Department of Economics- FEA/USP

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

LEILA PEREIRA
RAFAEL PUCCI

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Leila Pereira (leilaarocha@gmail.com)

Rafael Pucci (rafael.pucci@usp.br)

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*Pereira: Insper, leilaarocha@gmail.com. Pucci: University of São Paulo, rafael.pucci@usp.br. We thank Rodrigo Soares, Sergio Firpo, Rogerio Santarrosa, Fernando Ferreira, Francisco Costa, Arthur Bragança, Clarissa Gandour, Vítor Possebom, Luis Alvarez and all seminar and conference participants at Insper, Wharton, University of São Paulo, 2023 Conference on the Economics of Crime and Justice in Chicago, 12th Workshop on the Economics of Risky Behavior in London, 2023 Ridge Forum in Economics of Crime, 42nd Encontro Brasileiro de Econometria (EBE-SBE), CPI-PUC/Rio and Econometric Society Meetings in Malaysia, China, and Australia, LACEA, and NEUDC for their extremely valuable comments and suggestions. We also thank the Sao Paulo State Research Foundation (FAPESP) for their financial support (scholarship processes 2018/14183-3 and 2019/02389-9).

1 Introduction

A growing body of evidence indicates that the illegal exploitation of natural resources is intimately connected with violence and environmental degradation (Chimeli and Soares, 2017; Parker and Vadheim, 2017; Idrobo *et al.*, 2014). Efforts to curb this type of illegal activity typically rely on direct government control, requiring substantial state presence and monitoring capacity. In the context of the exploitation 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 how government regulations that delegate monitoring to private agents play a role in limiting illegality and associated violence. We explore a natural experiment in the market for raw gold produced by small-scale mining 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 deregulation exempted first-buyers from legal responsibility regarding the origin of acquired gold. This made it harder for authorities to monitor this market, as it diminished stores' incentives to scrutinize gold sellers, and ultimately encouraged the purchase of illegal gold.

We combine the shock to incentives driven by this deregulation with a measure of exposure to illegal gold mining, which is based on the location of gold deposits in areas where mining is forbidden. Then, utilizing information both on deforestation specifically associated with small-scale gold mining and on homicides, we run Difference-in-Differences analyses and find that illegal gold mining and violence increased substantially in *exposed* places after the deregulation.

The natural experiment we study in this paper directly targeted the monitoring incentives of first-buyers of gold. These are intermediary players between small-scale miners called *garimpeiros* — who supply raw gold — and financial institutions — who demand gold bars. First-buyers are fewer in number and much more spatially concentrated than gold miners, which makes it easier for authorities to monitor the former rather than the latter. Moreover, because legal and illegal gold are generally indistinguishable after the smelting process, first-buyers play an important role in tracking illegal products. They are expected to screen *garimpeiros* for proper mining permits and report potential irregularities — or face legal consequences. The effectiveness of this private monitoring mechanism thus hinges on the threat of government punishment to first-buyers who break the law.

Although enforcement was not perfect and illegal gold mining has existed in the Amazon for decades, the deregulation, by exempting first-buyers from liability, signaled that they could purchase illegal gold with no risk of punishment. In practice, it allowed these local stores to become *de facto* gold-launderers, buying raw illegal gold and helping mask its origin before introducing it into the financial system (Ministério Público Federal, 2020).

From an economic perspective, reducing the risk of punishment for first-buyers should decrease their costs in acquiring illegal gold, thereby shifting their demand for it upward. This, in turn, would amplify the exploitation of illegal gold and lead to more disputes in mining sites. Under poorly defined property rights and low access to formal conflict resolution, such disputes are more likely to become violent, especially when considering the high value per gram and liquidity of gold. Confrontations may emerge for various reasons, including displacing rival miners, labor disagreements among workers, and invasion of areas controlled by local communities, such as indigenous peoples.

We hypothesize that the deregulation in 2013 led to more violence by expanding illegal gold mining in locations more exposed to this activity. Our empirical exercise combines the timing of the deregulation with cross-sectional variation in the level of exposure to illegal gold mining across localities in the Brazilian Amazon. Exposure is defined based on the geological occurrence of gold deposits in areas where mining is not allowed. In our main analysis, places exposed to illegal gold mining are the ones with deposits inside *protected areas* — either Indigenous Territories or Conservation Areas —, where mining is strictly forbidden. This means that one cannot apply for mining permits to exploit deposits inside such areas, and all gold extracted from them is illegal. Despite the prohibition, however, small-scale mining inside such areas is widespread in the Brazilian Amazon (Ministério Público Federal, 2020; RAISG, 2020; Manzolli *et al.*, 2021).[1]

We divide our empirical approach into two parts. We begin by estimating the effect of the deregulation on illegal gold mining. To do this, we utilize fine-grained data on deforestation specifically associated with small-scale gold mining. Subsequently, we estimate the impact of the deregulation on violence using municipal-level data on homicides.

The first part is challenging and subject to imprecision because there are no direct measures of illegal mining — as is typically the case when dealing with illegal markets. To try and circumvent this limitation, we leverage the fact that, in the Amazon, mining is associated with

[1]To complement this analysis, we also investigate illegal mining outside protected areas. This is the case of miners who operate without a mining permit, even though they could apply for one.

deforestation (Sonter *et al.*, 2017; Espejo *et al.*, 2018). To run their operations, *garimpeiros* usually clear some forest cover to install camps, roads, and airstrips for small airplanes, which bring in supplies and fly out raw gold to be sold to first-buyers at urban centers. We use the scars left in the forest to infer changes in the size of gold mining in different localities of the Amazon.

Taking advantage of the fine-grained nature of the data on deforestation associated with gold mining, we divide the Brazilian Amazon into small grid cells. We then employ a Difference-in-Differences design, defining treated cells as those with gold deposits *inside* protected areas. We consider these cells as *more exposed* to illegal gold mining. Our control group consists of cells with all gold deposits *outside* protected areas. In this context, the identification hinges on the parallel trends assumption: absent the regulatory shock, alterations in deforestation in treated cells would not have systematically differed from changes in controls. We argue that this assumption should hold because even if the choice to exploit a mine is endogenous, exposure to both legal and illegal gold mining is determined by the geological distribution of deposits relative to protected areas.

Results confirm our expectations. The deforested area associated with gold mining expanded more in the *more exposed* group of cells, i.e., those with deposits inside protected areas, compared with the control group. This suggests that, after 2013, gold mining increased precisely in places where illegal gold mining is more likely to happen. We also investigate what happens to cells that are exposed to potential illegal mining *outside* protected areas, i.e., considering deposits in areas without mining permits, but we find no conclusive evidence. Moreover, we explore measures of deforestation that are not specific to gold mining, such as the total deforested area reported by the National Institute for Space Research (INPE). In this case, we find attenuated effects, since deforestation in the Amazon is largely driven by cattle raising and agriculture rather than gold mining.

After presenting evidence that the deregulation caused illegal gold mining to expand inside protected areas, we investigate its effect on violence. To do this, we rely on municipal-level information because municipalities are the smallest unit of analysis available for this data. Since we are concerned with violence happening in remote mining sites, we restrict our sample to municipalities with fewer than 200,000 inhabitants to minimize the influence of urban violence in our results.[2] This is a mild restriction, as small cities constitute the majority of our sample. Out of the 769 municipalities, only 14 have more than 200,000 inhabitants.[3]

[2]The sample restriction was based on the 2010 Census.

[3]Among these very populous municipalities, only 4 have gold deposits. Moreover, the municipalities in our sample have a median population of 14,000 inhabitants, a stark contrast to the median population of 367,121 in large urban centers.

We again employ a Difference-in-Differences design, but now our dependent variable is the homicide rate. Analogously to what we did before, treated — or more exposed — municipalities are the ones with gold deposits *inside* protected areas. Control municipalities have all gold deposits *outside* protected areas. Because of the increase in illegal gold mining after the 2013 deregulation, we expect treated municipalities to experience more violence after that as well.

Our findings suggest that the homicide rate in municipalities more exposed to illegal gold mining increased by almost eleven — or approximately 30% — after the deregulation, compared to less exposed areas. Through a counterfactual analysis, we estimate that between 2013 and 2019, a total of 1,308 deaths could have been prevented if the deregulation had not occurred. This accounts for 24% of the total homicides in municipalities exposed to illegal gold mining. To put results in perspective, these additional homicides per 100,000 people amount to roughly four and three times the average homicide rate in Asia and Europe respectively (UNODC, 2020).

We document that the increase in homicides is mainly driven by illegal mining inside protected areas. Analogously to the case of deforestation, we do not observe an upsurge in violence in municipalities where illegal gold mining could be happening outside protected areas — i.e., by miners operating without permits. We also verify that the differential increase in homicide rates in municipalities exposed to illegal gold mining was disproportionately larger for males, particularly those killed outside their homes and by firearms or knives.

To rule out potential alternative explanations for the increase in violence, we conduct a series of additional analyses. Such explanations include conflicts over land, clashes with law enforcement, or competition among miners for various minerals besides gold. We have also considered whether violence might stem from factors like increased income or population rather than disputes specifically at mining sites. Overall, these exercises support the hypothesis that fights for illegal gold deposits drive violence upward after the deregulation.

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 *et al.*, 2019). More specifically, our findings speak to the growing literature about violence and conflicts in markets with poorly enforced property rights (Alston *et al.*, 2000; Bandiera, 2003; Dell, 2015; Chimeli and Soares, 2017; Fetzer and Marden, 2017; Castillo *et al.*, 2020). Leveraging the deregulation and the association between gold mining and deforestation in the Amazon, we provide causal evidence on how the reduction of incentives for decentralized monitoring can lead to the expansion of illegal activities and associated violence.

Also studying the Amazon region, Idrobo *et al.* (2014) and Fetzer and Marden (2017) demonstrate that assigning and securing property rights can mitigate violent conflicts. While Idrobo *et al.* (2014) delves into gold mining in Colombia, Fetzer and Marden (2017) explores the establishment of Indigenous Territories and Conservation Areas in the Brazilian Amazon. We contribute to these findings by presenting evidence that policies defining property rights may need to be coupled with better monitoring strategies and incentive mechanisms for local players exploiting natural resources.

Closely related to our work, the final section of Berman *et al.* (2017) exhibits results indicating that having international certification of origin policies can help reduce armed conflicts for mineral deposits in African countries. By demanding that companies be more socially responsible and transparent, these policies discourage the transaction of minerals originating in conflict zones. Our paper differs from Berman *et al.* (2017) in key aspects. First, while their work studies the impact of both legal and illegal mining on conflicts driven by rent-seeking armed groups, our paper focuses on violence not tied to nationwide conflicts but instead linked to illegal behavior and a more local dispute for deposits. Second, differently from Berman *et al.* (2017), which examines policies targeting the reduction of mining-related conflicts, we study the impact of a policy aimed at exempting first-buyers from liability, not violence specifically. Finally, our paper focuses on the role of private players' incentives to acquire illegal gold in a context where there is already a policy to control the origin of minerals, which is the permit system. Hence, we add to the findings in Berman *et al.* (2017) by investigating not the introduction of a policy *per se* — either permits or certification —, but the responsibilities attributed to key players in the market by the regulation and how this affects violence in an illegal setting. Our results suggest that, if there is limited to no liability for some players, like the first-buyers, the effectiveness of a decentralized monitoring policy in curbing both illegal mining and violence can be compromised.

These findings may have relevant implications for policies aimed at discouraging production processes with high social and environmental costs, such as in Parker and Vadheim (2017). For example, origin certifications are supposed to assure consumers that they are buying food, wood, or jewelry with socially and environmentally responsible sourcing. Some certifications, as described in Berman *et al.* (2017), ensure that minerals are not coming from war or conflict zones; others certify that goods are not being supplied by farmers who invade Conservation Areas; and others still attest that loggers are not cutting down endangered trees. In each of these cases, certification policies ought to be coupled with regulatory mechanisms that hold market players genuinely accountable for engaging in transactions involving irregular or illegal products.

The rest of the paper is organized as follows. The next section provides additional background about gold mining in the Brazilian Amazon and the 2013 deregulation. Sections 3 and 4 outline the data and the empirical strategy. Sections 5 and 6 present the main results, as well as robustness checks. Section 7 concludes.

2 Background

2.1 Small-scale Mining and Gold Market in Brazil

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 17^{th} and 18^{th} centuries (Porto *et al.*, 2002). More recently, although the country went down in this ranking since then, it was still the world's 10^{th} largest producer in 2017, holding a 2.6% market share (U.S. Geological Survey, 2018).

Nowadays, the frontier of gold mining in Brazil is in the Amazon region, which spans nine federal states and occupies more than half of the Brazilian territory.[4] Partly because of the Amazon forest, this region is hard to access and scarcely populated. According to information from the Brazilian National Mining Agency, the Amazon states accounted for one-third of the country's gold production in 2017.

A large share of this output is retrieved from riverbeds by small-scale mining operations called *garimpos*. Data from gold royalties tax collection reveals that, in 2017, about 70% of the gold produced in the Amazon originated from *garimpos* and 30% from industrial — or large-scale — mining.[5] Additionally, according to land cover data processed by MapBiomas, *garimpos* are responsible for roughly 95% of the area occupied by gold mining activities in the Amazon.[6] *Garimpo* miners — the *garimpeiros* — employ diversified techniques ranging from rudimentary gold-mining pans to more advanced machinery such as tractors and floating dredges.[7] They can work alone, organize into informal groups of *garimpeiros*, or even form

[4]The nine federal states are Acre, Amapá, Amazonas, Maranhão, Mato Grosso, Pará, Roraima, Rondônia, and Tocantins.

[5]Additional information regarding the gold royalties data and the procedures we used for estimating gold production are in Appendix A.1.

[6]MapBiomas is a collaborative network formed by NGOs, universities, and technology startups, which utilizes high-resolution satellite imagery to produce data on Brazilian land use, land cover, and deforestation. Data on mining in the Amazon is available from MapBiomas Collection 8 - Mining (`https://brasil.mapbiomas.org/estatisticas/`).

[7]A recent report by Brazilian authorities speculates that the initial capital expenditures to start a *garimpo* can

government-regulated cooperatives.

Typically, a *garimpo* is formed when an individual finds a new gold deposit. This pioneer becomes the "owner" or leader of the *garimpo* and, as word spreads out, takes responsibility for organizing other incoming *garimpeiros* who wish to prospect the new mining site. In some cases, even in illegal mining sites, they might create a system to share profits and help *garimpeiros* who fall ill and cannot work for a few days (Rodrigues, 2020; da Silva Furtado, 2020).

Partially because all mineral resources in Brazil belong to the federal government, according to the country's Constitution, a *garimpo* can start almost anywhere. They need only request permission to the government, regardless of whether the land is public or private. In the latter case, however, the landowner is compensated with a fee.

The only restrictions for establishing a new *garimpo* are that it must not be located within a protected area, there should be no ongoing mining activity in the same location, and the total area of an individual *garimpeiro*'s mine should not exceed 50 hectares.[8] Therefore, there are minimal barriers to entry for *garimpeiros* who want to work legally outside protected areas.

Garimpos and any other legal mining operation in Brazil are authorized by a mining permit issued by the National Mining Agency. However, *garimpos* operate under specific rules that differ from the ones applicable to large mining companies. *Garimpeiros* apply for a special mining permit called *Permissão de Lavra Garimpeira* (*PLG*) designed for small-scale operations and mainly intended for the exploitation of easily accessible gold deposits, such as those on riverbeds. The idea of offering a simple process for obtaining permits to *garimpeiros* generally stems from the notion that these individuals are poorly equipped and barely make a living out of mining, even though this may not be true for all of them. Their activity is seen as a short-term enterprise that cannot afford to wait for long approval processes.

One simplifying feature of the *PLG*, for instance, is that *garimpeiros* are usually not required to comply with most environmental regulations that are imposed on large mining operations. Another simplification is that the *PLG* exempts *garimpeiros* from conducting a Prospective Study (*Pesquisa Mineral* in Portuguese), which is intended to estimate the potential size and productivity of new mineral deposits. Authorities from the Federal Prosecutor's Office in Brazil consider that Prospective Studies are important to detect illegal mining because they help in verifying whether the actual production of a deposit matches its estimated productivity (Ministério Público Federal, 2020). Without such information, it is easier to launder gold, i.e., forge its

range between sixty thousand and two million Brazilian Reais — or roughly US$12,000 and US$400,000 in 2020 (Ministério Público Federal, 2020).

[8]These rules are defined by Law 7,805 of 1989 (`https://www.planalto.gov.br/ccivil_03/leis/l7805.htm`). In addition, *garimpeiros* may apply for permits for multiple mines provided that each one does not exceed the size of 50 hectares.

origin by declaring that it came from a legal mining site even though it was produced elsewhere illegally.

For this paper, one important requirement of the *PLG* permit is that *garimpeiros* can only sell raw gold to government-authorized stores called *Ponto de Compra de Ouro (PCO)*, the first-buyers. These small establishments are the typical buyers of raw gold in the Amazon. They are usually located in towns with considerable gold production nearby and are owned by large financial institutions. *PCOs* are regulated by the Brazilian Central Bank and their main function is to acquire raw gold from *garimpeiros* and transfer it to melting facilities, which in turn produce gold bars for the financial system. In 2020, as per data from the Brazilian Central Bank, there were 65 *PCOs* in the Amazon, belonging to six distinct financial institutions and spanning 21 municipalities.

