and protected areas incidentally coincide, and even though mining inside them is strictly forbidden, vast anecdotal evidence shows that many garimpeiros venture to do so, especially to mine gold. For example, public authorities estimate that 20,000 garimpeiros are working inside one single Indigenous Territory with no more than 27,000 indigenous people living in it\(^\text{15,16}\). In Figure 2, we present a map of overlapping gold deposits and protected areas in the Amazon region.

Noticeably, a large portion of the Amazon is covered by protected areas, and thus it is no wonder that many gold deposits are located inside them. Roughly 15.8% of gold deposits in the Amazon are inside Indigenous Territories and 4.2% are inside Conservation Areas.

Furthermore, it is not necessarily true that illegal mining happens only inside these protected areas. Mining may also be considered illegal if miners do not have proper permits, regardless of where the deposit is located. Nevertheless, it seems most of the illegal gold mining — 55% to 84% — is happening in those areas, based on a map of illegal mining sites produced by Rede

\(^{14}\)There are two types of Conservation Areas in Brazil: Unidade de Conservação de Proteção Integral, where no economic activity is permitted; and Unidade de Conservação de Uso Sustentável, in which some activities are allowed. Because of this distinction, we only focus on the first group for the purposes of this paper. The only exception belonging to second group is Reserva Extrativista, where mining is forbidden even though some other activities are allowed.

\(^{15}\)A federal court has recently ordered these garimpeiros to leave due to increased concern about indigenous people being exposed to outsiders carrying Covid-19. More details available in https://bit.ly/3dxYOhY.

\(^{16}\)Still in this same Indigenous Territory, the federal police has closed a large garimpo housing more than 2,000 people and functioning almost like a small city, with markets, restaurants, and even dentists. More details in https://bit.ly/3w7gqw
Our main dependent variable is the homicide rate in each municipality and year — i.e., number of homicides per 100,000 inhabitants. To calculate this, we use population data (Instituto Brasileiro de Geografia e Estatística - IBGE, 2021) and total homicides registered by the Ministry of Health (Ministério da Saúde do Brasil - DATASUS, 2021), both at municipal level.

We categorize homicides using the International Classification of Diseases (ICD-10), maintained by the World Health Organization (WHO), and we include all deaths by assault. Moreover, we also use the ICD-10 classification to create additional explanatory variables to control for urbanization, such as deaths by suicide and traffic accidents, as in Chimeli and Soares (2017).\(^ {18}\)

\(^ {17}\)This project analyzed satellite imagery, data on official police raids against miners, and news pieces to try and map illegal mining operations across the Amazon. Although this database may not cover all operations in the Amazon, it provides evidence that illegal mining is mainly happening inside protected areas. More information is available at https://bit.ly/3K8cYr9.

\(^ {18}\)Death by assault corresponds to ICD-10 codes X91 through Y09. Deaths by traffic accidents are in categories...
Figure 3: Homicide Rates in Brazil


Figure 3a shows that the Amazon region has become increasingly more violent compared with other areas in Brazil. From 2006 to 2018, the homicide rate in the Amazon increased by approximately 60%. In contrast, it remained quite stable in other regions\(^\text{19}\).

Furthermore, Figure 3b indicates that, within the Amazon region, violence is increasing faster in smaller municipalities (i.e., those with less than 200,000 inhabitants), with the ratio becoming much steeper after 2013.

Many factors may have contributed to the increasing homicide rate in the Amazon since the 2000’s, especially in smaller municipalities. For instance, empirical evidence suggests that violence in the region is associated with illegal logging and deforestation (Chimeli and Soares, 2017)\(^\text{20}\), or land conflicts (Alston, Libecap and Mueller, 2000; Fetzer and Marden, 2017), or even the expansion of drug trafficking in the region (Machado, 2001).

In this paper, we provide evidence that illegal gold mining became one major driver of homicides after 2013, partially explaining the surge in violence in the Amazon, especially in smaller municipalities. Figure 4 shows that, in 2013, the homicide rate exploded in places more prone to illegal gold mining. These correspond to municipalities with gold deposits inside protected areas (represented by the solid red curve ‘illegal gold deposits’). At the same time, places less

---

\(^{19}\) The sharp decrease in homicides in all of Brazil in 2019 is not the scope of this paper, but it is interesting in and of itself. Some explanations include the consolidation of organized crime, policies to improve police intelligence, and others. More details in the following articles: https://bit.ly/3oYtO1L; https://bit.ly/3SZmyAA.

\(^{20}\)According to a Human Rights Watch report (https://bit.ly/3zxcrKA): “More than 300 people have been killed during the last decade in the context of conflicts over the use of land and resources in the Amazon — many of them by people involved in illegal logging (...).”
exposed to illegal gold mining (i.e., municipalities with gold deposits outside protected areas, represented by the dashed yellow curve ‘legal gold deposits’) do not observe a similar upsurge in homicides, even though their historical levels of violence were comparable to that of the first group.

### 4.4 Illegal Mining in Protected Areas

One additional challenge in this paper is to investigate how the regulatory change affected not only violence, but illegal gold mining itself. Even when focusing on protected areas, there are no official statistics of how many wildcat miners are working illegally inside them. We tackle this issue with two alternative measures of illegal gold mining inside protected areas: deforestation caused by garimpo and mining-related fines issued by the Brazilian environmental authority.

**Deforestation by Garimpo.** Starting a wildcat gold mining operation in the Amazon typically requires not only altering the flow of rivers, but also clearing the forest in surrounding areas to build camps and airstrips. We use this fact and analyze changes in forest cover to infer the expansion of illegal gold mining.

To do this, we use data produced by the MapBiomas Project (2022), a multi-institutional initiative that mapped land use and land cover in Brazil from 1985 to present days using automated
classification methods\textsuperscript{21}. We focus on one of their initiatives, which identifies deforestation caused specifically by garimpo gold miners based on a training sample with known mining sites.

\textit{Mining-related environmental crimes.} Although not all illegal miners will be fined for invading protected areas, we can still use law-enforcement efforts to have a sense of how the regulatory change in 2013 affected illegal gold mining.

We draw from a rich database with all fines issued for environmental crimes in Brazil since the 2000’s (IBAMA, 2021). The data includes a multitude of crimes, such as illegal logging, trafficking endangered species, illegal mining in protected areas, etc. We subset our sample to the 2006-2019 period and we select only fines that are related to illegal mining using simple text-mining tools. We provide further details of how we construct this measure in Appendix A.4.

\section{Empirical Strategy}

We propose a difference-in-differences estimator to test whether the deregulation affected violence disproportionately in municipalities more exposed to illegal gold mining. As laid out before, the argument is that dismantling decentralized monitoring stimulated the demand for illegal gold and encouraged more miners to work illegally inside protected areas. Consequently, disputes in illegal mining sites increased, leading to more violence.

The timing of the deregulation is the same for all municipalities in the Amazon. Hence, identification mainly relies on whether violence would have evolved similarly in the absence of the deregulation in both treated and control units — i.e., places with and without gold deposits inside protected areas, respectively.

Although we cannot test this assumption, we argue that it is likely to hold because the occurrence of gold deposits in protected areas was already given many years before the deregulation was designed. Hence, assignment to treated and control groups is exogenous to both the treatment and the outcome variable. Indeed, the location of gold deposits is the result of millions of years of geological formation. Also, the creation of protected areas, although subject to some policy discretion, occurred mainly as a result of the presence of Indigenous communities and important ecosystems. Furthermore, the vast majority of protected areas in the Amazon was created prior to our sample period and treatment, mainly in the 1990’s and beginning of the

\textsuperscript{21}The group uses Landsat imagery and provides land use and land cover classification at a 30-meter (Equator) resolution. More details about the methodology can be found in their website at https://bit.ly/3SiTTPN.
2000’s.\textsuperscript{22}

Given our assumptions, our main specification estimates the following regression, which gives the causal effect of the deregulation on municipalities more to illegal gold mining.

\begin{equation}
Homicides_{it} = \beta_1 GD_i \ast IGD_i \ast D_{t \geq 2013} + \beta_2 GD_i \ast D_{t \geq 2013} + \beta_3 IGD_i + \beta_4 GD_i + \beta_5 D_{t \geq 2013} + X_{it}' \rho + \tau_i + \theta_i + \mu_{st} + \epsilon_{it}
\end{equation}

(15)

Such that $Homicides_{it}$ is the homicide rate in municipality $i$ and year $t$; $GD_i$ stands for Gold Deposits and it is a dummy variable indicating whether municipality $i$ has any gold deposits; $IGD_i$ stands for Illegal Gold Deposits and it is a dummy indicating whether $i$ has any gold deposits located inside protected areas; $D_{t \geq 2013}$ is a dummy indicating the period after the deregulation; $\tau_i$ and $\theta_i$ are year and municipality fixed effects, respectively; $\mu_{st}$ is a state-specific year fixed effect; and $X_{it}$ is a vector of covariates that we will later discuss in details.

We are interested in $\beta_1$, which is the differential effect of the deregulation for municipalities more exposed to illegal gold mining, conditional on having gold deposits. Because we condition the effect on $GD_i$, we are essentially comparing municipalities exposed to illegal gold mining to those exposed to gold mining in general. We also remark that we do not include the double interaction $IGD_i \ast D_{t \geq 2013}$ in this model, because it would be collinear with the triple interaction\textsuperscript{23}.

From our theoretical implications, we expect $\beta_1$ to be statistically different from zero and \textbf{positive}, i.e., the regulatory change caused violence to increase more in places with $IGD_i = 1$ versus places with $IGD_i = 0$ and $GD_i = 1$.

Equation 15, however, reflects the average effect over all years after 2013. To see yearly effects, we also estimate Equation 16, with $S = \{2006, \ldots, 2019\}$.

\begin{equation}
Homicides_{it} = \sum_{s \in S, s \neq 2012} \lambda_s GD_i \ast IGD_i \ast 1\{s = t\} + \delta_1 GD_i + \delta_2 IGD_i + \sum_{s \in S, s \neq 2012} \psi_s GD_i \ast 1\{s = t\} + \sum_{s \in S, s \neq 2012} \xi_s \ast 1\{s = t\} + X_{it}' \phi + \theta_i + \mu_{st} + \epsilon_{it}
\end{equation}

(16)

In Equation 16, we are interested in all the estimates for $\lambda_s$ and we expect that each one should

\textsuperscript{22}Details available at: \url{https://bit.ly/3C9w1Sh}

\textsuperscript{23}This is so because whenever a municipality has an illegal gold deposit ($IGD_i = 1$) it necessarily has a gold deposit ($GD_i = 1$).
be positive and statistically significant for the 2013-2019 period.

Our preferred estimates contain vector $X_{it}$ with the following covariates to account for differences in economic development and urbanization that may affect both homicides and gold mining: log of municipal GDP per capita, the share of agriculture in GDP, the suicide rate, and death by traffic accidents rate.

Instead of including current values of covariates, we add them by interacting their fixed level in 2005 with year fixed effects. We do this to avoid bias arising from outcome and covariates being simultaneously determined. For example, more illegal mining — which is behind violence — in a specific municipality-year may contribute to an increase in municipal GDP in that year. At the same time, illegal gold mining can be affected by current municipal GDP\textsuperscript{24}.

Finally, we add state-specific time dummies to mitigate concerns about omitted variable bias caused by gold deposits and protected areas being spatially concentrated where violence is increasing due to regional factors\textsuperscript{25}.

To address other potential issues and confirm our interpretation of the results, we run multiple robustness tests in Section 6, which we will discuss later. Moreover, besides investigating these concerns, we also verify whether the mechanism behind increasing violence is indeed the intensification of illegal gold mining inside protected areas. In Section 7, we provide two additional empirical tests. First, we verify whether deforestation caused by garimpo increased more in protected areas with gold deposits after the deregulation compared with those lacking such deposits. Second, we analyze whether these places experienced a larger increase in mining-related environmental crimes after the regulatory change. Each of these variables work as proxies for illegal activity and can provide a sense of how the number of garimpeiros — or the intensity of illegal gold mining — inside protected areas responded to the deregulation.

Before we proceed to the results, Table 1 shows a brief quantitative description of the three groups of municipalities in our sample. We can see that municipalities with some kind of gold deposit (i.e., either “Illegal deposits” or “Legal deposits”) are more comparable between themselves than the ones with no gold deposits (i.e., “No deposits”). This is expected since gold mining likely impacts variables such as population, GDP per capita, and share of agricultural GDP.

Finally, in the next sections we will focus on results for municipalities with less than 200,000 people, because this is where violence is increasing faster. Moreover, removing larger cities will

\textsuperscript{24}For example, according to Ministério Público Federal (2020), page 96, mining sites in the Amazon may operate in a currency system based on gold rather than Brazilian Real.

\textsuperscript{25}For example, if one single state has many more gold deposits in protected areas than the others and simultaneously experiences an increase in homicides unrelated to the deregulation, we would overestimate the effect.
Table 1: Descriptive Statistics of Brazilian Amazon Municipalities with Less than 200,000 People and According to Presence and Type of Gold Deposit, from 2006 to 2012

<table>
<thead>
<tr>
<th>Observations</th>
<th>No deposits</th>
<th>Legal deposits</th>
<th>Illegal deposits</th>
<th>ND-ID</th>
<th>LD-ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>(s.e.)</td>
<td>(s.e.)</td>
<td>(s.e.)</td>
<td>(p-value)</td>
<td>(p-value)</td>
<td></td>
</tr>
<tr>
<td>Population (’000)</td>
<td>20.3</td>
<td>22.5</td>
<td>31.2</td>
<td>-10.9</td>
<td>-8.8</td>
</tr>
<tr>
<td>(23.5)</td>
<td>(21.4)</td>
<td>(31.5)</td>
<td>(0.0)</td>
<td>(0.0)</td>
<td></td>
</tr>
<tr>
<td>GDP per capita</td>
<td>14.1</td>
<td>15.7</td>
<td>18.7</td>
<td>-4.6</td>
<td>-3.1</td>
</tr>
<tr>
<td>(15.3)</td>
<td>(7.3)</td>
<td>(23.0)</td>
<td>(0.0)</td>
<td>(0.0)</td>
<td></td>
</tr>
<tr>
<td>% agricultural GDP</td>
<td>26.9</td>
<td>23.5</td>
<td>18.6</td>
<td>8.3</td>
<td>4.9</td>
</tr>
<tr>
<td>(14.7)</td>
<td>(12.8)</td>
<td>(16.2)</td>
<td>(0.0)</td>
<td>(0.0)</td>
<td></td>
</tr>
<tr>
<td>Homicides per 100,000</td>
<td>15.5</td>
<td>23.3</td>
<td>26.5</td>
<td>-11.0</td>
<td>-3.2</td>
</tr>
<tr>
<td>(19.7)</td>
<td>(22.4)</td>
<td>(27.1)</td>
<td>(0.0)</td>
<td>(0.0)</td>
<td></td>
</tr>
<tr>
<td>Suicides per 100,000</td>
<td>3.5</td>
<td>4.0</td>
<td>6.0</td>
<td>-2.6</td>
<td>-2.0</td>
</tr>
<tr>
<td>(7.5)</td>
<td>(6.9)</td>
<td>(10.7)</td>
<td>(0.0)</td>
<td>(0.0)</td>
<td></td>
</tr>
<tr>
<td>Traffic deaths per 100,000</td>
<td>19.8</td>
<td>23.3</td>
<td>19.0</td>
<td>0.8</td>
<td>4.3</td>
</tr>
<tr>
<td>(27.8)</td>
<td>(40.3)</td>
<td>(17.9)</td>
<td>(0.4)</td>
<td>(0.1)</td>
<td></td>
</tr>
</tbody>
</table>

Notes: GDP per capita is in 2019 BRL; standard errors are in parenthesis; ‘No deposits’ (ND) are all municipalities without gold deposits; ‘Legal deposits’ (LD) includes all municipalities with at least one legal gold deposit, but no illegal; ‘Illegal deposits’ (ID) includes all municipalities with at least one illegal gold deposit; Variables are at the municipality-year level; ‘ND-ID’ is the mean difference between ‘No deposits’ and ‘Illegal gold deposits’; and ‘LD-ID’ is the mean difference between ‘Gold deposits’ and ‘Illegal gold deposits’; Only municipalities with less than 200,000 people in the 2010 Census.

avoid comparisons with very urbanized areas where gold mining is not really relevant. In any case, results for the full sample are shown in Appendix C.726.

6 Main results

Table 2 reports estimates for $\beta_1$ and $\beta_2$ from Equation 15. The coefficient of the interaction between Illegal Gold Deposit and I(Year $\geq$ 2013) gives us the causal effect of the deregulation on violence in municipalities exposed to illegal gold deposits, conditional on having any gold deposit. Columns (1) to (3) present the results considering the homicide rate as the dependent variable, whereas columns (4) to (6) show a logarithmic transformation of the homicide rate27. Columns (1) and (4) control only for municipality fixed effects; columns (2) and (5) add year and state-year fixed effects; and columns (3) and (6) include the interaction of year fixed effects with municipal covariates’ levels in 2005.

26Descriptive statistics for the full sample is in Appendix A.3
27Because the homicide rate can contain zeros, however, we restrict ourselves to positive observations of the dependent variable in this case.
Table 2: Effect of Legislation Change on Homicides in Municipalities Exposed to Illegal Gold Mining, from 2006 to 2019

<table>
<thead>
<tr>
<th></th>
<th>Homicides/100,000 people</th>
<th>(log) Homicides/100,000 people</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>Illegal Gold Dep. × I(Year ≥ 2013)</td>
<td>12.00</td>
<td>8.69</td>
</tr>
<tr>
<td></td>
<td>(3.43)</td>
<td>(3.20)</td>
</tr>
<tr>
<td>Gold Dep. × I(Year ≥ 2013)</td>
<td>−3.33</td>
<td>−0.30</td>
</tr>
<tr>
<td></td>
<td>(1.43)</td>
<td>(1.61)</td>
</tr>
<tr>
<td>I(Year ≥ 2013)</td>
<td>6.15</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>(0.49)</td>
<td>(0.02)</td>
</tr>
</tbody>
</table>

Munic. FE X X X X X X
State-year FE X X X X X X
Year FE × Covariates in 2005 X X
N municipalities 755 755 755 751 751 751
Observations 10,570 10,570 10,570 7,591 7,591 7,591
R² 0.44 0.46 0.47 0.53 0.56 0.56

Notes: (1) and (4) Include municipality fixed effects; (2) and (5) Include state-year fixed effects; (3) and (6) Include interaction of year fixed effects with municipal covariates’ levels from 2005 (log of GDP per capita, share of agricultural GDP, deaths by suicides and deaths in traffic per 100,000). In logarithm specifications, the municipality-year observations with zero homicides were excluded. Only municipalities with less than 200,000 people in the 2010 Census. All errors are clustered at municipal level.