As entry-points of raw gold in the market, *PCOs* are responsible for checking and storing proofs of legal origin for the product they buy. These proofs include a valid *PLG* permit, a declaration disclosing the gold's origin, the seller's name, address, and identification document.[9] For each transaction, the *PCO* is required to issue four hard copies of the invoice, encompassing the seller's information, gold origin, and the quantity purchased. One copy must remain in-store for at least ten years, while the others are dispatched to (i) the financial institution owning the *PCO*, (ii) the Brazilian Federal Revenue Office responsible for tax assessments on the sale, and (iii) the gold seller.

The fact that *garimpeiros* are only allowed to legally sell gold to *PCOs* does not eliminate the existence of a parallel market for illegal *garimpo* gold. For instance, some illegally mined gold may be directly exported without involving the *PCOs*. However, anecdotal evidence suggests that *PCOs* are extensively used as intermediary players in the parallel market, potentially laundering illegal gold (Instituto Escolhas, 2022). This is likely attributable to the fact that, once *PCOs* acquire the gold, it becomes legal for all later transactions.

One common practice is for *garimpeiros* to claim that the illegal gold came from a different mining site, which is done by presenting a valid *PLG* permit in the moment of sale at the *PCO* (Ministério Público Federal, 2020). Manzolli *et al.* (2021) provide some quantitative evidence on this. They show that some *PCOs* acquired large sums of gold whose declared origins were areas under legal permits, but with little to no trace of mining activity. The implication is that such permits were likely being used to launder illegal gold mined elsewhere. As dis-

[9]The required identification document varies based on whether the seller is an individual or a company. For individuals, the documents include the Individual Taxpayer's Register (*Cadastro Nacional de Pessoa Física – CPF*) and the seller's Identity Card. For companies, the list of documents includes the National Registry of Companies (*Cadastro Nacional de Pessoa Jurídica - CNPJ*) and the Identity Card of the individual representing the company in the moment of sale.

cussed before, since mining sites operating under the *PLG* permit are not required to carry out a Prospective Study, it becomes more challenging for government authorities to monitor and penalize *garimpeiros* laundering gold.

Until 2013, *PCOs* were clearly liable for participating in gold laundering. Their legal obligation was regulated by the 1998 Anti-Money-Laundering Law (Lei 9.613/1998), which states that all parties participating in operations with illicit money and goods can be prosecuted and punished if they fail to report potential violations. The penalties span from 3 to 10 years in prison along with a fine if a *PCO* deliberately involves itself in gold laundering. Should a *PCO* neglect to report a suspicious transaction, it could have its authorization to transact gold revoked. Suspicious transactions that could be reported by *PCOs* include, for instance, multiple sales of gold by different people using the same *PLG*, or an unusually large amount of gold coming from the same mining site.

Although it is hard to observe the actions taken by *PCOs* to avoid government sanctions, the threat of punishment was sufficiently credible. This is illustrated by some Federal Police operations that tracked down and prosecuted *PCOs* and their respective parent financial institutions. For instance, in 2012, an operation named *Eldorado* identified and prosecuted a financial institution for illegal gold transactions amounting to approximately 150 million dollars (Globo G1, 2012; Procuradoria da República em Mato Grosso, 2013; Anjos *et al.*, 2020). Appendix A.2 presents a list of other Federal Police operations against illegal gold mining.

Moreover, the risk of being punished was high enough for large financial institutions to mobilize and lobby in favor of a regulation that exempted their *PCOs* from liability for buying illegal gold. In the following section, we provide more details about the deregulation, the political process behind it, and some descriptive evidence of its effects.

2.2 Deregulation of the Raw Gold Market

In 2013, a group of congressmen performed a political maneuver to amend norms regulating gold transactions. They appended these modifications to another bill under debate in Congress, but that had nothing to do with the mining sector.[10] These amendments were included after intense lobbying from both the National Association of Gold Producers and Buyers (ANORO, in Portuguese) and financial institutions. The deregulation was approved on July 19th of 2013 as part of Law 12.844/2013 (Congresso Nacional do Brasil, 2013). This was the second time legislators tried to pass such amendments. The first one was in February 2013, but it failed to

[10] The original bill under discussion was based on an executive act — called *Medida Provisória* — that reformed agricultural subsidies.

get approval on that occasion. This suggests that the matter was already in the political arena at least since the beginning of 2013.

According to the Federal Prosecutor's Office, ANORO and financial institutions lobbied Congress to reduce the exposure to legal risks faced by companies operating in the gold market. Financial institutions were directly interested in this because they are the parent companies of *PCOs*. As an example, in 2011, the partner of a financial institution called F.D'Gold, who started presiding ANORO in 2014, was accused of acquiring illegal gold (Tribunal Regional Federal da 1ª Região, 2011). The deregulation, by weakening the government's capacity to punish those acquiring illegal gold, may have benefited financial institutions like F.D'Gold (Ministério Público Federal, 2020).

The deregulation introduced two main changes. First, starting in 2013, *PCOs* were allowed to buy gold from *garimpeiros* under the principle of *Good Faith*. First-buyers could just *presume*, without liability, that *garimpeiros* were telling the truth about the origin of the gold they were selling. *PCOs* were still required to collect and keep copies of *garimpeiros*' IDs and *PLG* permits. However, they did not need to put effort into reporting suspicious amounts or origins because the word of *garimpeiros* was sufficient proof according to the law. In practice, *PCOs* were exempted from responsibility for buying illegal gold as long as they collected the required documents.

Consequently, the risk of punishment against *PCOs* decreased. This is illustrated by a recent court decision in favor of first-buyers. Based on Manzolli *et al.* (2021), federal prosecutors filed a lawsuit against a financial institution for buying illegal gold. According to prosecutors, the first-buyer acquired gold that was declared to come from 127 areas under *PLG* that had no sign of mining activity, and thus had likely been illegally mined somewhere else (Ministério Público Federal, 2021). Nonetheless, a court decision in 2022 cites the deregulation (Law 12.844/2013) to argue that there was no clear evidence of wrongdoing by this financial institution. According to the decision, the first-buyer was not legally required to verify whether the gold came from legal or illegal origin and was allowed to presume the seller was telling the truth (Vara Federal Cível e Criminal da SSJ de Itaituba-PA, 2022).

The second change introduced by the deregulation was to allow individuals other than *garimpeiros* themselves to sell gold to *PCOs*. The only requirement was that the seller had to be somehow associated with the mining activity, working as a service or goods provider to *garimpeiros*. This included, for example, airplane pilots and suppliers of food and fuel. These individuals were required to present the same documents as *garimpeiros* when selling gold to *PCOs*.

These changes significantly hampered the government's ability to identify and punish those involved in illegal gold mining. On the one hand, the principle of *Good Faith* made it more challenging for authorities to pursue legal action against *PCOs* under the terms of the Anti-Money Laundering Law. If prosecuted, *PCOs* could simply claim innocence because they had collected all required documents and assumed the information provided by *garimpeiros* was accurate.

On the other hand, due to the law's vagueness in defining who was permitted to sell gold to *PCOs*, the pool of potential sellers expanded significantly. As a result, in addition to the already costly task of cracking down on illegal miners scattered throughout the vast Amazon forest, authorities must monitor other players in the raw gold market. According to some anecdotal accounts, for example, drug dealers would sell gold to *PCOs* as a means to launder money from the drug trade with a lower probability of being tracked.[11]

In the following section, we discuss how the dismantling of the decentralized monitoring structure in the raw gold market may have affected violence associated with illegal mining.

2.3 Illegal Gold Mining and Violence

The changes implemented in 2013 sent a clear message to *PCOs* that they could buy illegal gold without fear of punishment. Consequently, this not only undermined the existing private monitoring structure, which depended on *PCOs* to function, but also encouraged *PCOs* to intentionally acquire illegal gold (Ministério Público Federal, 2020).

In theory, the decision of *PCOs* to purchase legal or illegal gold should be based on the characteristics of the products, their relative prices, and the expected costs associated with facing sanctions for engaging in illicit transactions. One can assume that the physical attributes of gold are independent of whether it is extracted from within or outside protected areas. If this were not the case, identifying those involved in illegal gold transactions would be more straightforward. Additionally, similar to markets for counterfeit products, illegal gold is expected to be available at a lower price compared to its legal counterpart. Illegal mines avoid costs linked to obtaining mining permits or adhering to regulations for adequate operations. Therefore, the risk of punishment is decisive in determining how much a *PCO* will demand of illegal gold.

By minimizing the risk of punishment, the deregulation is likely to incentivize *PCOs* to increase their demand for illegal gold. As mentioned earlier, a common strategy is for illegal gold to be sold as if it came from permitted areas. *PCOs* could be intentionally laundering gold — i.e., actively using *PLG* permits in their system for registering illegal gold — or simply

[11] For more details, refer to a recent news article: `https://bit.ly/3poJWde`.

not reporting suspicious transactions. In any case, it seems laundering happens at a large scale (Manzolli *et al.*, 2021).

Overall, *garimpo* gold production grew after the deregulation. According to aggregated data reported by the National Mining Agency, legal *garimpos*' output was 74% higher in the 2013-2017 period compared with 2008-2012. In the same period, gold produced by large mining companies grew only 29%.

Nevertheless, much of this growth seems to be driven by an increase in gold laundering, as indicated by a proxy for gold productivity in permitted areas. Figure 1 shows the gold production of legal *garimpos* inferred from tax data, divided by deforested area associated with gold *garimpo* inside permitted areas.[12] Deforestation, as mentioned previously, is a sign of *garimpo* activity.

The line in Figure 1 can thus be interpreted as a measure of gold productivity per area of legal *garimpo* over the years. Overall, we observe a substantial increase in what is allegedly the productivity of legal *garimpos*, particularly in 2013. This increase is not attributed to a reduction in the deforested area but is almost entirely due to more gold being reported as originating from permitted areas. Since such a rapid gain in productivity is quite unusual, it suggests that larger quantities of illegal gold are being produced and laundered after the deregulation.

Our hypothesis is that the increased circulation of illegal gold is driven by higher demand from *PCOs*, who are more willing to buy this product after the deregulation. This demand is expected to drive more *garimpeiros* to mine gold in unauthorized locations, including protected areas. This holds true regardless of whether the *garimpeiro* already possesses a *PLG*. Consequently, we anticipate that, following the deregulation, illegal gold *garimpo* activity will expand.

These illegal *garimpos* generally rely on informal rules to function, which may explain why they are often seen as violent environments. In the absence of formal conflict resolution mechanisms, violence and intimidation serve as alternative methods for settling territorial, power, and labor disputes. Furthermore, the presence of illegal gold mining in protected areas continually fuels tensions between *garimpeiros* and local communities, including indigenous peoples (Sassine, 2019; Dama and Oliveira, 2021).

The description above points to the two hypotheses tested in this paper. First, the deregu-

[12] We estimate gold production in legal *garimpos* using data on taxes paid at the moment of first sale. For further details, please refer to Appendix A.1. To determine gold *garimpo* deforestation inside *PLG* permits, we combine the geographical polygons of *garimpo* gold mining permits with data on deforestation associated with gold *garimpo*. Permit data are generated by the National Mining Agency (Agência Nacional de Mineração, 2022a) and further explained in Section 3. Gold *garimpo* deforestation is provided by MapBiomas and detailed also in Section 3. Because of data limitations and changes in taxation, we restrict ourselves to the 2010-2017 period.

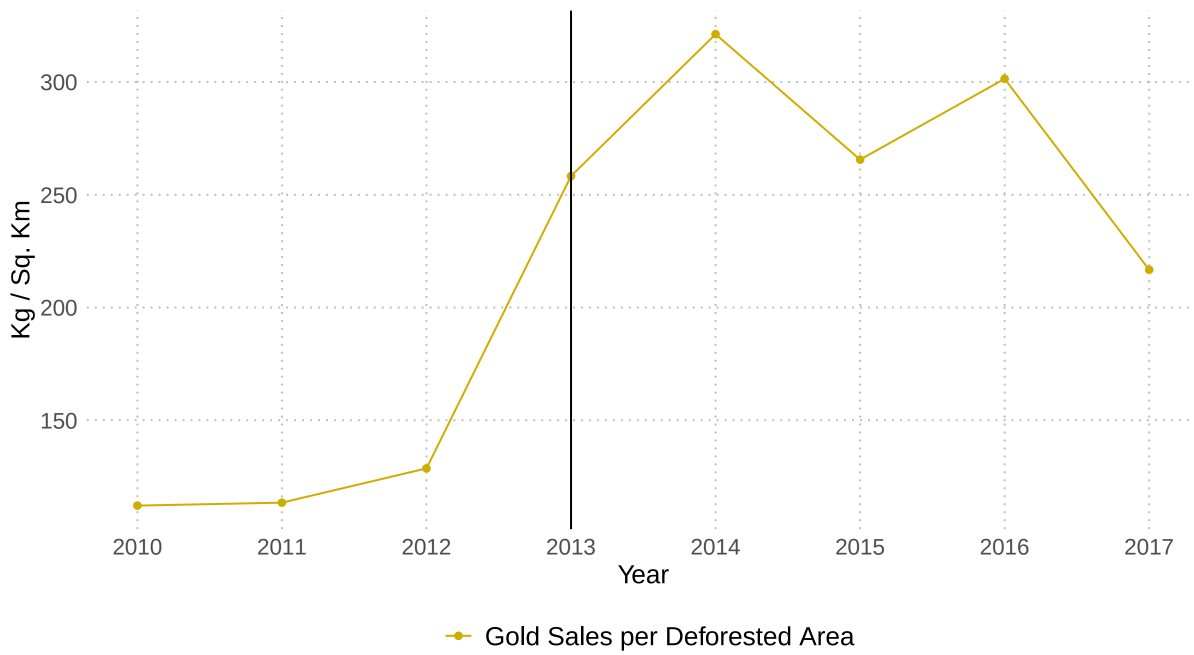

Figure 1: Quantity of Gold Sold Divided by Gold *Garimpo* Deforested Area Inside *PLG* Permitted Areas in the Amazon Region, 2010-2017

Notes: Gold Sales are estimated from tax data (Agência Nacional de Mineração, 2022b). More details are in Appendix A.1. Deforested Area is deforestation associated with gold *garimpo* inside *PLG* permit polygons. This is obtained by merging deforestation data from MapBiomas Project (2022) and mining permits from Agência Nacional de Mineração (2022a).

lation drove an expansion of illegal gold mining by making the acquisition of this product less risky for *PCOs*. This led to more *garimpo* activity inside protected areas, where it is forbidden. Second, as a result of more illegal gold mining, we expect violent disputes to become more frequent in locations exposed to this illegal activity.

We formalize this theoretical discussion with an economic model, which we defer to the Appendix B for the sake of brevity. There, we describe the main players in this market and the parameters affected by the deregulation, as well as the logical path leading from the deregulation to more illegal gold mining and, finally, to more violence.

Moving forward, we outline our data and reduced-form strategy to identify the effect of reducing incentives for private monitoring on both illegal activity and violence in the context of gold mining in Brazil.

3 Data

To conduct our empirical analysis, we draw data from multiple sources. To investigate the effect of the deregulation on illegal mining, we rely on deforested area measured by high-resolution satellite imagery. We leverage this fine-grained information by aggregating deforestation at a 3x3-kilometer cell level. To study the impact of the deregulation on violence, we utilize data on homicides at the smallest territorial unit available in this case — municipalities.

Regardless of the unit of observation, our empirical strategy relies on the timing of the deregulation and a variable indicating which areas are more susceptible to illegal gold mining. Essentially, we seek to determine whether, after the deregulation, there was a disproportionate increase in deforestation and homicides in areas exposed to illegal gold mining compared to areas where gold mining is more likely to be legal.

We define locations (either cells or municipalities) exposed to illegal gold mining as those with at least one gold deposit within a protected area. To do this, we combine the geographic coordinates of known gold deposits with the polygons outlining protected areas in the Amazon.

Next, we detail the construction of this measure of exposure to illegal gold mining. We then proceed with a comprehensive account of the datasets covering deforestation, violence, and crime, alongside additional variables used in the paper.

3.1 Defining Exposure to Illegal Gold Mining

Location of gold deposits: we use publicly available data on all known mineral deposits in Brazil provided by the Brazilian Geological Service (Serviço Geológico do Brasil, 2021).[13] The data include information on the mineral found in each deposit, the date of registry, and the approximate location, which is given by a pair of geographic coordinates — latitude and longitude. Due to the extension of the Brazilian territory, identifying the location of every possible mineral resource is nearly impossible. Therefore, we only observe the location of identified mineral deposits, irrespective of whether their exploitation is economically feasible or not.

Moreover, since many of these deposits have not yet been exploited, we do not know their size or the area they cover. In order to gauge the intensity of mining activity across different locations, we could rely on data regarding the number of deposits. This possibility is further

[13]The Brazilian Geological Service is a public company working under the Ministry of Mines and Energy. Among other things, it collects geological data and maps mineral deposits in Brazil. To do that, researchers start with a Geological Mapping Project for areas jointly defined by the Federal Government, the Ministry of Mines and Energy, and the Geological Service. Once areas are defined, they identify geological occurrences using multiple prospecting tools, such as geospatial modeling, remote sensors, and field studies.