Overall, the table shows that, after the deregulation, municipalities more exposed to illegal gold mining experienced an increase of 8.5 homicides per 100,000 inhabitants compared with municipalities exposed to gold mining in general. Moreover, the coefficients estimated using the log transformation of the dependent variable indicate that this effect corresponds to a 20% increase in the homicide rate in municipalities exposed to illegal gold mining. These estimates are robust to the inclusion of state-year fixed effects and other controls.

As expected, the results are not driven by municipalities exposed to gold mining in general. The coefficient of the interaction between Gold Deposits and I(Year ≥ 2013) suggests that municipalities with at least one gold deposit - legal or illegal - observe, if anything, a reduction in violence28. This reduction could be associated with migration from legal mining in one place to

28Table 5 in Appendix C shows the average effect for all municipalities with at least one gold deposit, regardless of whether it is inside a protected area or not.
illegal mining in another. Alternatively, it could be linked to increasing income in gold mining regions, since significance fades away when we include state-year fixed effects.

Combined, the positive effect of illegal deposits and the null effect of gold deposits reinforce our hypothesis that the law only encouraged more illegal gold mining, which then led to more violent conflicts in places more exposed to that activity. Breaking down the previous results by different types of homicides and victims’ characteristics also suggests that violence stems from garimpeiros’ increasing disputes for deposits: of the estimated additional homicides, 80% result from male homicides, and 66% are caused by firearms, knives, or other cutting weapons (see Appendix Table 6).

Next, we use an event study framework to estimate the main coefficient for each year. This is important both to verify the validity of the parallel trends assumption and to analyze the persistence of the estimated effect over the entire post-period. Figure 5 shows the yearly effects on the homicide rate based on the specification presented in Column (3) of Table 2.

Before the law came into effect in 2013, we see no significant differences between municipalities more exposed to illegal mining and those less exposed. There also does not seem to be a noticeable trend in the point estimates of each year prior to 2013. Moreover, the point estimates are consistently positive from 2013 to 2019 and are significant for most years in this period. This indicates that the deregulation seems to have had an immediate and enduring effect on violence.

One potential concern with our strategy is that garimpeiros might compete violently for all
sorts of minerals, not just gold. Then, if illegal deposits of both gold and other minerals largely coincide, we could be bundling together the effect of the deregulation with a more general surge of illegal mining. Table 7 in the Appendix suggests that this is not the case. We replicate our design using the location of illegal deposits of other minerals that garimpeiros extract, excluding gold, and we find that violence is increasing only where illegal gold deposits are.

Violence caused by land conflicts is also a source of concern. For example, disputes between land grabbers and local communities are common in Indigenous Territories, which is also where illegal gold mining is happening. We address this in Table 8 in the Appendix by adding a variable to capture exposure to the existence of protected areas. These new results confirm that it is really illegal gold mining that is driving the surge in violence after the deregulation, not underlying land conflicts.

Finally, Table 9 in the Appendix shows that municipalities more and less exposed to illegal mining are experiencing similar trends in urbanization, GDP, and population. This suggest that violence is not resulting from deteriorating social conditions caused by illegal mining. This is further corroborated by the fact violence does not seem to be just a consequence of more robberies in places where gold is sold, as shown in Table 10 in the Appendix.

The set of results above provides evidence that the deregulation enacted in 2013 has caused violence to increase disproportionately in municipalities more exposed to illegal gold mining in the Amazon. The underlying mechanism is that the regulatory change inhibited the government’s capacity to monitor illegal gold mining, allowing it to flourish inside protected areas. In the next section, we investigate precisely whether and how this happened.

7 Mechanism

As anticipated in Section 4, finding data on illegal mining can be quite challenging. In this paper, we use two alternative indirect measures to circumvent this issue: deforestation caused by garimpo and mining-related fines issued against environmental crimes. In this section, we plug these variables in a Difference-in-Differences design that is analogous to the one we have used before, except for two modifications.

First, because both deforestation and mining-related fines are geocoded, we can now work at a finer scale and measure illegal mining happening inside protected areas, which is the focus of this paper, instead of using municipal data. Hence, our observation units will now be protected areas contained inside each municipality.

Second, we include in this specification not only the usual dummy variable denoting ex-
posure to illegal gold mining, but also another dummy for exposure to illegal mining of other garimpo minerals\textsuperscript{29} that are not gold. This allows us to compare protected areas that are equally exposed to illegal mining, but some of them are specifically exposed to illegal gold mining.

Our final sample of protected areas contains 641 observations, with 47 of them with gold deposits and 24 of them with deposits of all garimpo minerals except gold. Additional descriptive statistics can be found in Appendix A.5. Equation 17 below details this modified Difference-in-Differences.

\[
Y_{jt} = \beta_1 IGD_j * D_{t \geq 2013} + \beta_2 OtherIllegal_j * D_{t \geq 2013} + \beta_3 IGD_j + \beta_4 OtherIllegal_j + \beta_5 D_{t \geq 2013} + \tau_t + \theta_i + \mu_{st} + \epsilon_{jt}
\]

(17)

Such that \(Y_{jt}\) can represent the following dependent variables: (i) stock or (ii) flow of deforestation by Garimpo (in square kilometers) in protected area \(j\) and year \(t\); (iii) dummy variable indicating whether we observe any positive deforestation in each \(j\) and \(t\); (iv) count of mining-related fines issued by IBAMA in each \(j\) and \(t\); and (v) a dummy indicating positive number of fines in each \(j\) and \(t\). \(IGD_j\) is a dummy equal to one if there is at least one gold deposit inside protected area \(j\); \(OtherIllegal_j\) is a dummy equal to one if there is any garimpo mineral deposit, except gold, inside \(j\); \(D_{t \geq 2013}\) is the treatment dummy; \(\tau_t\) and \(\theta_i\) are year and protected area fixed effects respectively; and \(\mu_{st}\) is a state-specific year fixed effect. Importantly, notice that we do not have the \(GD\) variable in this case because mining inside protected areas is always illegal.

Here, we are interested in \(\beta_1\), which gives the effect of the deregulation on the spread or intensity of illegal gold mining inside protected areas. Both in the case of deforestation and mining-related fines, we expect a positive effect: i.e., the new regulation encouraged illegal gold mining.

Table 3 shows the results for both indirect measures, which we discuss separately.

**Deforestation by Garimpo.** Columns (1) and (2) in Table 3 present the effect of the deregulation on both the stock of deforested areas and the flow of new deforestation. In both cases, we see positive effects indicating that the area devastated by garimpos (in square kilometers) increased after 2013, although none of them are statistically significant. Column (3), however, shows that the probability of observing deforestation in new protected areas (the effect on the extensive margin) is four percentage points higher after the treatment and statistically significant\textsuperscript{30}. This suggests that illegal gold mining might be moving to unexplored protected areas,

\textsuperscript{29}Defined by law as minerais garimpáveis (refer to Appendix A for a precise list of minerals).

\textsuperscript{30}We also test the same specification with a different measure of loss of forest cover in Appendix D.1, but results
Table 3: Effect of Legislation Change on Deforestation by Garimpo and Mining-related Fines Inside Protected Areas Exposed to Illegal Gold Mining, from 2006 to 2019

<table>
<thead>
<tr>
<th></th>
<th>Deforestation by Garimpo</th>
<th>IBAMA Fines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>Illegal Gold Dep. × I(Year ≥ 2013)</td>
<td>0.83</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>(0.52)</td>
<td>(0.16)</td>
</tr>
<tr>
<td>Other Illegal Dep. × I(Year ≥ 2013)</td>
<td>−0.03</td>
<td>−0.03</td>
</tr>
<tr>
<td></td>
<td>(0.08)</td>
<td>(0.02)</td>
</tr>
<tr>
<td>N Prot. Areas</td>
<td>641</td>
<td>641</td>
</tr>
<tr>
<td>Observations</td>
<td>8,974</td>
<td>8,974</td>
</tr>
<tr>
<td>R²</td>
<td>0.74</td>
<td>0.40</td>
</tr>
</tbody>
</table>

Notes: Columns (1)-(3) present results for deforestation and Columns (4) and (5) present results for IBAMA fines. Dependent variables are as follows: Column (1) - stock of deforested area in each year (sq. km); Column (2) - yearly deforestation (sq. km); Column (3) - dummy equal to one if deforestation was positive in a given year; Column (4) - number of IBAMA fines; Column (5) - dummy equal to one if number of IBAMA fines was positive in a given year. All columns include protected area fixed effects, year fixed effects, and state-year fixed effects. All errors are clustered at protected area level.

rather than expanding where garimpeiros were already working.

**Mining-related Fines.** Columns (4) and (5) present estimates for intensive and extensive margins respectively. This time, we find that both the number of fines — Column (4) — and the probability of observing a fine — Column (5) — increased in protected areas exposed to illegal gold mining.

One potential issue with these results is that they might reflect a change in IBAMA’s strategy as a response to the deregulation. This does not seem to be the case for two reasons. First, we do not see the same effect in areas exposed to Other Illegal Deposits, which suggests that IBAMA is not simply being more thorough in searching for mining-related crimes in general. Second, resources for law enforcement agencies that fight illegal mining have been decreasing rather than increasing in the Amazon\(^{31}\). With less capacity and not clearly targeting illegal mining after the deregulation, it seems authorities are issuing more fines for illegal gold mining simply because more people are engaging in this activity.

\(^{31}\)IBAMA and the Federal Police are responsible for combating mining-related crimes in the Amazon. Comparing the 2013-2019 period with 2006-2012, each organization experienced a decrease of 29.8% and 1.4% in personnel respectively. In addition, budget execution data provided by the Ministry of Planning (https://bit.ly/3SmYh6Y) indicate that, during the same period, IBAMA’s committed expenditures decreased by 9.2% in real terms.
Furthermore, it is interesting to notice that the extensive margin is significant for fines, but not for deforestation. One potential explanation is that a higher number of garimpeiros are crowding illegal mining sites that already existed, rather than expanding their borders. At the same time, they are also venturing into unexplored protected areas. In both cases, violence could increase either because garimpeiros are disputing a limited space, or because they are competing for getting to new mining sites first.

Overall, the positive effects on deforestation by garimpo and mining-related fines presented in Table 3 suggest that reducing incentives for PCOs to report illegal gold transactions indeed boosted illegal gold mining inside protected areas.

8 Final remarks

In this paper, we study the consequences of exempting downstream players from liability for buying illegal products. We investigate both theoretically and empirically how this affects the size of the upstream illegal market and subsequent violent disputes in an environment with poorly defined property rights.

We focus on a market deregulation in 2013 that weakened an existing decentralized structure to monitor illegal gold transactions that relied on local first-buyers, the PCOs. This allowed them to buy more illegal gold at a lower risk of getting caught, which ultimately led to the expansion of illegal gold mining and a surge in violence associated with it.

Using a difference-in-differences design, we show that municipalities with gold deposits in protected areas had a disproportionate increase in homicide rates after the deregulation was passed, compared with municipalities with gold deposits outside such areas. To verify our mechanism, we use indirect measures such as deforestation by garimpo and mining-related fines and provide evidence that illegal gold mining indeed expanded.

Although impressive, the dire consequences of such a small change in liabilities were not anticipated. As is often the case, violence as a byproduct of illegal markets was overlooked. Legislators debated for less than 2 minutes in session before approving the deregulation we study in this paper. Perhaps, such rush to change the rules might have been justified by an attempt to increase tax revenues, even at the expense of boosting illegal activities. Nonetheless, it seems the gains are small compared with the unintended increase in homicide rates of nearly 20% across municipalities exposed to illegal gold mining. Indeed, even assuming that all extra taxes levied from gold transactions at PCOs came from more illegal gold mining after the deregulation, total
revenues amounted to little less than 70% of the economic value of lives lost in the process\textsuperscript{32}.

In retrospective, our analysis also suggests that making local stores liable for buying illegal gold was more effective to deter this activity and its consequences than transferring the responsibility to central authorities. This is likely not only true for this case, but also for other markets in which the legal and the illegal coexist, such as logging, imported goods, cattle raising in illegal pastures etc. In all these cases, creating incentives for buyers to prefer legal rather than illegal products can propagate benefits upstream.

Finally, our findings raise caution for governments and companies implementing mechanisms similar to mining permits, such as product certification policies. What we uncover shows that certification must be coupled with proper verification by front-line buyers, which hinges on how accountable the latter are. Stringent certification requirements with no liability for the local buyers are likely to fail and make room for illegal production and violence.

References

\textbf{Abadie, Alberto, Maria C Acevedo, Maurice Kugler, and Juan Vargas.} 2015. “Inside the War on Drugs: Effectiveness and Unintended Consequences of a Large Illicit Crops Eradication Program in Colombia.”


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\textsuperscript{32}The value of gold tax revenues levied by PCOs is calculated from Transferências Obrigatórias da União para os Municípios (IOF ouro) and amounts to 875 million dollars (2015 values). The increase in tax revenues is computed by taking the difference between all revenues received in 2013-2019 and those received in 2006-2012. As for the value of lives lost, we assume an average Value of Statistical Life of 3.29 million Brazilian Reals (approximately 988 thousand dollars in 2015) based on Pereira, de Almeida and de Oliveira (2020), which gives a total loss of 1.28 billion dollars in the 2013-2019 period. Exchange rates are available at \url{https://bit.ly/3QVCjHb}. 28


A Appendix A - Additional Descriptive Figures and Tables

A.1 PLG Permits Requests

Here we assess how much garimpeiros are interested in exploring gold deposits in the Amazon by looking at the number of permit requests they have made under the PLG regime. Figure 6 shows the evolution of these requests over the years, as reported by ANM.

![Number of requested PLG permits](image)

Figure 6: Number of PLG Gold Mining Permit Requests in Brazil, from 2006 to 2019 [Source] National Mining Agency (ANM).

Although permits indicate an “intention-to-explore” legally, their spatial pattern suggests that garimpeiros are much more likely to mine gold in the Amazon than in anywhere else in Brazil. Their increasing interest in gold mining also seems to respond quite well to the global gold-price boom happening between 2005 and 2012.

A.2 Definition of Other Minerals - Minerais Garimpáveis

Minerais Garimpáveis were defined by regulators primarily based on the relative simplicity of their mining process compared with resources like iron or alloy, which require much more
capital investment and complex operations.

The list of *Minerais Garimpáveis* is determined by law and it comprises all the substances that *garimpeiros* can legally explore with a *PLG* permit (the same that they need to obtain to legally explore gold).

The full list that we use in this paper is as follows: diamond, cassiterite, columbite, niobium, tantalum, wolframite, tungsten, scheelite, rutile, quartz, beryllium, muscovite, spodumene, lepidolite, feldspar, mica. The list also includes “other gems” with no specification, and thus we include as many gems as we could find in the mineral deposits government database: amethyst, topaz, emerald, agate, aquamarine, garnet, jasper, opal, amber, jade, lapis lazuli, pearl, ruby, sapphire, tourmaline, turquoise. Finally, some of these minerals are typically components of other substances, such as cassiterite is the main component of tin. As an example, there is no natural occurrence of cassiterite in our database, but tin instead, so we include the latter in the list.

### A.3 Descriptive Statistics for All Municipalities

Descriptive statistics similar to Table 4 but including municipalities with population greater than 200,000 inhabitants.

<table>
<thead>
<tr>
<th>Observations</th>
<th>No deposits</th>
<th>Legal deposits</th>
<th>Illegal deposits</th>
<th>ND-ID</th>
<th>LD-ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population (<em>'000</em>)</td>
<td>622</td>
<td>99</td>
<td>48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(s.e.)</td>
<td>(30.2)</td>
<td>(31.6)</td>
<td>(39.0)</td>
<td>-8.7</td>
<td>-7.3</td>
</tr>
<tr>
<td>(105.1)</td>
<td>(62.5)</td>
<td>(61.8)</td>
<td></td>
<td>(0.0)</td>
<td>(0.1)</td>
</tr>
<tr>
<td>GDP per capita</td>
<td>14.3</td>
<td>16.1</td>
<td>19.0</td>
<td>-4.7</td>
<td>-2.9</td>
</tr>
<tr>
<td>(15.3)</td>
<td>(7.7)</td>
<td>(22.8)</td>
<td></td>
<td>(0.0)</td>
<td>(0.0)</td>
</tr>
<tr>
<td>% agricultural GDP</td>
<td>26.5</td>
<td>22.8</td>
<td>18.2</td>
<td>8.3</td>
<td>4.6</td>
</tr>
<tr>
<td>(14.9)</td>
<td>(13.1)</td>
<td>(16.2)</td>
<td></td>
<td>(0.0)</td>
<td>(0.0)</td>
</tr>
<tr>
<td>Homicides per 100,000</td>
<td>16.0</td>
<td>24.3</td>
<td>27.0</td>
<td>-11.1</td>
<td>-2.7</td>
</tr>
<tr>
<td>(20.1)</td>
<td>(23.8)</td>
<td>(27.0)</td>
<td></td>
<td>(0.0)</td>
<td>(0.1)</td>
</tr>
<tr>
<td>Suicides per 100,000</td>
<td>3.5</td>
<td>4.1</td>
<td>6.0</td>
<td>-2.6</td>
<td>-2.0</td>
</tr>
<tr>
<td>(7.4)</td>
<td>(6.8)</td>
<td>(10.6)</td>
<td></td>
<td>(0.0)</td>
<td>(0.0)</td>
</tr>
<tr>
<td>Traffic deaths per 100,000</td>
<td>19.9</td>
<td>24.0</td>
<td>19.7</td>
<td>0.2</td>
<td>4.2</td>
</tr>
<tr>
<td>(27.7)</td>
<td>(39.9)</td>
<td>(18.5)</td>
<td></td>
<td>(0.8)</td>
<td>(0.1)</td>
</tr>
</tbody>
</table>

*Notes*: GDP per capita is in 2019 BRL; standard errors are in parenthesis; ‘No deposits’ (ND) are all municipalities without gold deposits; ‘Legal deposits’ (LD) includes all municipalities with at least one legal gold deposit, but no illegal; ‘Illegal deposits’ (ID) includes all municipalities with at least one illegal gold deposit; Variables are at the municipality-year level; ‘ND-ID’ is the mean difference between ‘No deposits’ and ‘Illegal gold deposits’; and ‘LD-ID’ is the mean difference between ‘Gold deposits’ and ‘Illegal gold deposits’.