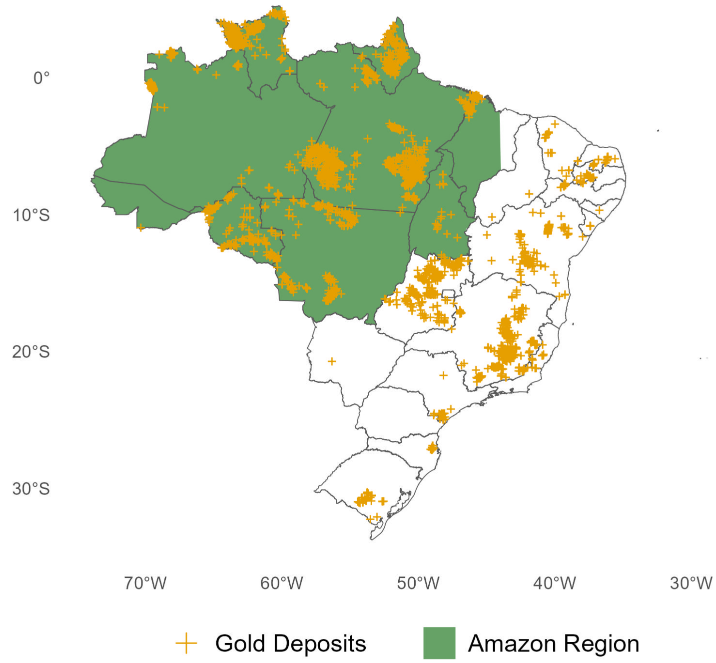

Figure 2: Known Gold Deposits in Brazil

Notes: Map shows all gold deposits in Brazil identified by the Brazilian Geological Service. Location is given by pairs of coordinates. The shaded area in green corresponds to the Amazon region, which is the focus of this paper. *Source:* Serviço Geológico do Brasil (2021)

examined in Section 6.3, but we anticipate one caveat. A high count of deposits does not necessarily imply higher production levels. A location might have numerous deposits, each yielding minimal output, while another location could possess a single, yet substantial deposit driving significant mining production.

Figure 2 shows the spatial distribution of mineral deposits in Brazil, with the Amazon shaded in green. Even though gold deposits are fairly distributed across the country, they are over-represented in the Amazon region. Around 57% of all gold deposits in Brazil are in the Amazon. For comparison, only 14% of other mineral deposits are in the region. Furthermore, most of the gold deposits in the Brazilian Amazon were identified up to 2006 (68% of the total). Analyzing exclusively those gold deposits inside protected areas, 95% of them were registered up to 2006. Hence, few of the deposits we use to define exposure have been registered after the 2013 deregulation.

We can have a sense of how much gold is extracted from these deposits by *garimpeiros*, but micro-data are limited. Our best guess on the total gold *garimpo* production is based on tax data, which we mentioned briefly in Section 2.3. *Garimpeiros* must pay a federal tax when selling gold to *PCOs*. Although this may be subject to under-reporting, we know that gold laundering takes place at *PCOs*, and thereby a portion of illegal gold also pays taxes. This allows us to infer that more than 90% of *garimpo* gold in Brazil comes from the Amazon region.

To circumvent the lack of data on illegal gold mining in*garimpos*, we combine information about deposits with the location of protected areas. As mentioned before, mining inside these areas, although frequent, is strictly forbidden. Hence, all gold coming from protected areas is illegal.

Protected areas: protected areas consist of Indigenous Territories and Conservation Areas, which are widespread in the Amazon. Datasets with the polygons of Indigenous Territories and Conservation Areas are provided by *Fundação Nacional do Índio* (FUNAI) — the federal agency of indigenous affairs — and the Ministry of the Environment, respectively.

Mining inside Indigenous Territories is forbidden according to the Brazilian Constitution of 1988. It states that the prohibition will be in effect until Congress elaborates a specific law regulating such activity. This has not yet happened, hence the prohibition stands. In the case of Conservation Areas, mining is forbidden by Law 9.985/2000.[14]

The procedure to create protected areas in Brazil is quite formalized. Indigenous Territories' borders are established by FUNAI 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. It does not seem to be the case that the creation of protected areas is endogenous to the spatial distribution of mineral deposits. In fact, in 2006, the first year of our sample, 90% of the Indigenous Lands and 80% of the Conservation Areas had already been created.

Despite mining being forbidden in protected areas, there are mineral deposits inside them, as well as vast anecdotal evidence showing that many *garimpeiros* venture to exploit these resources, especially gold. For instance, half of the operations against illegal mining conducted by the Federal Police between 2008 and 2017 have targeted *garimpos* inside protected areas.[15] In one dramatic case of illegal gold mining, public authorities estimate that 20,000 *garimpeiros* were inside one single Indigenous Territory with no more than 27,000 indigenous people living

[14]There are two types of Conservation Areas in Brazil: *Unidade de Conservação de Proteção Integral*, where no economic activity is permitted, including mining; and *Unidade de Conservação de Uso Sustentável*, in which some activities are allowed. We consider as protected areas all the units in the first group and one single unit of the second group called *Reserva Extrativista*, where mining is specifically prohibited, even though other activities are allowed.

[15]For more details about the operations, please refer to Appendix A.2.

in it.[16] Also in this territory, high levels of mercury contamination in indigenous villages have been associated with proximity to gold *garimpos* (Vega *et al.*, 2018). Additionally, despite the prohibition against mining inside protected areas, there are numerous permit requests overlapping with such areas registered in the National Mining Agency's system. Such requests cannot get approval, but they illustrate the pressure exerted on protected areas and suggest the presence of *garimpeiros* inside them (WWF, 2018).

In Figure 3, we present a map of gold deposits and protected areas in the Amazon region. Around 15.8% of gold deposits in the Amazon are inside Indigenous Territories and 4.2% are inside Conservation Areas.

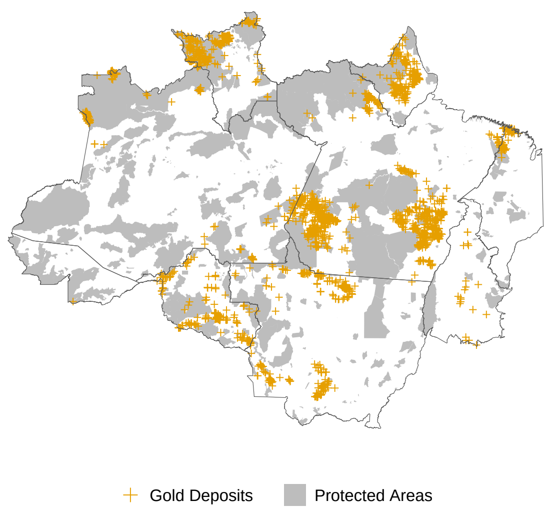

Figure 3: Gold Deposits and Protected Areas

Notes: Map shows the location of gold deposits and protected areas in the states of the Brazilian Amazon.
Sources: Serviço Geológico do Brasil (2021); Fundação Nacional do Índio - FUNAI (2021); Ministério do Meio Ambiente (2021)

We define exposure to illegal gold mining according to the overlapping of deposits and protected areas. Treated (exposed) units are either cells or municipalities containing at least one

[16] 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 are available in https://bit.ly/3dxY0hY. 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/3w7gqwf.

gold deposit within a protected area. Control units are those with gold deposits outside protected areas. Figure 4 illustrates all possible categories.

The left-hand side map displays the municipalities considered to analyze the impact of the deregulation on homicide rates. The black-shaded municipalities represent those exposed to illegal gold mining (i.e., treated units), while the grey-shaded ones have gold deposits outside protected areas (i.e., control units). Municipalities in white do not have any known gold deposits.

On the right-hand side map, we zoom in on the municipality of *Canaã dos Carajás* in the state of Pará. This outlines treated and control units at the 3x3-kilometer cell level, used for assessing the effects of the deregulation on deforestation.

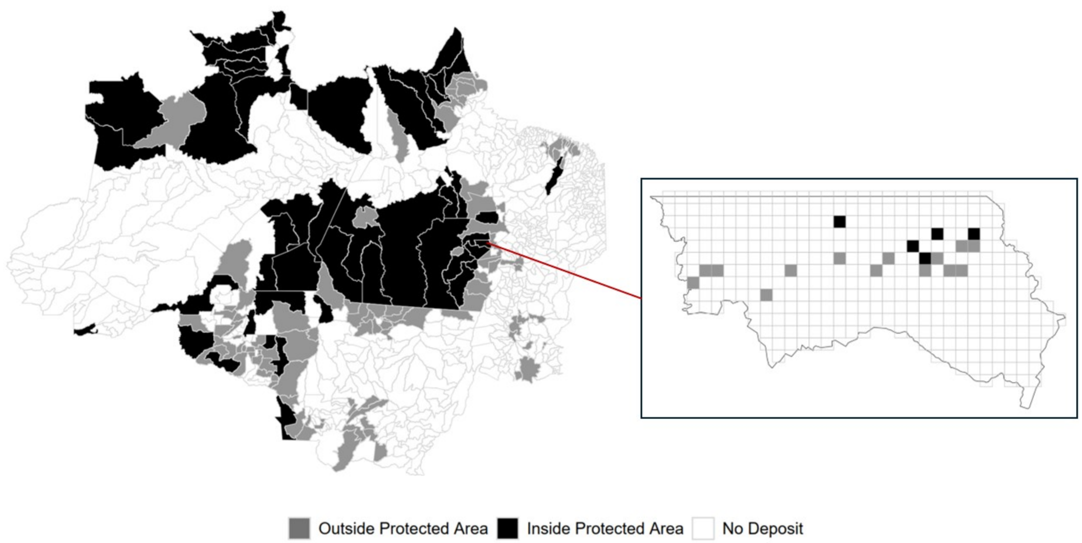

Figure 4: Exposure to Illegal Gold Mining in Municipalities and Grid Cells

Notes: Figure shows municipalities with gold deposits inside/outside protected areas on the left-hand side. On the right-hand side, it shows the municipality of *Canaã dos Carajás* in the state of Pará as an example, outlining its 3x3-kilometer grid cells with gold deposits inside/outside protected areas. *Sources:* Serviço Geológico do Brasil (2021); Fundação Nacional do Índio - FUNAI (2021); Ministério do Meio Ambiente (2021)

One additional point about illegal mining is that it does not necessarily occur only inside protected areas.[17] Mining can also be deemed illegal if miners lack proper permits to operate,

[17]Overlapping the polygons of protected areas with a map depicting illegal mining sites created by the RAISG suggests that illegal mining predominantly occurs within those areas. This initiative, arising from collaboration among civil society organizations in Amazonian countries, analyzed satellite imagery, data on official police raids against miners, and news pieces to try and map illegal mining operations across the Amazon. However, this database covers only a fraction of all mining operations in the Amazon. More information is available at `https://bit.ly/3K8cYr9`.

regardless of the deposit's location. While our primary results center on illegal mining within protected areas, we also investigate whether the deregulation might have impacted illegal mining outside protected areas.

To conduct this analysis, we incorporate geocoded information regarding the polygons of mining permits into our dataset (Agência Nacional de Mineração, 2022a). When miners request a mining permit from the National Mining Agency, they are required to provide location details and the polygon delineating the intended mining area. Leveraging this information, we identify all gold deposits situated outside protected areas that do not fall within permit polygons and construct measures of exposure to such deposits. This approach aims to capture potential changes in illegal mining occurring *outside* protected areas. To mitigate contamination from the impact of the deregulation on permit requests, we exclusively consider permits requested up until 2012, i.e., prior to the deregulation. Overall, about 60% of gold deposits are outside permit polygons.

Finally, we compute additional measures using data on mineral deposits and protected areas. These primarily serve as controls or independent variables in robustness exercises, which we will explain in more detail when presenting our results. Here, we briefly summarize some of these variables: exposure to illegal mining of other *garimpo* minerals; the share of the area covered by protected areas in each municipality or cell; the share of deposits inside protected areas with respect to the total number of gold deposits in each municipality or cell. This last variable is meant to capture intensive margin effects, since we do not have access to the size or area covered by gold deposits. Table 13 in the Appendix presents a comprehensive overview of all information sources used to construct variables related to mineral deposits and protected areas.

3.2 Deforestation as Measure of Illegal Gold Mining

We wish to identify whether the 2013 deregulation induced more illegal gold mining. However, there is little direct information about this activity. In the absence of official data, we explore the fact that mining is associated with deforestation in the Amazon, constituting an indirect measure to gauge the evolution of gold mining in our sample period (Sonter *et al.*, 2017; Espejo *et al.*, 2018). *Garimpeiros* often have to clear part of the forest surrounding the mining operation to make room for camps, roads, and airstrips. The latter are crucial because access to *garimpos* is hard in the middle of the forest. Small aircraft are often used to transport supplies to *garimpos* as well as to fly raw gold out to first-buyers in urban areas.[18]

[18] The interested reader may find out more about *garimpo* airstrips in a recent newspaper article (Andreoni *et al.*, 2022), which is available at `https://nyti.ms/47JnrDE`. Another news piece shows images of deforestation in

We use deforestation data obtained from high-resolution satellite imagery to capture changes in forest cover associated with gold mining. If the deregulation encouraged more illegal gold mining, we should observe more deforestation close to gold deposits inside protected areas than near gold deposits situated outside protected areas.

One potential challenge is that gold mining causes much less deforestation than cattle raising or agriculture for instance. According to data from INPE, mining activity accounted for only 1% of all deforestation detected since 2015 by Brazil's satellite monitoring program to combat the loss of forest cover.[19] Therefore, using data on total deforestation rather than some measure specific to gold mining will likely suffer from sizeable measurement error and may lead to attenuation bias. However, most data on deforestation either do not differentiate between the causes of this phenomenon or do not cover the years surrounding the deregulation.

We address this data limitation in two ways. First, because deforestation data is geocoded, we can observe geographical units that are much smaller than municipalities — which is our baseline unit for violence outcomes. This allows us to focus on areas that are very close to gold deposits and thus try and capture changes in deforestation that are more likely to be associated with gold mining. Second, we explore novel, processed data from MapBiomas, which rely on machine learning to identify deforestation that was specifically caused by *garimpo* gold mining (MapBiomas Project, 2022).

MapBiomas researchers employed Landsat imagery with a 30-meter resolution (at the Equator) to train an automated classification algorithm, incorporating the locations of established gold mining operations and deposits.[20] They draw information from multiple sources about the location of gold mining deposits and mining operations, including the Brazilian Geological Service, Amazon Network of Georeferenced Socio-Environmental Information (RAISG), Amazon Mining Watch, INPE, and others. They separate *garimpo* from other types of mining operations using data on the location of permitted areas, provided by the National Mining Agency. With these datasets, they can classify areas in their training sample as gold *garimpos*, large-scale gold mining sites, and other categories. Afterwards, based on the deforestation pattern of these areas, they use their algorithm to predict the location of gold *garimpos* in the entire sample of 30-meter cells covering the Brazilian Amazon.

To complement the analysis, we also look at total deforestation data from both MapBiomas

illegal *garimpos* and is available at https://www.bbc.com/portuguese/brasil-49053678.

[19] In 2004, the Brazilian government created a program to detect and combat deforestation in the Amazon called DETER and operated by INPE. It consists of real-time deforestation alerts issued to law enforcement agents who act against illegal deforestation in the Brazilian Amazon. As of 2015, data from DETER started differentiating between types of deforestation, such as the one caused by mining.

[20] Detailed methodology is available at https://bit.ly/3Hpfj0t.

and PRODES (Instituto Nacional de Pesquisas Espaciais, 2020). Both use similar satellites and image resolution, but PRODES is the official deforestation data for Brazil and has been widely used in academic research (Gatti *et al.*, 2021; Villoria *et al.*, 2022; Bragança and Dahis, 2022; Assunção *et al.*, 2023).[21]

To get a manageable sample, we aggregate these fine-grained data in square cells of 3x3 kilometers spanning the Brazilian Amazon. We then add information about protected areas, gold deposits, and other data to create a panel from 2007 to 2019. We start the sample in 2007 due to changes in methodology for PRODES data around this year.

As described previously, we categorize each of these cells according to the presence of gold deposits and whether these are inside or outside protected areas. In the end, we have a panel structure at the grid-cell level to analyze deforestation associated with illegal gold mining as well as total deforestation. Table 14 in the Appendix summarizes the deforestation measures we use and their respective sources.

3.3 Violence

The main hypothesis in this paper is that the 2013 deregulation, by encouraging illegal gold mining, led to violence associated with this activity. Data at the grid-cell level is not available for violence outcomes, so we assess this hypothesis using municipality-level information. Our main dependent variable is the municipal homicide rate (number of homicides per 100,000 inhabitants). We calculate this rate using 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). 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.[22]

Since the early 2000's, violence has surged in the Amazon. From 2006 to 2018, the homicide rate in the region increased by approximately 60%. In contrast, it remained quite stable in other regions of Brazil. Many factors may have contributed to the increasing homicide rate in the Amazon (Soares *et al.*, 2021). For instance, empirical evidence suggests that violence in the region is associated with illegal logging (Chimeli and Soares, 2017),[23] land conflicts (Alston

[21] Different from MapBiomas, PRODES does not rely on automated classification, but rather on visual interpretation of processed satellite imagery.