Table 4: Descriptive Statistics of Brazilian Amazon Municipalities According to Presence and Type of Gold Deposit, from 2006 to 2012
A.4 Fines for Mining-related Fines Environmental Crimes

The data provided by IBAMA is quite extensive and contains date of the crime, name of perpetrator, municipality, as well as a detailed description of the event. From this description, we can extract all words related to either mining or minerals typically explored by *garimpeiros*, such as gold, diamond, gems etc. There are also references to substances used to separate gold from mud, as well as wildcat mining per se — *garimpo*. We then categorize fines as “related to illegal mining” whenever they present such keywords.

The full list of keywords is as follows: *garimpo, garimpos, mineracao, mineral, minerais, minerio, garimpagem, garimpeira, minerios, extracao de ouro, extraindo ouro, extrair ouro, mercurio, gemas, diamante, cassiterita, estanho, columbita, niobio, tantalo, volframita, tungstenio, scheelita, rutilo, quartzo, berilio, muscovita, espodumenio, lepidolita, feldspato, mica, ametista, topazio, esmeralda, agata, agua-marinha, granada, jaspe, opala, ambar, jade, lapis-lazuli, perola, rubi, safira, turalina, turquesa.*

In the period of our sample, from 2006 to 2019, IBAMA has issued 265,810 fines in Brazil, 40% of which were in Amazon states. After we subset to geocoded observations, we are left with 70,915 fines issued in the Amazon in that period. Out of those, we identified 936 mining-related fines.

A.5 Descriptives for Mechanism Analyses

Our sample of protected areas contains a few hundred Conservation Areas and Indigenous Territories in the Amazon region. Because these protected areas often extend across state and municipal boundaries, we have split them in a way that their territories are contained inside a single municipality. This yields a total of 566 observations to which we will simply refer as “protected areas” henceforth.

From these 641 protected areas, there are 413 Indigenous Territories and 228 Conservation Areas. These units have an average and median area of 2,781 and 552 square kilometers respectively. Deforestation by *garimpo* in protected areas amounts to 0.01 square kilometers per year. Mining-related fines are rather sparse and the average for protected areas is 0.014 fines per year.
B Appendix B - Theoretical Model

In this section, we present the full derivation of our theoretical framework.

B.1 Garimpeiros’ Decision Tree

![Garimpeiros’ Decision Tree](image)

Figure 7: Garimpeiros’ Decision Tree

B.2 Solving the weapon-investing problem

We start by re-write the weapon-investing problem of illegal garimpeiros in Equation 7 as:

\[
\max_{w_g,m} \left\{ \Pi_{g,m}^0 \sum_{g' \in N_{m,1}} w_{g',m} - k - w_{g,m} \right\}
\]

where \( \Pi_{g,m}^0 = pI_y g,m - c(y_{g,m}) \) are the operational profits and \( s_{g,m} \) is the outcome of a contest function that determines the proportion of profits that the garimpeiro \( g \) is able to make when investing \( w_{g,m} \). Assuming garimpeiros in municipality \( m \) are symmetric, we have the following maximization condition:

\[
\frac{N_{m,1}w_{g,m} - w_{g,m}}{(N_{m,1}w_{g,m})^2} = \frac{1}{\Pi_{g,m}^0}
\]

Then, isolating \( w_{g,m} \) and plugging the equilibrium profits from equation 6 yields the equilibrium investment in weapons for each illegal garimpeiro as a function of prices, costs and the number
of illegal garimpeiros in each municipality:

\[ w^*_g, m = \Pi^*_{g, m} \frac{N_{m, I} - 1}{N^2_{m, I}} \]

\[ = \left\{ p_1 q(p_1) - c(q(p_1)) \right\} \frac{N_{m, I} - 1}{N^2_{m, I}} \]

(19)

To obtain the equilibrium violence in municipality \( m \), since garimpeiros are homogeneous, we simply multiply the equilibrium expenditure in weapons \( w^*_g, m \) by the number of illegal garimpeiros \( N_{m, I} \), yielding

\[ v^*_m = \Pi^*_{g, m} \frac{N_{m, I} - 1}{N_{m, I}} \]

\[ = \left\{ p_1 q(p_1) - c(q(p_1)) \right\} \frac{N_{m, I} - 1}{N_{m, I}} \]

(20)

Finally, by replacing \( w^*_g, m \) and \( \Pi^*_{g, m} \) in the objective function from equation 18, we obtain the garimpeiro’s profits from illegal gold production:

\[ \Pi^*_g, m, I = \Pi^*_{g, m} \frac{w^*_g, m}{N_{m, I}} - k - w^*_g, m \]

\[ = \Pi^*_{g, m} \frac{1}{N_{m, I}} - k - \Pi^*_{g, m} \frac{N_{m, I} - 1}{N^2_{m, I}} \]

\[ = \frac{1}{N^2_{m, I}} \Pi^*_{g, m, I} - k \]

(21)

B.3 Complete derivations of market clearing conditions

In equilibrium, total gold sold to PCOs must be equal to total gold mined legally and illegally by all garimpeiros. We assume that there is no migration of garimpeiros between municipalities, and thus the total population of garimpeiros in a municipality is simply the sum of legal and illegal miners:

\[ N_m = N^*_m, L + N^*_m, I \]

(22)
Additionally, we normalize the equilibrium price of legal gold such that $p^*_L = 1$. Then, since *garimpeiros* are identical, we can write the market clearing conditions as follows:

\begin{equation}
Y^*_L = \sum_m \sum_g y^*_{g,m,L} = N^*_{m,I}q(p^*_L)
\end{equation}

\begin{equation}
Y^*_L = \sum_m \sum_g y^*_{g,m,I} = (N_m - N^*_{m,I})q(1 - \tau)
\end{equation}

By plugging the equilibrium totals from Equations 23 and 24 in the prices from Equations 2 and 3, we can write expressions that implicitly give us the optimal price of illegal gold and the optimal number of illegal gold miners.

First, we will find the expression that implicitly gives the optimal price of illegal gold as a function of exogenous parameters. Let us start by the optimal legal prices, which are normalized to 1:

\begin{equation}
p^*_L = p\alpha \left( \frac{Y^*_L}{Y^*_I} \right)^{\alpha - 1} \tag{25}
\end{equation}

\begin{equation*}
1 = p\alpha \left( \frac{(N_m - N^*_{m,I})q(1 - \tau)}{N^*_{m,I}q(p^*_L)} \right)^{\alpha - 1}
\end{equation*}

\begin{equation*}
\frac{1}{p\alpha} \left( \frac{(N_m - N^*_{m,I})q(1 - \tau)}{N^*_{m,I}q(p^*_L)} \right) = \left( \frac{(N_m - N^*_{m,I})q(1 - \tau)}{N^*_{m,I}q(p^*_L)} \right)^\alpha
\end{equation*}

We now use this condition to find an expression that implicitly gives the optimal illegal prices from Equation 2.

\begin{equation}
p^*_I = p(1 - \alpha) \left( \frac{Y^*_L}{Y^*_I} \right)^\alpha - \mu \gamma
\end{equation}

\begin{equation}
= p(1 - \alpha) \left( \frac{(N_m - N^*_{m,I})q(1 - \tau)}{N^*_{m,I}q(p^*_L)} \right) - \mu \gamma
\end{equation}

\begin{equation}
= p(1 - \alpha) \frac{1}{p\alpha} \left( \frac{(N_m - N^*_{m,I})q(1 - \tau)}{N^*_{m,I}q(p^*_L)} \right) - \mu \gamma
\end{equation}

\begin{equation}
= \frac{(1 - \alpha)}{\alpha} \left( \frac{(N_m - N^*_{m,I})q(1 - \tau)}{N^*_{m,I}q(p^*_L)} \right) - \mu \gamma
\end{equation}

Finally, we can also find the equilibrium number of illegal miners (in Equation 12) using the
equilibrium profits. To do this, we find the threshold point at which *garimpeiros* are indifferent between operating in legal or illegal gold mining sites, which happens when profits are the same in both markets. Applying this condition yields the equilibrium number of illegal miners:

\[ \Pi_{g,m,I}^* = \Pi_{g,m,L}^* \]

\[
\frac{1}{(N_{m,I}^*)^2} \{ p_I^* q(p_I^*) - c(q(p_I^*)) \} - k = (1 - \beta) \{ p_L^* q(p_L^* - \tau) - c(q(p_L^* - \tau)) - \tau q(p_L^* - \tau) \} - k
\]

\[ \frac{1}{(N_{m,I}^*)^2} = (1 - \beta) \{ p_L^* q(p_L^* - \tau) - c(q(p_L^* - \tau)) \}
\]

\[ \frac{1}{(N_{m,I}^*)^2} = (1 - \beta) \{ q(1 - \tau) - c(q(1 - \tau)) - \tau q(1 - \tau) \}
\]

\[ (N_{m,I}^*)^2 = \frac{1}{(1 - \beta) \{ q(1 - \tau) - c(q(1 - \tau)) - \tau q(1 - \tau) \}} \]

\[ N_{m,I}^* = \sqrt{\frac{\{ p_I^* q(p_I^*) - c(q(p_I^*)) \}}{(1 - \beta) \{ q(1 - \tau) - c(q(1 - \tau)) - \tau q(1 - \tau) \}}}
\]

**B.4 Complete derivations to verify how changes in monitoring level affects violence**

We are interested in how the equilibrium number of illegal miners and level of violence respond to changes in our monitoring parameter \( \mu \).