[22] For precise ICD-10 codes refer to table 15 in the Appendix.

[23] 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 (...)"

et al., 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 also played a relevant role in this trend, especially due to the deregulation in 2013. We focus on municipalities with fewer than 200,000 inhabitants in order to capture the effect of the 2013 deregulation on homicides in remote areas rather than urban violence, which is typically present in large cities. This sample selection removes only 14 out of 769 municipalities in the Amazon. Moreover, only 4 of these municipalities have gold deposits and, among those, only one has a gold deposit located inside protected areas. For the interested reader, we replicate our main analyses with alternative population thresholds, as presented in Appendices D.5 and D.6.

Figure 5 shows that, in 2013, the homicide rate surged in places exposed to illegal gold mining. As defined previously, these are the municipalities with gold deposits inside protected areas (represented by the solid red curve). At the same time, places less exposed to illegal gold mining (i.e., municipalities with gold deposits outside protected areas, represented by the dashed yellow curve) do not observe a similar behavior, even though the historical levels of violence in the two groups were comparable prior to 2013. This pattern suggests that the deregulation may be behind the divergence.

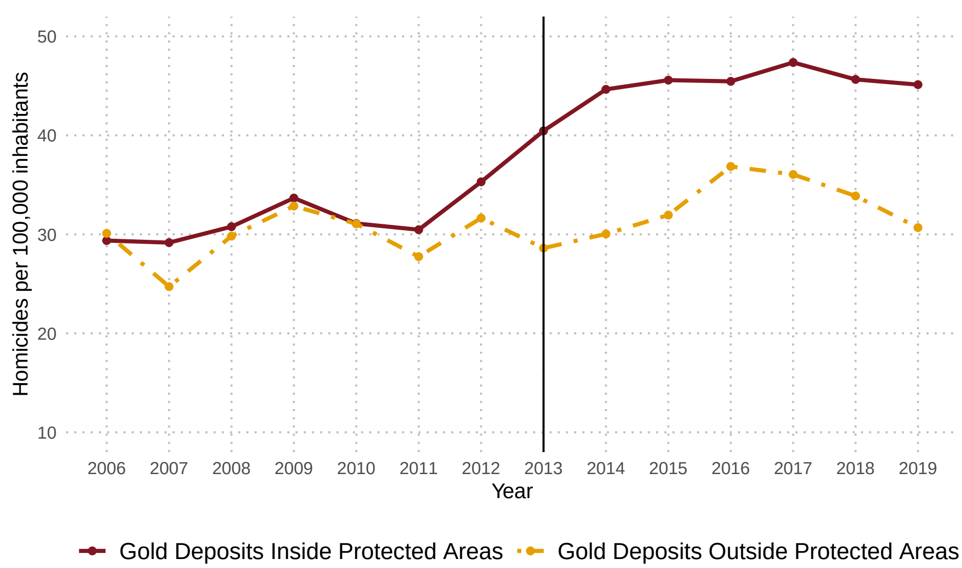

Figure 5: Homicide Rates in Small Municipalities in the Amazon - by Gold Deposits Availability, 2006-2019

Notes: Considering small municipalities as those with fewer than 200,000 inhabitants. *Sources:* Ministério da Saúde do Brasil - DATASUS (2021); Serviço Geológico do Brasil (2021); Fundação Nacional do Índio - FUNAI (2021); Ministério do Meio Ambiente (2021)

We complement the analysis of violence with data extracted from police reports in the state of Pará. This allows us to explore whether the 2013 deregulation had an impact on various forms of crimes, including bodily harm, sexual assault, and robbery. Access to data for these additional crime categories is contingent upon state police department records. Unfortunately, in many Amazon states, there is a lack of systematic organization and dissemination of this data, especially at the municipality-year level. Pará stands out as the sole state that recently made publicly available comprehensive crime records, registered by their police from 2010 to 2019.

Finally, we employ the ICD-10 classification to generate other outcomes and explanatory variables. We do this to address concerns about factors such as population growth contributing to the observed change in violence. Specifically, we examine death rates attributable to suicide, traffic accidents, and common diseases. Additionally, we assess homicide rates involving indeterminate actors or police intervention. To investigate whether violence is linked to land disputes, we compile data from *Comissão Pastoral da Terra* (CPT), a standard data source on land-related conflicts also used in Fetzer and Marden (2017). Details about these variables and their respective sources are provided in Table 15 in the Appendix.

3.4 Other Variables

We also incorporate other variables to control for relevant municipality characteristics that could be associated with both gold mining activity and the escalation of violence. For example, we use annual international gold prices to account for any increase in local income related to gold that could potentially contribute to a rise in violence, as done analogously in Dube and Vargas (2013), Idrobo *et al.* (2014), and Berman *et al.* (2017).

Additionally, we include municipality-level controls such as the municipal area, the proportion of protected areas, GDP per capita, the share of GDP in agriculture, life expectancy at birth, the percentage of individuals over 25 years old who have completed high school, the percentage of the population with access to electricity and sewage, and the distances from the municipality to the nearest road or river. Further details on these variables can be found in Table 16 in the Appendix.

Fewer covariates and alternative variables are available for grid data, since our 3x3-kilometer cells are not official administrative units. In this case, we use share of protected area in cell, share of tree cover in 2000, distance to nearest river or road, and distance to nearest city center.

4 General Empirical Strategy

In this paper, we are mostly interested in understanding what happened to violence associated with illegal gold mining after the deregulation. According to our hypothesis, the deregulation dismantled a decentralized monitoring system against illegal gold mining, which should stimulate this activity and foster conflict linked to it.

To test this hypothesis, we divide our study into two main steps. First, we estimate the effect of the deregulation on illegal gold mining, which is proxied by the deforested area associated with gold *garimpo*. Then, we estimate the deregulation's impact on violence, which is measured by homicide rates. In the first case, our sample comprises grid cells covering the Amazon from 2007 to 2019.[24] In the second case, our sample comprises municipalities in the Amazon from 2006 to 2019. Because the units of analysis are different, we split our results in two parts: first, we show the effect on deforested area at the cell level; then, we show the effect on violence at the municipal level.

To estimate the effect of the deregulation in both cases, we employ a Difference-in-Differences model with very similar features. We define 2013 as the first period of treatment. As explained in Section 2.2, the deregulation was enacted in July 2013 but it had been in the political arena at least since early 2013. Moreover, we believe gold producers and financial institutions immediately adapted their operations following the deregulation, given their intensive lobbying efforts to secure its approval.

Treated units are either cells or municipalities with gold deposits inside protected areas, while control units have gold deposits only outside protected areas. We also include units without gold deposits to help increase precision. Nevertheless, we estimate models both including and excluding these units without deposits, with results differing very little, as we will discuss later.

The timing of the deregulation is the same for all units. Hence, identification mainly hinges on whether illegal gold mining and violence would have evolved similarly in the absence of the deregulation in both treated and control groups — i.e., places with gold deposits inside and outside protected areas, respectively.

Although we cannot test this assumption, we argue that it should hold. Even if the decision of *garimpeiros* on where to mine is endogenous, the exposure to — or potential for — both legal and illegal gold mining is determined by the geological distribution of deposits across the Amazon. We also rely on the fact that protected areas do not seem to be created taking into

[24] As mentioned earlier, we start this analysis in 2007 due to methodological changes in deforestation data from PRODES.

consideration the location of gold deposits. As mentioned before, on the one hand, almost all known deposits inside protected areas were registered before 2006 and, thus, prior to the start of our sample period. On the other hand, the creation of protected areas 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 defined before our sample period, mainly in the 1990's and the beginning of the 2000's.[25]

Hence, the deregulation in 2013 should produce a plausibly exogenous variation on illegal gold mining and violence across units with gold deposits inside protected areas, which are naturally more exposed to illegal gold mining. We estimate these effects with the empirical model in Equation 1 below.

$$Y_{it} = \beta_1 IGD_i * D_{t\geq 2013} + \beta_2 GD_i * D_{t\geq 2013} + X'_{it}\rho + \theta_i + \mu_t + \varepsilon_{it} \tag{1}$$

Such that Y_{it} represents either the cell-level deforested area associated with gold *garimpo* (measured as a proportion of the area of the cell) or municipal-level homicide rate; GD_i stands for Gold Deposits and it is a dummy variable indicating whether unit i (either the cell or the municipality) has any gold deposits; IGD_i stands for Illegal Gold Deposits and it is a dummy indicating whether i has any gold deposit located inside protected areas; $D_{t\geq 2013}$ is a dummy indicating the period after the deregulation; θ_i and μ_t are unit and year fixed effects, respectively; and X_{it} is a vector of covariates. Because we have cell-level and municipal-level data, covariates will differ across the analyses. Some of them, however, are common, such as the distance to the nearest roads or rivers and the share of protected areas covering each cell and municipality. For the sake of clarity, we leave further details about covariates to the sections dedicated to each estimation.

We are interested in β_1, the coefficient of $IGD_i * D_{t\geq 2013}$. This is the same coefficient that one would obtain by replacing $IGD_i * D_{t\geq 2013}$ with the triple interaction $GD_i * IGD_i * D_{t\geq 2013}$ because of collinearity. Whenever $IGD_i = 1$, $GD_i = 1$, i.e., units that have gold deposits inside protected areas must have at least one gold deposit in general.

Hence, β_1 captures the differential effect of the deregulation for units more exposed to illegal gold mining ($IGD_i = 1$) compared with less exposed ones ($GD_i = 1$ and $IGD_i = 0$). In other words, the treated group is composed of units with gold deposits inside protected areas. The control group consists of units with gold deposits outside protected areas. Units without gold deposits, although in the sample, are not in either group.

[25] In 2006, respectively, 90% and 80% of the Indigenous Lands and Conservation Areas already existed. In any case, we also run tests considering only deposits and protected areas created up to 2006.

The same effect can be estimated with a sample restricted only to units with gold deposits. That is, we could eliminate units without deposits, in which there should be little exposure to gold mining, legal or illegal. This may sound more natural, but it comes at the cost of less precision in estimating the coefficients. Throughout the paper, we provide results for both cases: a full sample with all units available; a sub-sample only with units that have gold deposits, i.e., such that $GD_i = 1$ always.[26]

We expect β_1 to be statistically different from zero and **positive**, i.e., the deregulation should cause both deforestation associated with gold mining and violence to increase in places more exposed to illegal gold mining (with $IGD_i = 1$) versus places less exposed (with $IGD_i = 0$ and $GD_i = 1$).

To see dynamic effects, we also estimate Equation 2, with $S = \{2007, ..., 2019\}$ in the cell-level analysis or $S = \{2006, ..., 2019\}$ in the municipality-level analysis.

$$
\begin{aligned}
Y_{it} = & \sum_{s \neq 2012}^{s \in S} \lambda_s IGD_i * 1\{s = t\} + \\
& + \sum_{s \neq 2012}^{s \in S} \psi_s GD_i * 1\{s = t\} + X_{it}' \phi + \theta_i + \varepsilon_{it}
\end{aligned}
\tag{2}
$$

In Equation 2, we are interested in all the estimates for λ_s and we expect them to be positive. Moreover, this allows us to investigate potential pre-trends.

One important aspect of our empirical strategy is that protected areas, which define our treatment, are also related to deforestation dynamics. As we detail in Section 5, protected areas may substantially deter deforestation. Moreover, because cells with $IGD_i = 1$ necessarily have protected areas, it is more likely that a larger share of their territory will be under protection. In this case, the parallel trends assumption can only be satisfied by conditioning on the share of protected areas.

One alternative for incorporating this conditional parallel trends assumption involves estimating Equations 1 and 2 with a simple two-way fixed-effects regression, including the share of protected areas interacted with time dummies as covariates. However, this alternative requires deforestation trends to be linear functions of the share of protected areas to produce consistent estimates. This may not hold if, for instance, the marginal returns of the share of protected areas

[26] If $GD_i = 1$ for all units, we estimate the following equation:

$$Y_{it} = \beta_1 IGD_i * D_{t \geq 2013} + X_{it}' \rho + \theta_i + \mu_t + \varepsilon_{it}$$

in curbing deforestation are decreasing.

To allow for a more flexible empirical model, when examining deforestation, we employ a weighted regression using the Doubly-Robust Difference-in-Differences method proposed in Sant'Anna and Zhao (2020). This method is called Doubly Robust because it combines an Outcome Regression (OR) strategy, as in Heckman *et al.* (1997), with an Inverse Probability Weighting (IPW) strategy (Abadie, 2005). By combining these two strategies, the Doubly Robust approach allows us to relax the consistency condition outlined earlier. Having specified either the IPW or the OR correctly is sufficient for estimates to be consistent. Moreover, if both the IPW and OR specifications are correct, then the DRDID also provides more efficient estimates than the two-way fixed effects model.

For homicide rates at the municipal level, the influence of protected areas is less of an issue. Although they could affect land conflicts, for instance, protected areas cover a much smaller area of municipalities than cells, in relative terms. Moreover, the Sant'Anna and Zhao (2020) method does not allow for heterogeneity analyses, which are an important part of our investigation of the effect of the deregulation on violence. Nonetheless, to mitigate potential concerns, we show in Section 6 that our main results for homicides do not change substantially when estimated based on Sant'Anna and Zhao (2020).

In the next two sections, we provide descriptive statistics, discuss the inclusion of covariates, and show results for both the cell-level and the municipality-level analyses separately.

5 Area Deforested by Gold *Garimpo* at Cell Level

5.1 Descriptive Statistics for Cell-Level Data

First, we analyze the evolution of illegal gold mining following the deregulation. The intuition for this is that miners typically clear some forest areas around deposits to install their operations. To measure the presence of gold mining, we leverage data on deforestation associated with gold *garimpo*. This is calculated by MapBiomas, relying on high-resolution satellite data and a predictive algorithm that detects gold *garimpo* sites based on known operations.

Our units of analysis are 3x3-kilometer grid cells spanning the entire Amazon. Our main dependent variable is the proportion of the area of each cell that was deforested by gold *garimpo* from 2007 to 2019. This area can increase or shrink over the years, depending on whether trees are cut down faster than the forest regenerates.[27]

[27] Another potential measure is the deforestation rate, which is the incremental deforested area every year. The use of this measure is problematic, however, because deforestation is persistent. Large losses of forest cover in one

Table 1 shows descriptive statistics for variables used in this analysis as of 2012, the year prior to the deregulation. The table shows three categories of cells: without gold deposits (*Without Deposits*), such that $GD_i = 0$; with gold deposits outside protected areas (*Deposits Outside P.A.*), such that $GD_i = 1$ and $IGD_i = 0$; and with gold deposits inside protected areas (*Deposits Inside P.A.*), such that $GD_i = 1$ and $IGD_i = 1$.

	Without Deposits	**Deposits Outside P.A.**	**Deposits Inside P.A.**
Number of Cells	568,402	1,451	422
	(s.e.)	(s.e.)	(s.e.)
Distance to Nearest Road (km)	65.551	45.721	112.150
	(61.602)	(44.286)	(70.863)
Distance to Nearest Waterway (km)	62.053	63.277	146.503
	(58.580)	(48.968)	(102.147)
Distance to Nearest City Center (km)	73.884	53.357	174.694
	(62.816)	(47.340)	(90.319)
Share of Protected Areas	0.331	0.015	0.963
	(0.462)	(0.086)	(0.131)
Share of PRODES Deforestation in 2007	0.142	0.384	0.017
	(0.291)	(0.392)	(0.065)
Share of Tree Cover in 2000 (Hansen et al. 2013)	0.772	0.703	0.918
	(0.319)	(0.314)	(0.224)
Deforestation by Gold Garimpo (sq. km) - MapBiomas	0.000	0.089	0.022
	(0.017)	(0.321)	(0.231)
Total Deforestation (sq. km) - MapBiomas	2.924	4.053	0.927
	(3.552)	(3.425)	(2.315)
Total Deforestation (sq. km) - PRODES	1.348	3.608	0.177
	(2.686)	(3.549)	(0.671)

Notes: Table shows means and standard errors (in parenthesis) for multiple variables in 2012. We use 2012 instead of pre-period because variables are either stocks or constant. 'Without Deposits' are all cells without gold deposits. 'Deposits Outside P.A.' refers to cells with at least one gold deposit, but none inside protected areas. 'Deposits Inside P.A.' refers to all cells in which at least one gold deposit is inside a protected area. Unit of observation is a 3x3-kilometer grid cell in the Amazon.

Table 1: Descriptive Statistics of 3x3-kilometer cells in the Brazilian Amazon According to Presence and Location of Gold Deposits, 2012

Cells with deposits *inside* protected areas have baseline differences compared with the other groups. As anticipated in the previous section, this is somewhat expected. The existence of protected areas both helps defining our treatment group and is associated with distance to transportation networks and deforestation (Soares-Filho *et al.*, 2010; Andam *et al.*, 2008). Not surprisingly, cells more exposed to illegal gold mining are further away from roads, rivers, and city centers. Moreover, their forest cover is better preserved than other cells. Finally, they almost mechanically have a larger share of protected areas within their territory.

year impact the area subject to deforestation in subsequent years. For instance, if a given cell loses all its trees in one year, there is nothing left to be deforested in the following years.