To answer that, we start with the sign of the partial derivative \( \frac{\partial v_m^*}{\partial \mu} \), which gives the effect of indirect monitoring on violence. By differentiating Equation 8 with respect to \( \mu \), rearranging terms and using the fact that \( q(.) = c^{-1}(.) \), we get

\[
\frac{\partial v_m^*}{\partial \mu} = \frac{1}{(N_{m,I}^*)^2} \frac{\partial N_{m,I}^*}{\partial \mu} \{ p_I^* q(p_I^*) - c(q(p_I^*)) \} + \frac{N_{m,I}^* - 1}{N_{m,I}^*} \left[ q(p_I^*) - c'(q(p_I^*))q'(p_I^*) + p_I^* q'(p_I^*) \right] \frac{\partial p_I^*}{\partial \mu}
\]

\[
(28)
\]

\[
\frac{\partial v^*_m}{\partial \mu} = \frac{1}{(N_{m,I}^*)^2} \frac{\partial N_{m,I}^*}{\partial \mu} \{ p_I^* q(p_I^*) - c(q(p_I^*)) \} + \frac{N_{m,I}^* - 1}{N_{m,I}^*} \left[ q(p_I^*) - p_I^* q'(p_I^*) + p_I^* q'(p_I^*) \right] \frac{\partial p_I^*}{\partial \mu}
\]

\[
\frac{\partial v^*_m}{\partial \mu} = \frac{1}{(N_{m,I}^*)^2} \frac{\partial N_{m,I}^*}{\partial \mu} \{ p_I^* q(p_I^*) - c(q(p_I^*)) \} + \frac{N_{m,I}^* - 1}{N_{m,I}^*} q(p_I^*) \frac{\partial p_I^*}{\partial \mu}
\]
To proceed, we need to determine the sign of the partial derivatives in the right-hand side of Equation 28. We start by \( \frac{\partial N_{m,l}^*}{\partial \mu} \), which is determined by differentiating Equation 12 with respect to \( \mu \).

\[
\frac{\partial N_{m,l}^*}{\partial \mu} = \frac{1}{2N_{m,l}^* (1-\beta)} \left\{ q(1-\tau) - c(q(1-\tau)) - \tau q(1-\tau) \right\} \frac{\partial p_I^*}{\partial \mu} [q(p_I^*) - p_I^* q'(p_I^*) + p_I^* q'(p_I^*)] \\
= \frac{1}{2N_{m,l}^* (1-\beta)} \left\{ q(1-\tau) - c(q(1-\tau)) - \tau q(1-\tau) \right\} \frac{\partial p_I^*}{\partial \mu} q(p_I^*) \\
= \frac{1}{2N_{m,l}^* (1-\beta) g(1-\tau)} \frac{\partial p_I^*}{\partial \mu} g(p_I^*)
\]

(29)

Such that \( g(1-\tau) = q(1-\tau) - c(q(1-\tau)) - \tau q(1-\tau) \). Then, by plugging 29 in 28 and using \((N_{m,l}^*)^2\) from 12 to simplify,

\[
\frac{\partial v_m^*}{\partial \mu} = \frac{1}{2N_{m,l}^*(N_{m,l}^*)^2} \frac{\partial p_I^*}{\partial \mu} q(p_I^*) \left\{ p q(p_I) - c(q(p_I)) \right\} + \frac{N_{m,l}^* - 1}{N_{m,l}^*} q(p_I^*) \frac{\partial p_I^*}{\partial \mu} \\
= q(p_I^*) \frac{\partial p_I^*}{\partial \mu} \left[ \frac{1}{2N_{m,l}^*} + \frac{N_{m,l}^* - 1}{N_{m,l}^*} \right] = q(p_I^*) \frac{\partial p_I^*}{\partial \mu} \left[ \frac{2N_{m,l}^* - 1}{2N_{m,l}^*} \right]
\]

(30)

Because \( \left[ \frac{2N_{m,l}^* - 1}{2N_{m,l}^*} \right] > 0 \) for any positive, natural number of illegal miners and \( q(p_I^*) \geq 0 \), the sign of the derivative hinges on \( \frac{\partial p_I^*}{\partial \mu} \). From 26,

\[
\frac{\partial p_I^*}{\partial \mu} = \frac{1 - \alpha}{\alpha(N_{m,l}^*)^2 q^2(p_I^*)} \left[ - \frac{\partial N_{m,l}^*}{\partial \mu} q(1-\tau) N_{m,l}^* q(p_I^*) + \frac{(1-\alpha)}{\alpha(N_{m,l}^*)^2 q^2(p_I^*)} \left[ -(N_m - N_{m,l}) q(1-\tau) q(p_I^*) + N_{m,l} q(p_I) \frac{\partial p_I^*}{\partial \mu} \right] \right] - \gamma
\]

(31)
Then, plugging 29 in 32 and rearranging terms to isolate \( \frac{\partial p_I^*}{\partial \mu} \) finally yields

\[
\frac{\partial p_I^*}{\partial \mu} = -\gamma \left[ \frac{2(N_{m,I}^*)^3(1-\beta)\alpha g(1-\tau)}{2(N_{m,I}^*)^3(1-\beta)\alpha g(1-\tau)+(1-\alpha)q(1-\tau)N_M} \right] *
\]

\[
\left[ \frac{\alpha N_{m,I}^* q^2(p_I^*)}{\alpha N_{m,I}^* q^2(p_I^*) + (1-\alpha)(N_m-N_{m,I}^*)q(1-\tau)q'(p_I^*)} \right] < 0
\]

Finally, given \( \frac{\partial p_I^*}{\partial \mu} < 0 \), we have that

\[
\frac{\partial v_m^*}{\partial \mu} < 0
\]

\[
\frac{\partial N_{m,I}^*}{\partial \mu} < 0
\]

\[
\frac{\partial p_I^*}{\partial \mu} < 0
\]

This means that increasing private monitoring of illegal mining activity has a negative effect on the price paid for illegal gold by the PCOs. This makes intuitive sense, because a higher risk of getting caught by the government increases PCOs’ perceived cost of acquiring illegal gold. This makes them shift the demand towards legal gold, which is safer.
C Appendix C - Additional Figures and Tables for Results and Robustness Checks

C.1 Effect of regulatory change on all municipalities exposed to gold mining.

We show the effect of the regulatory change in all municipalities with gold deposits, regardless of their location (i.e., inside or outside protected areas). We estimate Equation 36 ($Homicides_{it}$, $GD_i$, $D_{t \geq 2013}$ and $X_{it}$ are as defined in Section 5).

\begin{equation}
Homicides_{it} = \beta_1 GD_i + \beta_2 D_{t \geq 2013} + \beta_3 GD_i \times D_{t \geq 2013} + X_{it}^{'} \rho + \tau_t + \theta_i + \mu_{it} + \varepsilon_{it}
\end{equation}

Table 5: Effect of Legislation Change on Homicides per 100,000 People in Municipalities with Gold Deposits, from 2006 to 2019

<table>
<thead>
<tr>
<th></th>
<th>Homicides/100,000 people</th>
<th>(log) Homicides/100,000 people</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>Gold Deposits $\times I(\text{Year} \geq 2013)$</td>
<td>0.62 (1.54)</td>
<td>2.38 (1.59)</td>
</tr>
<tr>
<td>Gold Deposits</td>
<td>6.15 (0.49)</td>
<td></td>
</tr>
</tbody>
</table>

Munic. FE X X X X X X
State-year FE X X X X X X
Year FE $\times$ Covariates in 2005 X X
N municipalities 755 755 755 755 751 751
Observations 10,570 10,570 10,570 7,591 7,591 7,591
$R^2$ 0.43 0.46 0.46 0.51 0.56 0.56

Notes: (1) and (4) Include municipality fixed effects; (2) and (5) Include state-year fixed effects; (3) and (6) Include interaction of year fixed effects with municipal covariates’ levels from 2005 (log of GDP per capita, share of agricultural GDP, deaths by suicides and deaths in traffic per 100,000). In logarithm specifications, the municipality-year observations with zero homicides were excluded. Only municipalities with less than 200,000 people in the 2010 Census. All errors are clustered at municipal level.

Table 5 shows small and non-significant effects for the average municipality exposed to gold mining. This evidence supports our theoretical predictions that the 2013 change in legislation should only encourage illegal gold mining activity.
C.2 Characterization of Homicides

Table 6: Effect of Legislation Change on Homicides per 100,000 People in Municipalities Exposed to Illegal Gold Mining, from 2006 to 2019 - Characterization of Homicides

<table>
<thead>
<tr>
<th></th>
<th>Homicides per 100,000 People</th>
<th></th>
<th>Male Firearm or Knives</th>
<th>Male Firearm or Knives</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>Illegal Gold Dep. × I(Year ≥ 2013)</td>
<td>8.52 (3.23)</td>
<td>5.70 (2.84)</td>
<td>6.96 (2.93)</td>
<td>4.85 (2.65)</td>
</tr>
<tr>
<td>Gold Dep. × I(Year ≥ 2013)</td>
<td>−0.48 (1.62)</td>
<td>−0.53 (1.51)</td>
<td>−0.38 (1.48)</td>
<td>−0.29 (1.42)</td>
</tr>
<tr>
<td>N municipalities</td>
<td>755</td>
<td>755</td>
<td>755</td>
<td>755</td>
</tr>
<tr>
<td>Observations</td>
<td>10,570</td>
<td>10,570</td>
<td>10,570</td>
<td>10,570</td>
</tr>
<tr>
<td>R²</td>
<td>0.47</td>
<td>0.45</td>
<td>0.45</td>
<td>0.44</td>
</tr>
</tbody>
</table>

Notes: Dependent variable is the homicide rate (per 100,000 inhabitants); Homicides by Firearm or Knives also include homicides by other cutting instruments; All models include municipality fixed effects, state-year fixed effects, interaction of year fixed effects with municipal covariates from 2005 (log of GDP per capita, share of agricultural GDP, deaths by suicides and deaths in traffic per 100,000); Only municipalities with less than 200,000 people in the 2010 Census. All errors are clustered at municipal level.

C.3 Is violence also increasing in other minerals’ mining sites?

We verify whether the violence surge also happens in places where other valuable minerals coincide with protected areas. To do this, we map deposits of other minerals extracted under the PLG permit regime (see definition in Appendix A). Table 7 presents the result of this exercise.

As opposed to the case of gold mining, once we introduce time-varying controls, we do not see a significant increase in violence in municipalities with deposits of other garimpo minerals (excluding gold) inside protected areas. This suggests that it was really the permissiveness specific to gold transactions introduced by the 2013 legislation that affected violence in municipalities with illegal gold deposits, not some common factor affecting all sorts of illegal deposits that garimpeiros explore.
Table 7: Effect of Legislation Change on Homicides per 100,000 People in Municipalities Exposed to Illegal Mining of Garimpo Minerals, Excluding Gold, from 2006 to 2019

<table>
<thead>
<tr>
<th></th>
<th>Homicides/100,000 people</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td>Other Illegal Dep. × I(Year ≥ 2013)</td>
<td>1.76</td>
<td>−0.53</td>
<td>−0.78</td>
</tr>
<tr>
<td></td>
<td>(3.77)</td>
<td>(3.56)</td>
<td>(3.54)</td>
</tr>
<tr>
<td>Other Dep. × I(Year ≥ 2013)</td>
<td>−2.07</td>
<td>−0.85</td>
<td>−0.80</td>
</tr>
<tr>
<td></td>
<td>(2.30)</td>
<td>(2.25)</td>
<td>(2.27)</td>
</tr>
<tr>
<td>Illegal Gold Dep. × I(Year ≥ 2013)</td>
<td>11.25</td>
<td>8.86</td>
<td>8.78</td>
</tr>
<tr>
<td></td>
<td>(3.50)</td>
<td>(3.47)</td>
<td>(3.47)</td>
</tr>
<tr>
<td>Gold Dep. × I(Year ≥ 2013)</td>
<td>−3.57</td>
<td>−0.42</td>
<td>−0.58</td>
</tr>
<tr>
<td></td>
<td>(1.45)</td>
<td>(1.60)</td>
<td>(1.61)</td>
</tr>
<tr>
<td>I(Year ≥ 2013)</td>
<td>6.32</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.50)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>X</th>
<th>X</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Munic. FE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>State-year FE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year FE × Covariates in 2005</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N municipalities</td>
<td>755</td>
<td>755</td>
<td>755</td>
</tr>
<tr>
<td>Observations</td>
<td>10,570</td>
<td>10,570</td>
<td>10,570</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.44</td>
<td>0.46</td>
<td>0.47</td>
</tr>
</tbody>
</table>

Notes: (1) Includes municipality fixed effects; (2) Includes state-year fixed effects; (3) Includes interaction of year fixed effects with municipal covariates’ levels from 2005 (log of GDP per capita, share of agricultural GDP, deaths by suicides and deaths in traffic per 100,000). Only municipalities with less than 200,000 people in the 2010 Census. All errors are clustered at municipal level.

C.4 Is violence caused by exposure to protected areas?

In this exercise, we run our main specification, but now we account for the presence of protected areas in municipalities in two ways. In Table 8, Column (1) excludes all municipalities without protected areas; Column (2), explicitly models the effect of protected areas on violence with a dummy interacted with the treatment period.

In both cases, we see that the main effect remains fairly unchanged. Furthermore, we see no significant effect of the presence of protected areas on violence. These results suggest that increasing violence in municipalities exposed to illegal mining is not coming from proneness to land conflicts arising from the mere presence of protected areas.
Table 8: Effect of Legislation Change on Homicides per 100,000 People by the Presence of Protected Areas, from 2006 to 2019

<table>
<thead>
<tr>
<th></th>
<th>Homicides/100,000 people</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td>Illegal Gold Deposits. × I(Year ≥ 2013)</td>
<td>7.24 (3.43)</td>
</tr>
<tr>
<td>Gold Deposits × I(Year ≥ 2013)</td>
<td>0.32 (2.16)</td>
</tr>
<tr>
<td>Gold Deposits. × I(Year ≥ 2013) × I(Protected)</td>
<td>1.66 (3.00)</td>
</tr>
<tr>
<td>I(Year ≥ 2013) × I(Protected)</td>
<td>−0.13 (1.09)</td>
</tr>
</tbody>
</table>

N municipalities | 385 | 755 |
Observations    | 5,390 | 10,570 |
R²              | 0.51 | 0.47 |

Notes: (1) We only include in the sample those municipalities with at least one protected area (Indigenous Territory or Conservation Area); (2) We interact the main effects with a dummy indicating whether the municipality has at least one protected area (Indigenous Territory or Conservation Area); All models include municipality fixed effects, state-year fixed effects, interaction of year fixed effects with municipal covariates’ levels from 2005 (log of GDP per capita, share of agricultural GDP, deaths by suicides and deaths in traffic per 100,000). Only municipalities with less than 200,000 people in the 2010 Census. All errors are clustered at municipal level.

C.5 Effect of regulation on covariates.

One potential alternative story is that violence in municipalities exposed to illegal gold mining is coming from the fact that this activity draws many social problems to these places, such as drug addiction, suicides, prostitution etc. In such case, violence would come from worsening social conditions rather than disputes for property rights. This possibility should be partially captured by our covariates, but it is still important to check whether municipalities with illegal gold deposits are experiencing different social dynamics than the others. To do this, we repeat the difference-in-differences exercise, but we now use each of the covariates in our model as a dependent variable, which are meant to measure this sort of dynamics. Table 9 shows our findings.

From these results, there does not seem to be a significant difference in any of those variables after the regulation changes. Moreover, point-wise estimates seem to be small. This suggests that municipalities exposed to illegal gold mining are not evolving differently, at least in terms or urbanization (measured by suicides and deaths in traffic), GDP per capita, GDP composition (share of agricultural product), or population growth.
Table 9: Effect of Legislation Change on Model Covariates in Municipalities Exposed to Illegal Gold Mining, from 2006 to 2019

<table>
<thead>
<tr>
<th></th>
<th>Suicides</th>
<th>Deaths Traffic</th>
<th>(log) GDP</th>
<th>(%) agric.</th>
<th>(log) pop.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illegal Gold Dep. × I(Year ≥ 2013)</td>
<td>-0.47</td>
<td>-0.31</td>
<td>-0.06</td>
<td>-0.15</td>
<td>-0.03</td>
</tr>
<tr>
<td></td>
<td>(0.91)</td>
<td>(2.54)</td>
<td>(0.05)</td>
<td>(0.99)</td>
<td>(0.04)</td>
</tr>
<tr>
<td>Gold Dep. × I(Year ≥ 2013)</td>
<td>0.14</td>
<td>1.27</td>
<td>0.03</td>
<td>-0.08</td>
<td>-0.003</td>
</tr>
<tr>
<td></td>
<td>(0.55)</td>
<td>(1.97)</td>
<td>(0.02)</td>
<td>(0.64)</td>
<td>(0.01)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>X</th>
<th>X</th>
<th>X</th>
<th>X</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>Munic. FE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>State-year FE</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Year FE × Covariates in 2005</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>N municipalities</td>
<td>755</td>
<td>755</td>
<td>755</td>
<td>755</td>
<td>755</td>
</tr>
<tr>
<td>Observations</td>
<td>10,570</td>
<td>10,570</td>
<td>9,060</td>
<td>9,060</td>
<td>10,570</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.20</td>
<td>0.40</td>
<td>0.94</td>
<td>0.90</td>
<td>0.99</td>
</tr>
</tbody>
</table>

Notes: (1) Suicides per 100,000 people as dependent variable; (2) Deaths in traffic per 100,000 people as dependent variable; (3) (log) GDP per capita as dependent variable; (4) Share of agricultural GDP as dependent variable; (4) (log) population as dependent variable; All models include municipal fixed effects, year fixed effects, and state-year fixed effects. All models include the interaction between year fixed effects and all covariates in 2005, except for the covariate in the left-hand side. Only municipalities with less than 200,000 people in the 2010 Census. All errors are clustered at municipal level.
C.6 Violence in mining sites and/or in the places of sale?