The fact that protected areas can have a negative effect on the level and evolution of deforestation — and therefore on our measure of illegal gold mining — is key. As we have seen before, these protected areas are likely not endogenously related to the existence of gold deposits. Nonetheless, they can still affect the trend of deforestation in each group of cells. In particular, failing to account for the share of protected areas in our model can lead to a negative bias in our estimates, since deforestation is likely to increase much less in cells with large portions of land under protection.

As discussed earlier, we address this issue by running the conditional version of the multi-period Difference-in-Differences model based on the Doubly-Robust approach described in Sant'Anna and Zhao (2020). The intuition for the coefficients estimated with this method is very similar to that of a regular Difference-in-Differences model. However, instead of running a two-way fixed-effects specification with controls, we run a weighted regression in which weights are calculated based on pre-period covariate levels — as in an IPW strategy (Abadie, 2005).

With the Doubly Robust estimator, we can obtain consistent estimates for the effect of the deregulation while considering more flexible assumptions about the relationship between the dynamics of deforestation and the share of protected areas. Moreover, this approach can also be more efficient than the two-way fixed effects regression if both the IPW and Outcome Regression models are correctly specified. Besides conditioning on the share of protected areas, we also include the following covariates: share of tree cover in 2000; log of distance to nearest road or river plus one; log of distance to nearest city center plus one.

5.2 Results

Table 2 presents the estimated Difference-in-Differences coefficients for the two samples we have explained in Section 4. Columns (1)-(3) present estimates using the entire sample of cells, regardless of whether they contain gold deposits. In this case, we include the presence of any gold deposit, i.e., GD_i, as a covariate. Hence, results are conditional on exposure to gold mining. Alternatively, in Columns (4)-(6), instead of conditioning on the existence of gold deposits, we simply restrict the sample only to cells that contain such deposits. That is, we only include cells for which $GD_i = 1$. Errors are clustered at cell and municipal level to account for serial and spatial correlation.[28]

In Column (1), we only control for gold deposits, cell and year fixed effects. In Column (4),

[28] We also allow for spatial correlation following Conley (1999). These results are shown in Table 1 in the Appendix.

Table 2: Effect of Deregulation on Gold Garimpo Deforestation (MapBiomas) in 3x3-km Grid Cells Exposed to Illegal Gold Mining, from 2007 to 2019

	Full Sample			Cells with Gold		
	(1)	(2)	(3)	(4)	(5)	(6)
IGD × $I(Year \geq 2013)$	-0.256	0.107	0.114	-0.256	0.158	0.214
	(0.094)	(0.058)	(0.063)	(0.060)	(0.059)	(0.099)
Cell and Year FEs	Yes	Yes	Yes	Yes	Yes	Yes
Share of Protected Areas		Yes	Yes		Yes	Yes
All Covariates			Yes			Yes
Observations	7,413,575	7,413,575	7,413,575	24,349	24,349	24,349
# Cell FE	570,275	570,275	570,275	1,873	1,873	1,873
# Year FE	13	13	13	13	13	13

Notes: All errors are clustered at cell and municipal levels to allow for serial and spatial correlation. In Columns (1)-(3), sample includes all cells, regardless of the existence of gold deposits. In Column (1)-(3), all specifications control for the presence of at least one gold deposit. In Columns (4)-(6), sample only includes cells with gold deposits. Columns (1) and (4) are the unconditional models. Column (2) and (5) control for the share of protected areas in grid cell. Columns (3) and (6) include the following covariates: share of protected areas in grid cell, share of tree coverage from Hansen et al (2013), log of distance to nearest road or waterway plus one, and log of distance to nearest city center plus one.

since this is the restricted sample, we only include cell and year fixed effects. In both cases, we see a negative coefficient for the treatment variable. This is expected, since we are ignoring the deterring effect of protected areas on deforestation. Given that illegal gold deposits are defined based on their location inside protected areas, it is reasonable that the deforested area increases less in the treated group. This is not only true for deforestation associated with gold *garimpo*, but also for total deforestation, measured either by PRODES or MapBiomas, as shown in Columns (1) and (4) of Tables 2 and 3 in the Appendix.

Once we run the Difference-in-Differences conditional on the share of protected areas in each cell, presented in Columns (2) and (5), we account for its deterring effect on deforestation. As a result, coefficients change substantially, and now we find that deforestation associated with gold *garimpo* increases significantly after the deregulation in 2013. Columns (3) and (6) show that estimates are robust to including other covariates such as the share of tree coverage, the log of distances to the nearest road or river, and the log of distance to the nearest city center. Among cells with gold deposits, those exposed to illegal gold mining experience a 0.21 percentage point increase in the proportion of deforested area associated with gold *garimpo* after the deregulation.

Although apparently small, the effect corresponds to almost doubling the pre-treatment average proportion of deforested area associated with gold *garimpo* in exposed cells (with gold deposits inside protected areas).

Furthermore, in Appendix Tables 2 and 3, we observe that the effect on total deforestation[29] becomes virtually zero once we account for all covariates. This is also reasonable, because gold mining is responsible for a very small proportion of the deforested area in the Amazon. Therefore, we expect substantial attenuation bias when using total deforestation as the dependent variable instead of deforestation specifically associated with gold *garimpo*.

Figure 6 shows the dynamic effect for Columns (3) and (6) of Table 2. The proportion of deforested area associated with gold *garimpo* in each cell increases already in 2013, expanding gradually afterwards.[30] This indicates that the response of illegal gold mining to the deregulation was fast, which is consistent with the piece of descriptive evidence on gold laundering presented in Figure 1.

Additionally, Figure 9 in the Appendix shows that our conclusions are robust to changing the size of cells. Moreover, it seems that the effect on gold *garimpo* deforestation grows larger as we use more precise — smaller — cells.

We also analyze the extensive margin effect of the deregulation in Appendix Table 4. The results point in the same direction as intensive margin estimates but are less precise. This may suggest that *garimpeiros* are not opening new fronts of deforestation but instead expanding existing ones. In such a scenario, the dispute associated with illegal gold mining would arise from a higher concentration of *garimpeiros* around existing *garimpos*, rather than being caused by a race towards new locations.

Finally, the deregulation may also have affected illegal mining that happens outside protected areas. This is the case of *garimpeiros* who work without permits in places that are, in principle, available for mining. We believe this should not significantly impact our conclusions. If there is an increase in illegal gold mining in cells with gold deposits outside protected areas but lacking valid permits, our baseline estimates would be underestimating the true deforestation resulting from the deregulation.

Nevertheless, we test this conjecture using geocoded data on mining permits' polygons, which miners inform as part of the permit application process. We identify all deposits outside protected areas that are not inside permitted polygons and create measures of exposure to such

[29] Analogously as before, the dependent variable is the proportion of total deforested area in each cell.

[30] One may notice that standard errors grow over the years. This occurs because our outcome variable reflects the stock of deforested area within each cell. Therefore, the extent of deforestation in a cell over one year is contingent on what was cleared in the preceding years.

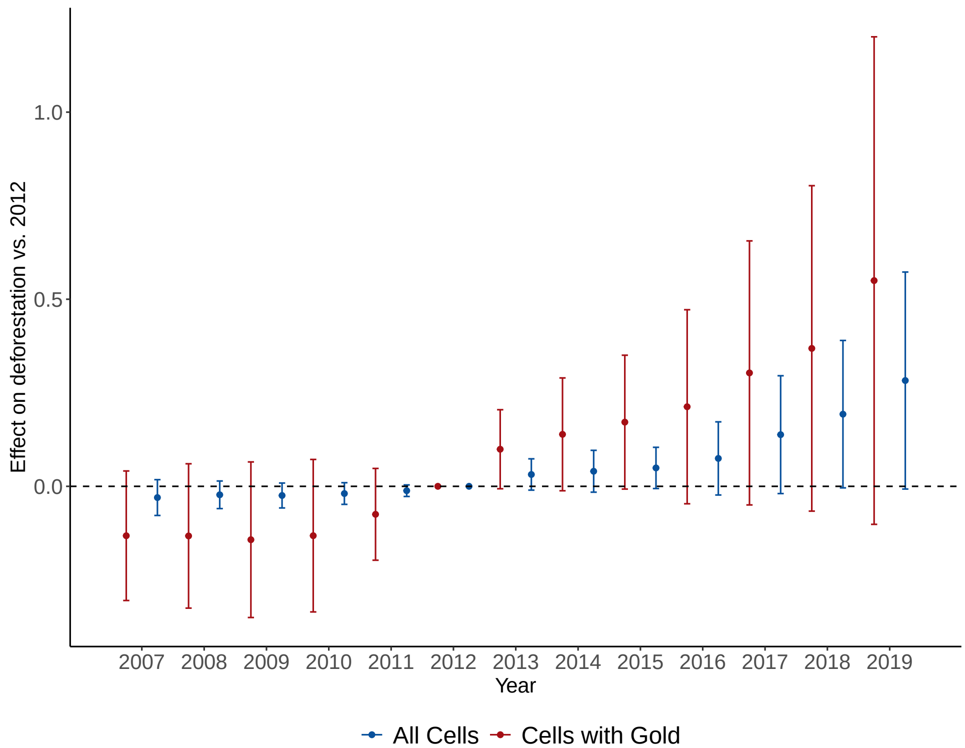

Figure 6: Average Difference in Gold *Garimpo* Deforestation (MapBiomas) between Cells More and Less Exposed to Illegal Gold Mining - Full Set of Controls (95% c.i.)

deposits. This should capture potential changes in illegal mining *outside* protected areas. To avoid contamination from the effect of the deregulation on permits, we only consider permits requested until 2012, i.e., prior to the shock.

Table 3 summarizes our findings. Column (1) presents our baseline results with IGD_i as the treatment indicator. In Column (2), we run a specification defining treated cells as the ones containing deposits outside permit polygons. As before, the effect is conditional on having at least one gold deposit. Column (3) repeats the exercise in (2), but excludes cells that have both a deposit inside protected areas and a deposit outside permit polygons. This is meant to remove contamination from cells with deposits inside protected areas (our main exposure variable).[31]

Overall, the deregulation has no significant effect on illegal mining outside protected areas. We only see a positive and significant effect on deforestation associated with gold *garimpo* for cells with deposits inside protected areas.

Combined, these pieces of evidence indicate that illegal gold mining inside protected areas

[31] We do this restriction as an alternative to running interactions, which are not available for the Doubly Robust method in Sant'Anna and Zhao (2020).

Table 3: Heterogenous Effect of Deregulation on Gold Garimpo Deforestation (MapBiomas) and the Availability of Gold Deposits Outside Protected Areas as of 2012, with 3x3-km Grid Cells, from 2007 to 2019

	Full Sample			Cells with Gold		
	(1)	(2)	(3)	(4)	(5)	(6)
IGD $\times$ $I(Year \geq 2013)$	0.114			0.214		
	(0.057)			(0.104)		
No Permit $\times$ $I(Year \geq 2013)$		0.023	-0.035		0.026	-0.033
		(0.101)	(0.166)		(0.058)	(0.073)
Cell and Year FEs	Yes	Yes	Yes	Yes	Yes	Yes
Share of Protected Areas	Yes	Yes	Yes	Yes	Yes	Yes
All Covariates	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7,413,575	7,413,575	7,408,089	24,349	24,349	18,863
# Cell FE	570,275	570,275	569,853	1,873	1,873	1,451
# Year FE	13	13	13	13	13	13

Notes: All errors are clustered at cell and municipality levels. Columns (1) and (4) present baseline estimates. Columns (2) and (5) consider cells as treated if they have at least one gold deposit without permit. Columns (3) and (6) repeats (2) and (4), but the sample excludes cells with gold deposits inside protected areas.

quickly expanded after the deregulation in 2013. Based on this, we now turn to the main analysis and see how violence is affected by the deregulation in locations more exposed to illegal gold *garimpo* inside protected areas.

6 Violence at Municipal Level

6.1 Descriptive Statistics for Municipal-Level Data

Table 4 shows descriptive statistics for all variables used in the municipal-level analysis. We split the sample into three groups of municipalities: without gold deposits (*Without Deposits*), such that $GD_i = 0$; with gold deposits outside protected areas (*Deposits Outside P.A.*), such that $GD_i = 1$ and $IGD_i = 0$; and with gold deposits inside protected areas (*Deposits Inside P.A.*), such that $GD_i = 1$ and $IGD_i = 1$.

In some dimensions, such as the homicide rate, municipalities with gold deposits inside and outside protected areas are more comparable. Nonetheless, there are still some baseline differences in many covariates. To account for potential issues arising from these differences,

	Without Deposits	Deposits Outside P.A.	Deposits Inside P.A.
Observations	612	96	47
Population ('000)	20.3	22.5	31.2
	(23.5)	(21.4)	(31.5)
Homicide Rate	15.5	23.3	26.5
	(19.7)	(22.4)	(27.1)
GDP per capita ('000 BRL)	14.1	15.7	18.7
	(15.3)	(7.3)	(23.0)
% agricultural GDP	26.9	23.5	18.6
	(14.7)	(12.8)	(16.2)
Area ('000 km2)	4.6	6.5	32.3
	(8.6)	(8.5)	(35.2)
Sh. Protected Area	0.1	0.1	0.5
	(0.2)	(0.2)	(0.3)
Other Deaths Rates	23.3	27.3	25.0
	(30.0)	(41.5)	(22.1)
Unemployment	0.1	0.1	0.1
	(0.1)	(0.1)	(0.1)
Highschool Compl. Rate	0.1	0.1	0.1
	(0.0)	(0.0)	(0.1)
Life Expectancy	65.6	67.0	67.6
	(3.2)	(2.3)	(2.1)
Electricity	0.7	0.7	0.6
	(0.2)	(0.2)	(0.2)
Sewage	0.3	0.4	0.4
	(0.2)	(0.2)	(0.2)
Dist. Road (km)	32.8	23.4	31.2
	(46.2)	(34.5)	(44.1)
Dist. River (km)	33.2	47.6	42.6
	(36.5)	(37.9)	(55.2)

Notes: Table shows means and standard errors (in parenthesis) for multiple variables between 2006 and 2012 (pre-period) in municipalities with less than 200,000 people. GDP per capita is measured in 2019 prices. Other Deaths are suicides and deaths in traffic. 'Without Deposits' are all municipalities without gold deposits. 'Deposits Outside P.A.' refers to municipalities with at least one gold deposit, but none inside protected areas. 'Deposits Inside P.A.' refers to all municipalities in which at least one gold deposit is inside a protected area. Variables are at the municipality-year level.

Table 4: Descriptive Statistics of Brazilian Amazon Municipalities According to Presence and Location of Gold Deposits, 2006-2012

our preferred specification will include the following covariates: log of real gold price, log of municipal GDP per capita, share of agriculture in GDP, log of municipal area, share of protected areas, suicide rate, death by traffic accidents rate, unemployment rate, high school completion rate, log of life expectancy at birth, access to electricity and sewage, log of distance to the nearest road plus one, and log of distance to the nearest waterway plus one.[32]

For all covariates, except gold prices, we interact their fixed level prior to our sample period with year fixed effects instead of using their contemporaneous levels.[33] We do this to avoid bias arising from outcome and covariates possibly 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.

In the case of real gold prices, we leverage the fact that they are exogenously determined by the global market. This feature has been explored in previous work estimating the effect of commodity prices on violence (Dube and Vargas, 2013; Idrobo *et al.*, 2014; Berman *et al.*, 2017). In our context, we interact gold prices with the indicators *GD* and *IGD* to control for their potentially different impact on violence across municipalities with gold deposits inside and outside protected areas.

Finally, we add state-specific time dummies to mitigate concerns about omitted variable bias caused by gold deposits and protected areas being spatially concentrated in a few regions. 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.[34]

6.2 Benchmark Results

Table 5 reports estimates for β_1 and β_2 from Equation 1. 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 with gold deposits inside protected areas (i.e., those exposed to illegal gold mining), compared to municipalities with gold deposits outside protected areas. Columns (1) to (3) present the results considering the full sample of municipalities with less than 200,000 inhabitants.[35] Columns (4) to (6) show the results for the subset of municipalities

[32] Table 16 in the Appendix presents additional information on data sources for those variables.

[33] The log of municipal GDP per capita, and the share of agriculture in GDP are measured in 2005. The other variables come from the 2000 Census.

[34] Once state-specific fixed effects are added, year fixed effects must be removed due to collinearity.