In this paper, our main hypothesis is that violence increased in municipalities that are more exposed to illegal gold mining because dispute for deposits among garimpeiros increases after the regulation changes. However, it is also possible that the spike in homicides in and after 2013 comes from more criminals robbing garimpeiros as they go to the PCO stores to sell their product. In this case, the legislation would be affecting violence much more via income effect rather than via property rights disputes at mining sites.

To test whether the effect is coming from violence at points of sale, we repeat our difference-in-differences exercise, but this time take into account that some municipalities might be hubs of raw gold transactions. Indeed, most sales from garimpeiros to PCOs happen in three cities in the Amazon: Itaituba (PA), Peixoto Azevedo (MT), and Poconé (MT), according to the volume of taxes collected from these operations. Moreover, they account for almost half of all PCOs in the Amazon region.

In Table 10, we present the results for three different exercises. Column (1) shows the effect of decreasing decentralized monitoring on violence in municipalities more exposed to illegal mining, excluding those three cities. Of these municipalities, only one - the largest gold-market, Itaituba (PA) - has gold deposits in protected areas. Column (2) excludes all 23 municipalities that possess at least one PCO store - out of which 6 also have gold deposits in protected areas. Finally, in Column (3) we interact the presence of PCOs with the existence of legal and illegal gold deposits. This latter specification should give us the effect of the regulatory change on violence in municipalities more exposed to illegal mining, controlling for whether that municipality is a point of sale or not.

We observe that the main effect only decreases slightly when we exclude the largest official markets for garimpeiros’ gold. Moreover, although it decreases more when we exclude all municipalities with PCOs, it is still large and significant. This suggests that increasing homicides in municipalities exposed to illegal mining are likely driven by violence at the places of production of gold, where garimpeiros dispute for illegal mining sites.

Nonetheless, Column (3) shows an additional interesting result. Although the effects are not significant, it is possible that the presence of PCOs also affects violence at the places of sale. This is quite reasonable, since more people are bringing valuable items to these places and are exposed to violent robberies. This does not, however, invalidate our previous hypothesis, but

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33 Between 2006 and 2019, these three municipalities accounted for 67% of IOF taxes levied in the Amazon region from garimpeiros at the moment they sell raw gold to first-buyers.

34 The location of all PCO stores is reported by the Brazilian Central Bank and is available at https://bit.ly/3rfeu25.
Table 10: Effect of Legislation Change on Homicides per 100,000 People by the Presence of PCOs, from 2006 to 2019

<table>
<thead>
<tr>
<th>Homicides/100,000 people</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illegal Gold Deposits × I(Year ≥ 2013)</td>
<td>8.26 (3.23)</td>
<td>6.60 (3.31)</td>
<td>6.67 (3.30)</td>
</tr>
<tr>
<td>Illegal Gold Deposits × I(Year ≥ 2013) × I(PCO)</td>
<td></td>
<td>10.83 (8.35)</td>
<td></td>
</tr>
<tr>
<td>Gold Deposits × I(Year ≥ 2013)</td>
<td>−0.91 (1.61)</td>
<td>−1.15 (1.69)</td>
<td>−1.12 (1.69)</td>
</tr>
<tr>
<td>Gold Deposits × I(Year ≥ 2013) × I(PCO)</td>
<td></td>
<td>7.14 (4.36)</td>
<td></td>
</tr>
</tbody>
</table>

N municipalities | 752 | 740 | 755 |
Observations | 10,528 | 10,360 | 10,570 |
R² | 0.46 | 0.45 | 0.47 |

Notes: (1) We remove the 3 municipalities with largest gold tax revenues: Itaituba, Pocone, and Peixoto de Azevedo. (2) We remove all municipalities with PCOs. (3) We interact gold deposits with a dummy indicating the presence of PCOs. All models include municipality fixed effects, state-year fixed effects, interaction of year fixed effects with municipal covariates’ levels from 2005 (log of GDP per capita, share of agricultural GDP, deaths by suicides and deaths in traffic per 100,000). Only municipalities with less than 200,000 people in the 2010 Census. All errors are clustered at municipal level.

instead complements it by showing another implication of the increasing illegal gold mining activities caused by decreasing private monitoring.

C.7 Results for Full Sample of Municipalities

Here, we present the main results of the paper, but we do not limit our sample to municipalities with less than 200,000 people. Overall, main effects are slightly weaker, but still significant for this larger sample.

Figure 8 shows the yearly effect for the full sample, and Table 11 presents the main the effect of the regulatory change on all municipalities — large or small — exposed to illegal gold mining in the Brazilian Amazon region. As in Table 2, columns (4) to (6) shows the specification using a logarithmic transformation of homicides per 100,000 people, limiting the sample to observations with strictly positive number of homicides.
Figure 8: Average Difference in Homicides per 100,000 Between Municipalities More and Less Exposed to Illegal Gold Mining Among Those with Gold Deposits, from 2006 to 2019, with Full Set of Controls (95% c.i.)
<table>
<thead>
<tr>
<th></th>
<th>Homicides/100,000 people</th>
<th>(log) Homicides/100,000 people</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td>Illegal Gold Dep. × I(Year ≥ 2013)</td>
<td>11.73 (3.41)</td>
<td>8.42 (3.18)</td>
</tr>
<tr>
<td>Gold Dep. × I(Year ≥ 2013)</td>
<td>−3.68 (1.43)</td>
<td>−0.68 (1.61)</td>
</tr>
<tr>
<td>I(Year ≥ 2013)</td>
<td>6.23 (0.49)</td>
<td></td>
</tr>
</tbody>
</table>

|                          |                          |                               | Munic. FE | X | X | X | X | X | X |
|                          |                          |                               | State-year FE | X | X | X | X | X | X |
|                          |                          |                               | Year FE × Covariates in 2005 | X | X |
| N municipalities          | 769                      | 769                           | 769        | 765 | 765 | 765 |
| Observations             | 10,766                   | 10,766                        | 10,766     | 7,787 | 7,787 | 7,787 |
| R²                       | 0.46                     | 0.49                          | 0.49       | 0.54 | 0.57 | 0.58 |

Notes: (1) and (4) include municipality fixed effects; (2) and (5) include state-year fixed effects; (3) and (6) include interaction of year fixed effects with municipal covariates’ levels from 2005 (log of GDP per capita, share of agricultural GDP, deaths by suicides and deaths in traffic per 100,000). In logarithm specifications, the municipality-year observations with zero homicides were excluded. All errors are clustered at municipal level.
D Appendix D - Additional Mechanisms Tests

D.1 Different measure for loss of forest cover.

In this exercise, we use an alternative measure for loss of forest cover from DEGRAD (Instituto Nacional de Pesquisas Espaciais, 2016). This project was devised by the Brazilian space agency to detect subtle and gradual changes in forest cover using high-resolution satellite imagery.\(^{35}\) The project ran from 2007 to 2016 and produced yearly spatial polygons with areas of loss of forest cover in the Amazon.

Table 12 presents the results using DEGRAD, and conclusions are the same as in the case of deforestation by *garimpeiros* from MapBiomas.

Table 12: Effect of Legislation Change on Loss of Forest Cover Inside Protected Areas Exposed to Illegal Gold Mining, from 2006 to 2019

<table>
<thead>
<tr>
<th>Loss of Forest Cover</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Illegal Gold Dep. × I(Year≥ 2013)</td>
<td>30.05</td>
<td>1.80</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>(18.92)</td>
<td>(5.01)</td>
<td>(0.04)</td>
</tr>
<tr>
<td>Other Illegal Dep. × I(Year≥ 2013)</td>
<td>−3.11</td>
<td>−2.47</td>
<td>−0.12</td>
</tr>
<tr>
<td></td>
<td>(5.38)</td>
<td>(1.95)</td>
<td>(0.06)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>N Prot. Areas</th>
<th>641</th>
<th>641</th>
<th>641</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observations</td>
<td>6,410</td>
<td>6,410</td>
<td>6,410</td>
</tr>
<tr>
<td>(R^2)</td>
<td>0.81</td>
<td>0.46</td>
<td>0.50</td>
</tr>
</tbody>
</table>

*Notes:* Columns (1)-(3) present results for deforestation and Columns (4) and (5) present results for IBAMA fines. Dependent variables are as follows: Column (1) - stock of loss of forest cover in each year (sq. km); Column (2) - yearly loss of forest cover (sq. km); Column (3) - dummy equal to one if loss of forest cover was positive in a given year; All columns include protected area fixed effects, year fixed effects, and state-year fixed effects. All errors are clustered at protected area level.

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\(^{35}\)The minimum area mapped by DEGRAD is 6.25 hectares and the imagery comes mostly from LANDSAT and CBERS satellites with spatial resolution of 30 meters at the Equator.