[35] As mentioned previously, we select the sample of municipalities with less than 200,000 inhabitants to clean our effects from urban violence in large cities. Appendix D.5 shows that all the results are robust when considering the full sample of municipalities. Furthermore, Table 12 demonstrates that the benchmark results remain robust even when using different population thresholds to subset the sample, such as 50,000 and 100,000 inhabitants.

with at least one gold deposit. Columns (1) and (4) control only for municipality and year fixed effects; Columns (2) and (5) add state-year fixed effects; and Columns (3) and (6) include all covariates described in the previous subsection. To address potential spatial correlation, we compute standard errors based on Conley (1999) with a distance threshold of 100 kilometers, as in Carreira *et al.* (2024), who study an analogous context.[36]

Table 5: Effect of Deregulation on Homicide Rates in Municipalities Exposed to Illegal Gold Mining, from 2006 to 2019

	Homicide Rate					
	Full Sample			Munic. with Gold		
Model:	(1)	(2)	(3)	(4)	(5)	(6)
Illegal Gold Deposits $\times$ $I(Year \geq 2013)$	12.0	8.7	10.9	12.0	10.3	14.7
	(3.5)	(2.9)	(2.4)	(3.5)	(3.2)	(2.8)
Any Gold Deposit $\times$ $I(Year \geq 2013)$	-3.3	-0.30	0.25			
	(1.4)	(1.6)	(1.6)			
Munic FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE (14)	Yes			Yes		
State-Year FE (126)		Yes	Yes		Yes	Yes
Covariates*Year			Yes			Yes
# Munic FE	755	755	755	143	143	143
Observations	10,570	10,570	10,570	2,002	2,002	2,002
R^2	0.45	0.46	0.47	0.49	0.53	0.58
Within R^2	0.005	0.003	0.02	0.02	0.01	0.10

Notes: Municipalities with less than 200,000 people. Standard errors computed as in Conley (1999) with distance threshold of 100 kilometers. Covariates include the following: log of real gold prices; log of GDP per capita in 2005, share of agricultural GDP in 2005, log of municipal area, share of protected areas in municipality, rate of suicides and deaths in traffic, unemployment rate in 2000, highschool completion rate in 2000, log of life expectancy in 2000, access to electricity and sewage in 2000, log of distance to nearest road plus one, and log of distance to nearest waterway plus one. Gold prices are interacted with dummies GD and IGD, whereas other covariates are interacted with year fixed effecs.

Overall, the table shows that, after the deregulation, municipalities more exposed to illegal gold mining experienced an increase of 10.9 homicides per 100,000 inhabitants compared with municipalities exposed to gold mining outside protected areas. These estimates are robust to including state-year fixed effects and other controls. When restricting the sample to municipalities

[36] Appendix Figure 11 presents robustness tests to alternative distance thresholds.

with gold deposits, we observe that estimates in columns (1) and (4) look identical. This is expected because, if fixed effects were absent, the pointwise estimates for the treatment effects in the two columns should be exactly the same. As mentioned before, by including municipalities without gold deposits, we are only improving the precision of our estimates. Moreover, once we add state-year fixed effects and covariates interacted with year fixed effects, the estimated coefficient becomes slightly stronger in the more restricted sample (Column 6).

The magnitude of these effects is quite high. The additional violence generated by the deregulation corresponds to almost three times the average homicide rate in Europe (UNODC, 2020) and to approximately 30% of the average homicide rate observed in municipalities exposed to illegal gold mining prior to 2013.

As expected, the results are not driven by municipalities exposed to legal gold mining. The coefficient of the interaction between *Any Gold Deposit* and $I(Year \geq 2013)$ suggests that municipalities with gold deposits outside protected areas — such that $GD = 1$ and $IGD = 0$ — observe no change in violence compared to municipalities without gold deposits.[37] This could be linked to increasing income in gold mining regions or related to the effect of other covariates, since significance fades away when we include state-year fixed effects.

Next, we use an event study framework to estimate the main coefficient for each year. This is important both to verify the plausibility of the parallel trends assumption and to analyze the persistence of the estimated effect over the entire post-period. Figure 7 shows the yearly effects on the homicide rate based on the specifications presented in Columns (3) and (6) of Table 5.

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 point estimates 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, which is consistent with results for deforestation.

Our findings remain valid when assuming that parallel trends only hold conditional on predetermined covariates. Appendix Table 2 and Figure 10 present results using the Doubly Robust methodology proposed in Sant'Anna and Zhao (2020). As opposed to the case of deforestation, using this more complex approach changes very little the coefficients. This indicates that, when examining homicides, both treated and control municipalities show parallel trends regardless of conditioning on covariates. As such, we continue to use the simpler version of the Difference-in-

[37] Table 1 in the Appendix shows the average effect for all municipalities with at least one gold deposit, regardless of whether it is inside a protected area or not. As expected, we find a smaller effect, since this specification mixes exposure to legal and illegal gold mining.

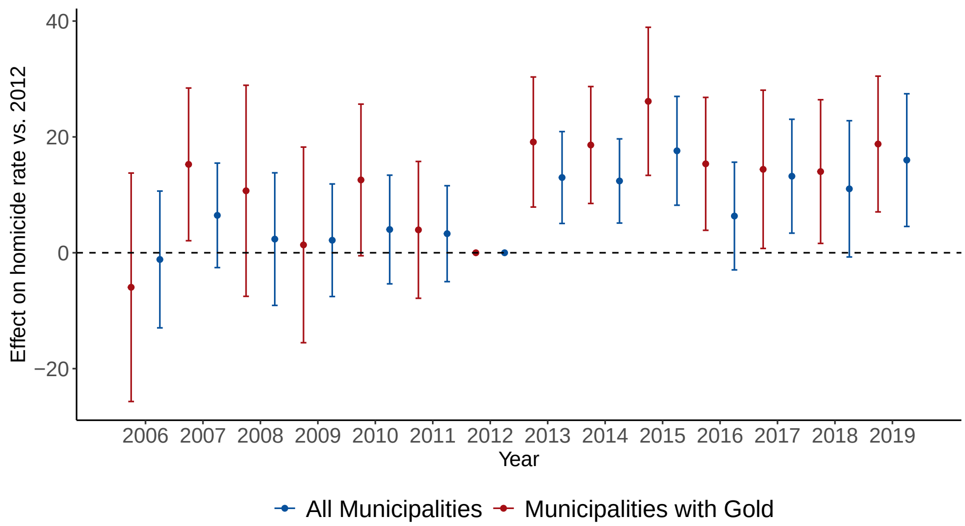

Figure 7: Average Difference in Homicide Rates Between Municipalities More and Less Exposed to Illegal Gold Mining, with Full Set of Controls (95% c.i.)

Notes: Considering the sample of municipalities with less than 200,000 people. Standard errors computed as in Conley (1999) with distance threshold of 100 kilometers to account for spatial correlation.

Differences model, which grants us more flexibility to explore interactions and heterogeneities.

To uncover nuances of the growing trend in violence, we decompose the homicide rate into different types of homicides and by victims' characteristics. Table 6 summarizes our findings for the full sample, including municipalities with and without gold deposits. Results for the sub-sample are in Appendix Table 13.

Column (1) presents our baseline results. In Columns (2) and (3), we restrict the analysis to male homicides and then to homicides of men aged 20–49. Columns (4) and (5) present the estimated effect on homicides of men whose deaths happened either at home or not. Column (6) displays estimates for homicides caused by firearms, knives, or other cutting weapons. Column (7) shows the effect on homicides motivated by land conflicts. Column (8) gives the estimate for deaths caused by law enforcement agents. Finally, Column (9) shows the effect on deaths by indeterminate causes, which may also reflect deaths caused by law enforcement agents.[38]

Table 6 shows that 80% of the total effect on homicides is driven by male homicides. Analogously, 70% of the effect is attributable to homicides outside of home and 72% to homicides caused by firearms, knives, and other cutting weapons. Furthermore, the rather small and non-significant estimate in Column (7) suggests that the effect is not driven by an increase in land conflicts, which are a typical concern in the Amazon region.[39] Columns (8) and (9) further

[38]Table 15 provides information on the ICD-10 codes and the sources of the variables utilized in this analysis.

[39]The CPT dependent variable indicates municipalities that registered deaths due to land conflicts according to

Table 6: Decomposition of Effect of Deregulation on Homicide Rates in Municipalities Exposed to Illegal Gold Mining, from 2006 to 2019

	Total	Homicide Rate - Men					Other Homicides		
	Homicide Rate	Men	Men 20-49	Men At Home	Men Out of Home	Firearm or Knife	CPT	Police	Indet.
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Illegal Gold Deposits × $I(Year \geq 2013)$	10.9	9.1	4.8	0.50	8.6	8.4	0.03	0.13	0.98
	(2.4)	(2.2)	(1.7)	(0.93)	(2.0)	(2.1)	(0.04)	(0.13)	(1.0)
Any Gold Deposit × $I(Year \geq 2013)$	0.25	0.32	0.61	0.35	-0.02	0.34	-0.01	0.02	-0.25
	(1.6)	(1.4)	(1.0)	(0.64)	(1.2)	(1.7)	(0.02)	(0.04)	(0.82)
Munic FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	10,570	10,570	10,570	10,570	10,570	10,570	10,570	10,570	10,570
R^2	0.47	0.46	0.40	0.22	0.45	0.45	0.21	0.11	0.17
Within R^2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02

Notes: Municipalities with less than 200,000 people. Standard errors computed as in Conley (1999) with distance threshold of 100 kilometers. Covariates include the following: log of real gold prices; log of GDP per capita in 2005, share of agricultural GDP in 2005, log of municipal area, share of protected areas in municipality, rate of suicides and deaths in traffic, unemployment rate in 2000, highschool completion rate in 2000, log of life expectancy in 2000, access to electricity and sewage in 2000, log of distance to nearest road plus one, and log of distance to nearest waterway plus one. Gold prices are interacted with dummies GD and IGD, whereas other covariates are interacted with year fixed effecs. Dependent variable is the homicide rate (per 100,000 inhabitants). Homicides by Firearm or Knives also include homicides by other cutting instruments. CPT is an indicator variable equal to one when there are deaths in the countryside due to land conflicts according to the Comissão Pastoral da Terra. Police and Indet. are homicide rates committed by the police or by an indeterminate actor.

demonstrate that the effect does not seem to be driven by violence related to confrontations with law enforcement agents, which could happen if the government targeted enforcement in areas exposed to illegal gold mining after the deregulation.

Overall, these results show a significant effect of the deregulation on homicides in places more exposed to illegal gold mining. The location of these homicides, demographic groups involved, and weapons used are all consistent with disputes in mining sites. We also do not find evidence that more land conflicts or harsher law enforcement are behind the growth in homicides.

6.3 Heterogeneities and Other Outcomes

In the following analyses, we explore heterogeneous effects and other outcomes to further support our argument that the estimated effect on homicides after 2013 is related to disputes for

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illegal gold deposits located inside protected areas.

We start with an exercise similar to what we did for deforestation. We examine whether violence increased in places exposed to illegal gold mining *outside* protected areas. As opposed to the case of deforested area, the level of violence associated with illegal mining inside protected areas may be negatively affected by the availability of unclaimed gold deposits outside those areas. If miners can access gold deposits outside protected areas, they might be less inclined to fight for deposits inside them.

Again, we create variables capturing the exposure to deposits that are not inside mining permit polygons. We only consider permits requested until 2012. Table 7 presents our estimates.

Columns (1) and (3) present the baseline results for the full sample and the sub-sample of municipalities containing gold deposits. Columns (2) and (4) add an indicator for municipalities with gold deposits **not** covered by permit polygons. The effect associated with illegal gold mining, shown in the first row of Table 7, remains positive, significant, and even larger for some specifications. We do not observe, however, a significant impact of the deregulation on violence in municipalities where gold deposits are outside protected areas and are not covered by permit polygons. This is consistent with the fact that we have not observed an increase in deforested area in places with deposits outside permit polygons. This suggests that the effect of the deregulation on violence was mainly driven by the growth of illegal gold mining *inside* protected areas.

Additionally, the negative estimated coefficient for the interaction of *Gold Dep. w/o Permit* and *I(year* $\geq$ *2013)* (Column 4) may suggest that available gold deposits (i.e., without permit) outside protected areas attenuate the impact on violence driven by exposure to illegal gold mining. This could be the case if miners compete less for deposits inside protected areas when they also exist outside such territories. However, estimates are very noisy, preventing us from drawing further conclusions.

There might also be concerns about alternative explanations for the relative increase in violence across municipalities more exposed to illegal gold mining inside protected areas. Table 8 below offers a series of results to mitigate such concerns. This table refers to the full sample of municipalities with less than 200,000 people (with and without gold deposits). For the sake of brevity, we provide results for the full sample of municipalities and the sub-sample of municipalities with gold deposits in Appendix Tables 8 and 14, respectively.

Column (1) presents our benchmark result, which corresponds to Column (3) of Table 5. In Column (2), we investigate whether there are intensive margin effects. To do this, we compute the share of gold deposits inside protected areas for each municipality. As explained in Section 3,

Table 7: Heterogenous Effect of Deregulation and the Availability of Gold Deposits Outside Protected Areas as of 2012

	Homicide Rate			
	Full Sample		Munic. with Gold	
Model:	(1)	(2)	(3)	(4)
Illegal Gold Deposits × $I(Year \geq 2013)$	10.9	10.6	14.7	15.4
	(2.4)	(3.0)	(2.8)	(3.7)
Gold Dep. w/o Permit × $I(Year \geq 2013)$		-3.8		-3.9
		(2.7)		(3.3)
Illegal Gold Deposits × Gold Dep. w/o Permit × $I(Year \geq 2013)$		0.16		-3.1
		(7.3)		(7.6)
Any Gold Deposit × $I(Year \geq 2013)$	0.25	1.7		
	(1.6)	(1.7)		
Munic FE	Yes	Yes	Yes	Yes
State-Year FE (126)	Yes	Yes	Yes	Yes
Covariates	Yes	Yes	Yes	Yes
# Munic FE	755	755	143	143
Observations	10,570	10,570	2,002	2,002
R^2	0.47	0.47	0.58	0.58
Within R^2	0.02	0.02	0.10	0.11

Notes: Municipalities with less than 200,000 people. Standard errors computed as in Conley (1999) with distance threshold of 100 kilometers. Covariates include the following: log of real gold prices; log of GDP per capita in 2005, share of agricultural GDP in 2005, log of municipal area, share of protected areas in municipality, rate of suicides and deaths in traffic, unemployment rate in 2000, highschool completion rate in 2000, log of life expectancy in 2000, access to electricity and sewage in 2000, log of distance to nearest road plus one, and log of distance to nearest waterway plus one. Gold prices are interacted with dummies GD and IGD, whereas other covariates are interacted with year fixed effecs.

Table 8: Effect of Deregulation on Homicide Rates in Municipalities Exposed to Illegal Gold Mining, from 2006 to 2019 - Heterogeneities

	Baseline	Intensive Margin	Other Garimpo Minerals		Presence of PAs		Treat. Defined in 2006	Presence of PCOs	
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
IGD × Post2013	10.9		9.7	10.5	9.8	10.2	11.4	9.8	9.1
	(2.4)		(2.7)	(2.5)	(2.8)	(2.6)	(2.8)	(2.8)	(2.8)
Share IGD × Post2013		11.1							
		(6.0)							
IGD × Post2013 × PCO									10.6
									(8.0)
Other Illegal Dep. × Post2013				1.3					
				(3.8)					
GD × Post2013 × PA						2.4			
						(3.1)			
GD × Post2013	0.25	1.7	0.59	0.25	0.50	-1.1	0.14	0.09	-0.24
	(1.6)	(1.5)	(1.7)	(1.7)	(2.7)	(2.1)	(1.7)	(1.7)	(1.7)
Post2013 × PA						1.3			
						(1.3)			
Other Dep. × Post2013				-0.04					
				(2.2)					
Munic FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State-Year FE (126)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Covariates	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
# Munic FE	755	755	755	755	385	755	741	740	755
Observations	10,570	10,570	10,570	10,570	5,390	10,570	10,374	10,360	10,570
R^2	0.47	0.47	0.47	0.47	0.53	0.47	0.47	0.46	0.47
Within R^2	0.02	0.02	0.02	0.02	0.05	0.02	0.02	0.02	0.02

Notes: Municipalities with less than 200,000 people. Standard errors computed as in Conley (1999) with distance threshold of 100 kilometers. Abbreviations: IGD - Illegal Gold Deposits; GD - Gold Deposits; PA - Protected Area; Other Illegal Dep. - Munics with deposits of other garimpo minerals inside PAs; Column (1) presents baseline results. Column (2) considers the share of illegal gold deposits as intensive margin type of treatment. Column (3) adds year dummies interacted with variables indicating the presence of other *garimpo* minerals inside or outside PAs. Column (4) adds post-2013 dummy interacted with variables indicating the presence of other *garimpo* minerals inside or outside PAs. Column (5) displays results for the sample of municipalities with at least one protected area. Column (6) introduces the interaction of two dummies: PA for protected areas and GD for gold deposits. Column (7) uses only gold deposits and protected areas registered up to 2006 to define treatment. Columns (8) and (9) assess whether results vary depending on the existence of PCOs in a municipality. Column (8) considers only municipalities without PCOs, while column (9) explicitly introduces a dummy variable indicating the presence of a PCO.

we only have data on the number of deposits, not on their size or area. Despite this imprecision, we still find positive intensive margin effects. This means that the more deposits a municipality has inside protected areas, the larger the increase in homicides after the deregulation.

Columns (3) and (4) specifically address the concern that *garimpeiros* might engage in violent competition for a broad range of minerals, not just gold. If illegal deposits of both gold and other minerals largely coincide, our findings could be bundling together the effects of the deregulation with a more general surge in illegal mining. However, the results in Columns (3) and (4) suggest that this is not the case. In Column (3) we add year dummies interacted with variables indicating the presence of other *garimpo* minerals inside or outside protected areas. In Column (4) we replicate our measure of exposure to illegal mining, but now using other *garimpo* mineral deposits, excluding gold.[40] We still find a strong and significant coefficient for the main effect, but only find a small and non-significant effect for places exposed solely to other minerals. Hence, it appears that it is the presence of gold, not that of other minerals, that is driving the increase in violence. For the interested reader, we analyze these other minerals separately in Appendix D.4 and we still find that our results are driven by exposure to illegal gold mining, not illegal mining in general.

Violence caused by land conflicts is another 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 Columns (5) and (6) of Table 8. First, we estimate the results using a sample that only includes municipalities with protected areas. Alternatively, in Column (6), we explicitly model the effect of protected areas on violence. We add the dummy *PA*, which is equal to one if the municipality has a protected area, and interact it with the treatment period. Notice that a municipality may have the indicator for protected areas $PA_i = 1$ and $GD_i = 1$, but $IGD_i = 0$. In this case, the municipality has gold deposits in its territory, as well as a protected area, but the two do not coincide.

Results in Columns (5) and (6) indicate that it is really illegal gold mining that is driving violence after the deregulation, not underlying land conflicts. More than that, violence does not seem to be picking up in protected areas after 2013, as the small and non-significant coefficient of interaction of $Post2013 \times PA$ indicates. This is consistent with our finding that deforestation associated with gold mining only increased close to deposits inside protected areas, as shown in Section 5.

Because new gold deposits continue to be identified, there might be a concern that the discovery of these deposits may be correlated with either the 2013 regulatory change or new incidents

[40] The definition of other *garimpo* minerals is in Appendix A.4

of violence. For instance, if the Brazilian Geological Service opts to prioritize investigations to discover gold deposits within protected areas, it is possible that our estimates of increased violence could be partially explained by new deposits being found, attracting more people to the region, and ultimately leading to violence. Similarly, the creation of protected areas may be endogenously driven by governments seeking to deter illegal gold mining and its associated consequences. Column (7) in Table 8 alleviates these concerns by restricting our definition of treatment to deposits and protected areas registered up to 2006. In this exercise, the number of municipalities is smaller than our baseline scenario because we removed municipalities from the control group if, after 2006, gold deposits were registered or protected areas were created over gold deposits in them. This was done to ensure our controls were not contaminated. Even after this restriction, the main result remains almost unchanged.

Another interpretation for our findings is that the legislation would affect violence via income effect rather than via property rights disputes at mining sites. In other words, the spike in homicides after 2013 could result from more criminals robbing *garimpeiros* on their way to *PCOs*, instead of disputes in the mining sites.

To verify which of these effects drives our results, in Columns (8) and (9) in Table 8, we repeat our Difference-in-Differences exercise, considering now that some municipalities might be hubs of raw gold transactions. Column (8) excludes all municipalities that possess at least one *PCO* store — out of which 6 also have gold deposits inside protected areas.[41] In Column (9), we interact the presence of *PCOs* with exposure to illegal gold mining. This latter specification allows us to control for the presence of *PCOs* as well as to understand the heterogenous effects of *PCOs* on violence in exposed municipalities.

We observe that the main effect remains relatively stable and significant when we exclude all municipalities with *PCOs*. This suggests that homicides in municipalities exposed to illegal mining are increasing because of disputes in mining sites. Column (9) provides a similar conclusion, but also shows an additional result. Although the effect is not significant, it is possible that the presence of *PCOs* also affects violence at the places of sale. This is consistent with a larger flow of people selling gold at *PCOs* after the deregulation and being exposed to violent robbery.

Column (9) thus suggests that the deregulation may have had additional effects, if we consider the impact on other types of violence and crime. Although we do not have data for the

[41] The location of *PCOs* is reported by the Brazilian Central Bank at `https://bit.ly/3rfeu25`. 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 transactions. Between 2006 and 2019, these three municipalities accounted for 67% of taxes levied from *garimpeiros* selling raw gold to first-buyers. Moreover, they account for almost half of all *PCOs* in the Amazon region.

entire Amazon to investigate this possibility, we do have access to information on other crimes in the state of Pará between 2010 and 2019. This is the second-largest state in the region and accounts for roughly 30% of its population and GDP. The state also has 42.5% of all gold deposits in the Amazon and 19% of those that are located inside protected areas.

Based on the same Difference-in-Differences design as before, Table 9 presents the effects of the deregulation on other crimes such as body injury, sexual assault and robbery. Despite the reduction in sample size, estimates for Pará show that municipalities exposed to illegal gold mining still experience statistically significant increases in body injury (fatal) and sexual assault — Columns (2) and (3), respectively. Moreover, although only statistically significant at 10%, the point-wise estimates for both crimes of non-fatal body injury and robberies (either fatal or not) are positive — Columns (1), (5) and (6), respectively.

Table 9: Effect of Deregulation on Crime Rates in Pará Municipalities Exposed to Illegal Gold Mining, from 2010 to 2019

	Body Injury	Body Injury Fatal	Sexual Assault	Sexual Assault Fatal	Robbery	Robbery Fatal
Model:	(1)	(2)	(3)	(4)	(5)	(6)
Illegal Gold Deposits × $I(Year \geq 2013)$	51.9	0.70	10.5	-0.02	250.1	1.0
	(53.7)	(0.32)	(4.7)	(0.02)	(144.9)	(0.59)
Any Gold Deposit × $I(Year \geq 2013)$	-11.5	0.02	1.5	-0.02	-42.0	0.16
	(30.6)	(0.16)	(4.5)	(0.02)	(68.5)	(0.39)
Munic FE (139)	Yes	Yes	Yes	Yes	Yes	Yes
Year FE (10)	Yes	Yes	Yes	Yes	Yes	Yes
Covariates*Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,390	1,390	1,390	1,390	1,390	1,390
R^2	0.77	0.18	0.55	0.17	0.92	0.32
Within R^2	0.16	0.07	0.11	0.07	0.18	0.16

Notes: Municipalities with less than 200,000 people in the state of Pará. Standard errors computed as in Conley (1999) with distance threshold of 100 kilometers. 'Fatal' denotes whether crime led to victims' death. Dependent variables are the crime rates per 100,000 inhabitants and each column shows the results for a different type of crime. Covariates are the same as those used in baseline results.

Overall, these results for the state of Pará indicate that other types of violence increased in exposed municipalities after the deregulation. Moreover, more robberies are expected if more gold is circulating in the region. Lastly, the effect on sexual assaults is consistent with reports of the vulnerability of women working or living near *garimpos* (Pimentel, 2023; Freitas, 2016).

Finally, our last set of results discusses some alternative socioeconomic explanations for the relative increase in homicides in municipalities more exposed to illegal gold mining. We analyze how some indicators, such as GDP per capita or the share of agriculture on GDP, are evolving in these areas during the same period, instead of just including them as controls. For example, gold mining could attract a large number of people in a short period of time to exposed municipalities, leading to worse social conditions and, thus, more violence.

Using our sample including all Amazon states again, Table 10 shows the results with some socioeconomic indicators — previously covariates — as dependent variables.

We also look at the response of common diseases to the deregulation, as they can indicate changes in demographics or urbanization. Table 11 presents the results.

Overall, Tables 10 and 11 suggest no noticeable changes in socioeconomic conditions or disease rates after the deregulation. Moreover, point-wise estimates seem to be small. This indicates that municipalities exposed to illegal gold mining are not evolving differently in other dimensions that could correlate with gold mining.

We reach the same conclusions using the sub-sample of municipalities with at least one gold deposit. Results are presented in Tables 16 and 17 in the Appendix.

Table 10: Effect of Deregulation on Covariates in Municipalities Exposed to Illegal Gold Mining, from 2006 to 2019

Model:	Suicide Rate (1)	Traffic Deaths Rate (2)	(log) GDP (3)	Share Agric. GDP (4)	(log) Pop. (5)
Illegal Gold Deposits $\times$ $I(Year \geq 2013)$	-0.41	-2.0	-0.04	-1.5	-0.01
	(1.0)	(2.8)	(0.04)	(0.87)	(0.02)
Any Gold Deposit $\times$ $I(Year \geq 2013)$	0.58	1.2	0.01	0.46	-0.01
	(0.68)	(1.9)	(0.02)	(0.52)	(0.006)
Munic FE (755)	Yes	Yes	Yes	Yes	Yes
State-Year FE	Yes	Yes	Yes	Yes	Yes
# State-Year FE	126	126	108	108	126
Observations	10,570	10,570	9,060	9,060	10,570
R^2	0.21	0.41	0.94	0.91	0.99
Within R^2	0.02	0.02	0.03	0.03	0.13

Notes: Municipalities with less than 200,000 people. Standard errors computed as in Conley (1999) with distance threshold of 100 kilometers. Covariates include the following: log of real gold prices; log of GDP per capita in 2005, share of agricultural GDP in 2005, log of municipal area, share of protected areas in municipality, rate of suicides and deaths in traffic, unemployment rate in 2000, highschool completion rate in 2000, log of life expectancy in 2000, access to electricity and sewage in 2000, log of distance to nearest road plus one, and log of distance to nearest waterway plus one. Gold prices are interacted with dummies GD and IGD, whereas other covariates are interacted with year fixed effecs. All models include the interaction of year fixed effects with constant covariates' levels, excluding covariate in the left-hand side.

Table 11: Effect of Deregulation on Other Death Rates in Municipalities Exposed to Illegal Gold Mining, from 2006 to 2019

Model:	Infect Parasite (1)	Neoplasm (2)	Circulatory (3)	Respiratory (4)	Digestive (5)
Illegal Gold Deposits × $I(Year \geq 2013)$	-1.2	1.5	2.2	-0.22	0.20
	(1.1)	(1.6)	(2.8)	(1.7)	(1.0)
Any Gold Deposit × $I(Year \geq 2013)$	-0.06	-1.6	1.5	-0.26	-0.86
	(0.60)	(1.2)	(2.1)	(0.98)	(0.74)
Munic FE (755)	Yes	Yes	Yes	Yes	Yes
State-Year FE (126)	Yes	Yes	Yes	Yes	Yes
Covariates	Yes	Yes	Yes	Yes	Yes
Observations	10,570	10,570	10,570	10,570	10,570
R^2	0.47	0.43	0.56	0.44	0.47
Within R^2	0.02	0.02	0.02	0.02	0.02

Notes: Municipalities with less than 200,000 people. Standard errors computed as in Conley (1999) with distance threshold of 100 kilometers. Covariates include the following: log of real gold prices; log of GDP per capita in 2005, share of agricultural GDP in 2005, log of municipal area, share of protected areas in municipality, rate of suicides and deaths in traffic, unemployment rate in 2000, highschool completion rate in 2000, log of life expectancy in 2000, access to electricity and sewage in 2000, log of distance to nearest road plus one, and log of distance to nearest waterway plus one. Gold prices are interacted with dummies GD and IGD, whereas other covariates are interacted with year fixed effecs.

7 Final Remarks

This paper explores a natural experiment to present causal evidence on how reducing incentives for decentralized monitoring via private market regulation can ultimately lead to more illegal activities and violence. We demonstrate these effects by examining a deregulation of the market for raw gold in Brazil that exempted first-buyers of gold from responsibility regarding the origin of the acquired product. Leveraging fine-grained data on deforestation associated with gold mining, we initially find that the deregulation fostered an expansion of illegal gold mining within protected areas. Then, we provide evidence that municipalities with gold deposits within protected areas, and thus more exposed to illegal mining, experienced a disproportionately higher increase in homicide rates following the deregulation compared to municipalities less exposed to illegal mining.

The violence pattern we observed in our results is consistent with escalating disputes over illegal deposits under poorly defined property rights. We run several different exercises and document that the rise in homicides is not related to an expansion of illegal gold mining happening without permits outside protected areas, or to the illegal exploitation of other minerals also found in the Amazon, or even to land-related conflicts and shifts in socioeconomic conditions.

Our findings suggest that what seemed to be a small change in the attribution of liability to first-buyers, maybe intended to facilitate business, may have had dire consequences. According to our estimates, between 2013 and 2019, a total of 1,308 deaths could have been prevented if the deregulation had not occurred. This amounts to 24% of the total homicides in municipalities exposed to illegal gold mining. Furthermore, even if the motive for the deregulation was to boost fiscal proceeds, the additional income from gold tax revenue is modest compared to what these municipalities typically receive from federal transfers — their primary source of income. From 2013 to 2019, the gold tax revenues collected by these municipalities accounted for only 3.5% of what they received from federal transfers.[42]

While some studies indicate that certification of origin policies can help mitigate conflicts over mineral deposits, this paper provides novel evidence connecting legal accountability of private monitors, illicit markets, and violent outcomes. Our analysis suggests that holding first-buyers accountable for acquiring illegal gold is crucial in deterring such activities and their associated consequences, even when there already exists a policy to control the origin of minerals — like the permit system operating in Brazil. This is likely applicable not just to this scenario but also to other markets where legal and illegal activities coexist, such as logging, imported goods, and cattle raising in illegal pastures. In all these instances, assigning responsibility to buyers should encourage them to opt for legal products, fostering positive effects throughout the production chain.

Hence, our findings raise caution for governments and companies implementing mechanisms similar to mining permits or 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.

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A Appendix A - Additional Descriptive Figures and Tables

A.1 Estimating Gold Aggregate Sales from Royalties Data

Because mineral resources are owned by the federal government, a royalty tax called the Financial Compensation for Mineral Exploration (*CFEM* in Portuguese) is imposed on the initial transaction involving raw gold. Before 2010, *garimpo* gold was exempt from this tax. From 2010 to 2017, the *garimpo* gold tax rate was 0.2%, increasing to 1.5% from 2018 onward. Industrial mines paid a 1% tax rate until 2017 and 1.5% from 2018 onward.

The Brazilian National Mining Agency administers *CFEM* and provides a database with the total tax revenue for each gold sale in a municipality and year. However, it only informs the mining permits' identification for industrial mines. Therefore, in this dataset, we can't precisely determine from which *garimpo* permit area one specific gold sale originates. Still, we can estimate the overall gold production from *garimpos*. To do this, we identify industrial mines using their permit numbers and calculate *garimpo's* tax revenue by subtracting industrial mines' tax revenues from the total. Then, we use tax rates to compute the total value of gold transactions from each mine type and year. We estimate the quantity of gold sold by dividing these values by global gold prices obtained from FRED of the St. Louis FED (`https://fred.stlouisfed.org/`).

A.2 Federal Police Operations Inside Protected Areas

Based the complete list of operations from 2008 to 2017 available in this link, we manually collected information on those associated with illegal gold *garimpo*.

The selected operations are listed in the Table 12 below:

Table 12: Federal Police operations related to gold-mining, 2008 to 2017

Operation Name	Launch Date	State	Inside Protected Area	News Coverage
Xawará	Jul'2012	RR	Yes	link
Eldorado	Nov'2012	MT	Yes	link
Curaretinga	Mar'2013	RR	Yes	link
Caiari	Sep'2014	RO	Yes	link
Caiari - phase 2	Dec'2014	RO	Yes	link
Warari Koxi	Mai'2015	RR	Yes	link
Corrida do Ouro	Nov'2015	MT	Yes	link
Reco	Nov'2015	MT	Yes	link
Atalho	Jun'2016	RR	Yes	link
Alfeu	Jul'2016	AC	Yes	link
Dakji	Mar'2016	PA	Yes	link
Muiraquitã	Jul'2017	PA	Yes	link
Dakji - phase 2	Aug'2017	PA	Yes	link
Akator	Jun'2008	AP	No	link
Parvo	Jan'2012	AM	No	link
Rio De Ouro	Mar'2012	RO	No	link
Azougue	Mar'2013	AP	No	link
Filão Do Abacaxi	Sep'2015	AM	No	link
Mãe Do Ouro	Oct'2015	MT	No	link
Mãe Do Ouro - phase 2	Nov'2015	MT	No	link
Crisol	Feb'2017	AP	No	link
Ourives	Jun'2017	AP	No	link
Estrada Real	Sep'2017	AP	No	link
Salão De Ouro	Dec'2017	MT	No	link

A.3 Variables and Data Sources

Table 13: Mineral Deposits and Protected Areas - Variables and Sources

Variable	Source	Description	Period	Unit of Obs.	Scope
Gold Deposits	SGB	Deposits' coords.	cross-sect.	Geo. Coords.	Brazil
Other Minerals Deposits	SGB	Deposits' coords.	cross-sect.	Geo. Coords.	Brazil
Indigenous Terrs. (IT)	FUNAI	IT Polygons	cross-sect.	Geo. Poly.	Brazil
Conservation Areas (CA)	MMA	CA Polygons	cross-sect.	Geo. Poly.	Brazil
Gold Mining Permits	ANM	Permit's Polygons (has date of request)	cross-sect.	Geo. Poly.	Brazil
Protected Areas (PA)	Own calcs.	Union of ITs and CAs	cross-sect.	Geo. Poly.	Brazil
GD	Own calcs.	GD= 1 if has gold deposit	cross-sect.	Municipality and grid	Brazil
IGD	Own calcs.	IGD= 1 if has gold deposit inside PA	cross-sect.	Municipality and grid	Brazil
GD w/o Permit	Own calcs.	1 if has a gold deposit outside PA, but no overlapping permit	cross-sect.	Municipality and grid	Brazil
Share IGD	Own calcs.	N gold dep. in PA / N gold dep.	cross-sect.	Municipality and grid	Brazil
Share of PAs	Own calcs.	Area of PA/Munic area	cross-sect.	Municipality and grid	Brazil

Notes: The 'Period´ column provides details about the time span considered in our analysis for each variable. For certain variables listed as cross-sections, like mineral deposits, indigenous territories, conservation areas, and mining permits, we also have the registration date of each information. SGB: Brazilian Geological Service; FUNAI: National Indigenous People Foundation; MMA: Ministry of the Environment; ANM: National Mining Agency.

Table 14: Deforestation - Variables and Sources

Variable	Source	Description	Period	Unit of Obs.	Scope
Deforestation					
Deforestation PRODES	PRODES	Stock of deforested areas (sq. km)	2007-2019	3x3-km grid	Brazil
Deforestation MapBiomas	MapBiomas	Stock of deforested areas (sq. km)	2007-2019	3x3-km grid	Legal Amazon
Deforestation by gold garimpo	MapBiomas	Stock of deforested areas by gold garimpo (sq. km)	2007-2019	3x3-km grid	Legal Amazon
Share of total deforested area	Own calcs.	Total deforestation by grid area	2007-2019	3x3-km grid	Legal Amazon
Share of deforested area driven by gold garimpo	Own calcs.	MapBiomas gold garimpo deforestation/grid area	2007-2019	3x3-km grid	Legal Amazon
Share of tree coverage	Hansen et al. (2013)	Tree coverage/grid area	2007-2019	3x3-km grid	Legal Amazon

Notes: The 'Period´ column provides details about the time span considered in our analysis for each variable. PRODES: Project to Monitor Deforestation in the Amazon from INPE (Brazilian National Institute for Space Research);

Table 15: Deaths and Crime - Variables and Sources

Variable	Source	Description	Period	Unit of Obs.	Scope
Death Rates per 100k inhabitants					
Homicide Rate	DATASUS	ICD-10: X85-Y09	2006-2019	Municipality	Brazil
Hom. Rate - Firearm or Knives	DATASUS	ICD-10: X93-X95;X99	2006-2019	Municipality	Brazil
Hom. Rate by Police	DATASUS	ICD-10: Y35-Y36	2006-2019	Municipality	Brazil
Hom. Rate by Undetermined Actor	DATASUS	ICD-10: Y10-Y34	2006-2019	Municipality	Brazil
Suicide Rate	DATASUS	ICD-10: X60-X84	2006-2019	Municipality	Brazil
Traffic Deaths Rate	DATASUS	ICD-10: V01-V99	2006-2019	Municipality	Brazil
Infect. Parasit. Dis.	DATASUS	ICD-10: A00-B99	2006-2019	Municipality	Brazil
Neoplasms	DATASUS	ICD-10: C00-D48	2006-2019	Municipality	Brazil
Circulatory	DATASUS	ICD-10: I00-I99	2006-2019	Municipality	Brazil
Respiratory	DATASUS	ICD-10: J00-J99	2006-2019	Municipality	Brazil
Digestive	DATASUS	ICD-10: K00-K93	2006-2019	Municipality	Brazil
CPT Index	CPT	=1 if munic observes death related to land conflict	2006-2019	Municipality	Brazil
Crime Rates per 100k inhabitants					
Body Injury	SEGUP-PA	Body injury incidents	2010-2019	Municipality	Pará State
Body Injury - Fatal	SEGUP-PA	Body injury incidents that led to victim's death	2010-2019	Municipality	Pará State
Sexual Assault	SEGUP-PA	Sexual assault incidents	2010-2019	Municipality	Pará State
Sexual Assault - Fatal	SEGUP-PA	Sexual assault incidents that led to victim's death	2010-2019	Municipality	Pará State
Robbery	SEGUP-PA	Robbery incidents	2010-2019	Municipality	Pará State
Robbery - Fatal	SEGUP-PA	Robbery incidents that led to victim's death	2010-2019	Municipality	Pará State

Notes: The 'Period´ column provides details about the time span considered in our analysis for each variable. DATASUS: Dababases from Ministry of Health; SEGUP-PA: Pará State Public Security Secretariat; CPT: Land Pastoral Commission.

Table 16: Controls - Variables and Sources

Variable	Source	Description	Period	Unit of Obs.	Scope
Other Variables and Controls					
Gold Prices	FED St Louis and IBGE	Real intl. prices (BRL)	2006-2019	Global	Brazil
Population	IBGE	Population	2006-2019	Municipality	Brazil
GDP per capita	IBGE	Munic. GDP / Population	2005; 2006-2017	Municipality	Brazil
Share of Agriculture on GDP	IBGE	Share of agric. on GDP	2005; 2006-2017	Municipality	Brazil
Municipal area	IBGE	Area in sq km	cross-sect.	Municipality	Brazil
Unemployment	IBGE - Census 2000	Unemployment rate (pop. 18+)	2000	Municipality	Brazil
Highschool Compl. Rate	IBGE - Census 2000	Perc. pop. 25+ with highschool	2000	Municipality	Brazil
Life Expectancy	IBGE - Census 2000	Life expectancy at birth	2000	Municipality	Brazil
Electricity	IBGE - Census 2000	Perc. Pop. with electricity	2000	Municipality	Brazil
Sewage	IBGE - Census 2000	Perc. Pop. w/o sewage	2000	Municipality	Brazil
Dist. Road	MINFRA and IBGE	Dist. nearest road - munic. bndry (km)	cross-sect.	Municipality	Brazil
Dist. River	MINFRA and IBGE	Dist. nearest river - munic. bndry (km)	cross-sect.	Municipality	Brazil

Notes: The ‘Period´ column provides details about the time span considered in our analysis for each variable. For GDP per capita and the Share of Agriculture on GDP, when incorporating these variables as controls, we use an interaction between their levels in 2005 and year dummies. When employed as dependent variables, our analysis considers their annual variation from 2006 to 2017. MMA: Ministry of the Environment; FED St Louis: Federal Reserve Economic Data of St. Louis; IBGE: Brazilian Institute of Geography and Statistics; MINFRA: Ministry of Infrastructure.

A.4 Definition of Other *Garimpo* Minerals

Other *garimpo* minerals 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 other *garimpo* minerals 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.

B Appendix B - Theoretical Model

In this section, we devise a simple theoretical framework that helps to understand some implications of reducing the level of legal responsibility for buyers of raw gold on the level of illegal mining activity and the violent disputes for deposits.

B.1 Setup

Let the gold industry be composed of 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.

B.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 γ). Therefore, the *PCOs* solve the following problem:

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

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 γ in addition to the unit price. Alternatively, with probability $(1-\mu)$, no irregularities are found, and the *PCO* only pays p_I.

Solving Problem 3 yields the following equilibrium inverse demand functions. The higher the expected sanctions ($\mu\gamma$), the less *PCOs* are willing to pay for illegal gold.

(4) $$p_I = p(1-\alpha)\left(\frac{Y_L}{Y_I}\right)^{\alpha} - \mu\gamma$$

(5) $$p_L = p\alpha\left(\frac{Y_L}{Y_I}\right)^{\alpha-1}$$

B.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 8 illustrates this decision process.

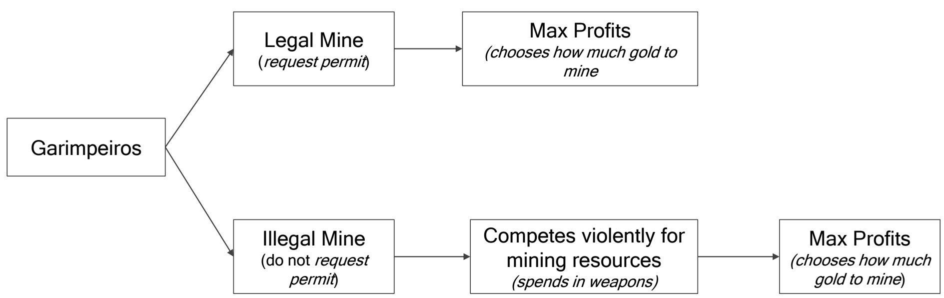

Figure 8: *Garimpeiros*' Decision Tree

Next, we solve the Illegal Miners' problem by backward induction.

Illegal Miners maximize gold production in conquered deposits:

(6) $$\max_{y_{g,m,I}} p_I y_{g,m,I} - c(y_{g,m,I}) - k$$

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:

(7) $$y^*_{g,m,I} = q(p_I)$$

(8) $$\Pi^*_{g,m,I} = p_I q(p_I) - c(q(p_I)) - k$$

By backward induction, illegal *garimpeiros* first choose how much to invest on weapons $w_{g,m}$. This investment determines how much each *garimpeiro* will hold of total weapons of a given municipality, consequently influencing their share of illegal gold mining profits. Following Castillo *et al.* (2020), we use a contest success function to include those disputes over deposits in our model. In this function, 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:

$$\max_{w_{g,m}} \{\Pi^o_{g,m} s_{g,m} - k - w_{g,m}\} \tag{9}$$

Assuming that all *garimpeiros* in municipality m solve the same problem above (i.e., they are symmetric), we have the following maximization condition:

$$\frac{N_{m,I} w_{g,m} - w_{g,m}}{(N_{m,I} w_{g,m})^2} = \frac{1}{\Pi^o_{g,m}}$$

Then, isolating $w_{g,m}$ and plugging the equilibrium profits from equation 8 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:

$$\begin{aligned} w^*_{g,m} &= \Pi^{o*}_{g,m} \frac{N_{m,I} - 1}{N^2_{m,I}} \\ &= \{p_I q(p_I) - c(q(p_I))\} \frac{N_{m,I} - 1}{N^2_{m,I}} \end{aligned} \tag{10}$$

We assume that the more each *garimpeiro* invests in weapons in a given municipality, the more violent it will be. Hence, we obtain the equilibrium level of violence by adding weapons' expenditures of all *garimpeiros* in each municipality, yielding:

$$v^*_m = \sum_g w^*_{g,m} = \{p_I q(p_I) - c(q(p_I))\} \frac{N_{m,I} - 1}{N_{m,I}} \tag{11}$$

Equation 11 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.

Optimal profits from illegal mining are derived by replacing $w^*_{g,m}$ and $\Pi^{o*}_{g,m}$ in the objective function from equation 9.

$$\Pi^*_{g,m,I} = \frac{1}{N^2_{m,I}} \{p_I q(p_I) - c(q(p_I))\} - k \tag{12}$$

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 (τ)[43]. Their maximization problem is as follows:

$$\max_{y_{g,m,L}}(1-\beta)\{p_L y_{g,m,L} - c(y_{g,m,L}) - \tau y_{g,m,L}\} - k \tag{13}$$

Problem 13 yields similar first order conditions as in Equations 7 and 8, except for the additional costs associated with permits:

$$y^*_{g,m,L} = q(p_L - \tau) \tag{14}$$

$$\Pi^*_{g,m,L} = (1-\beta)\{p_L q(p_L-\tau) - c(q(p_L-\tau)) - \tau q(p_L-\tau)\} - k \tag{15}$$

B.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. Because municipalities in the Amazon cover very large areas and transportation infrastructure is poor, we assume that there is no migration of *garimpeiros* between municipalities $(N_m = N^*_{m,L} + N^*_{m,I})$.[44] Then, normalizing the equilibrium price of legal gold such that $p^*_L = 1$, market clearing conditions are as follows:

$$Y^*_I = \sum_m \sum_g y^*_{g,m,I} = N^*_{m,I} q(p^*_I) \tag{16}$$

$$Y^*_L = \sum_m \sum_g y^*_{g,m,L} = (N_m - N^*_{m,I}) q(1-\tau) \tag{17}$$

Combining these conditions with equilibrium inverse demand functions in Equations 4 and 5, we reach the optimal illegal gold price as a function of exogenous parameters. Starting with

[43] This could include fees for either permit renewal or submitting environmental reports for example.

[44] The average and median sizes of municipalities in the Amazon are around 6500 and 2300 square kilometers, respectively. By way of comparison, São Paulo, the most populated city in Brazil, covers only 1500 square kilometers.

the optimal legal prices, which we normalize to 1:

(18)
$$p_L^* = 1 = p\alpha \left(\frac{Y_L^*}{Y_I^*}\right)^{\alpha-1}$$
$$\frac{1}{p\alpha}\left(\frac{(N_m - N_{m,I}^*)q(1-\tau)}{N_{m,I}^* q(p_I^*)}\right) = \left(\frac{(N_m - N_{m,I}^*)q(1-\tau)}{N_{m,I}^* q(p_I^*)}\right)^{\alpha}$$

We then use this condition to find the optimal illegal prices.

(19)
$$p_I^* = p(1-\alpha)\left(\frac{Y_L^*}{Y_I^*}\right)^{\alpha} - \mu\gamma$$
$$= \frac{(1-\alpha)}{\alpha}\left(\frac{(N_m - N_{m,I}^*)q(1-\tau)}{N_{m,I}^* q(p_I^*)}\right) - \mu\gamma$$

Then, to find the optimal number of illegal miners in Equation 20, we compute the profit threshold that makes *garimpeiros* indifferent between operating legally or not.

(20)
$$N_{m,I}^* = \sqrt{\frac{\{p_I^* q(p_I^*) - c(q(p_I^*))\}}{(1-\beta)\{q(1-\tau) - c(q(1-\tau)) - \tau q(1-\tau)\}}}$$

B.3 Changes in monitoring level and violence

Finally, to understand how the monitoring parameter μ affects the equilibrium number of illegal miners and violence, we depart from Equations 20 and 11, respectively, and study the sign of the partial derivatives below. We leave the details of this derivation for the interest reader in the following subsection.

(21)
$$\frac{\partial N_{m,I}^*}{\partial \mu} < 0$$

(22)
$$\frac{\partial v_m^*}{\partial \mu} < 0$$

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.

B.3.1 Complete derivations to verify how changes in monitoring affect violence

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

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 11 with respect to μ, rearranging terms and using the fact that $q(.) = c'^{-1}(.)$, we get

$$\begin{aligned}
\frac{\partial v_m^*}{\partial \mu} &= \frac{1}{(N_{m,I}^*)^2}\frac{\partial N_{m,I}^*}{\partial \mu}\{p_I^* q(p_I^*) - c(q(p_I^*))\} + \\
&\quad + \frac{N_{m,I}^* - 1}{N_{m,I}^*}\left[q(p_I^*) - c'(q(p_I^*))q'(p_I^*) + p_I^* q'(p_I^*)\right]\frac{\partial p_I^*}{\partial \mu} \\
\frac{\partial v_m^*}{\partial \mu} &= \frac{1}{(N_{m,I}^*)^2}\frac{\partial N_{m,I}^*}{\partial \mu}\{p_I^* q(p_I^*) - c(q(p_I^*))\} + \\
&\quad + \frac{N_{m,I}^* - 1}{N_{m,I}^*}\left[q(p_I^*) - p_I^* q'(p_I^*) + p_I^* q'(p_I^*)\right]\frac{\partial p_I^*}{\partial \mu} \\
\frac{\partial v_m^*}{\partial \mu} &= \frac{1}{(N_{m,I}^*)^2}\frac{\partial N_{m,I}^*}{\partial \mu}\{p_I^* q(p_I^*) - c(q(p_I^*))\} + \frac{N_{m,I}^* - 1}{N_{m,I}^*} q(p_I^*)\frac{\partial p_I^*}{\partial \mu}
\end{aligned} \tag{23}$$

To proceed, we need to determine the sign of the partial derivatives in the right-hand side of Equation 23. We start by $\frac{\partial N_{m,I}^*}{\partial \mu}$, which is determined by differentiating Equation 20 with respect to μ.

$$\begin{aligned}
\frac{\partial N_{m,I}^*}{\partial \mu} &= \frac{1}{2N_{m,I}^*}\frac{\frac{\partial p_I^*}{\partial \mu}\left[q(p_I^*) - c'(q(p_I^*))q'(p_I^*) + p_I^* q'(p_I^*)\right]}{(1-\beta)\{q(1-\tau) - c(q(1-\tau)) - \tau q(1-\tau)\}} \\
&= \frac{1}{2N_{m,I}^*}\frac{\frac{\partial p_I^*}{\partial \mu}\left[q(p_I^*) - p_I^* q'(p_I^*) + p_I^* q'(p_I^*)\right]}{(1-\beta)\{q(1-\tau) - c(q(1-\tau)) - \tau q(1-\tau)\}} \\
&= \frac{1}{2N_{m,I}^*}\frac{\frac{\partial p_I^*}{\partial \mu} q(p_I^*)}{(1-\beta)\{q(1-\tau) - c(q(1-\tau)) - \tau q(1-\tau)\}} \\
&= \frac{\partial p_I^*}{\partial \mu}\frac{q(p_I^*)}{2N_{m,I}^*(1-\beta)g(1-\tau)}
\end{aligned} \tag{24}$$

Such that $g(1-\tau) = q(1-\tau) - c(q(1-\tau)) - \tau q(1-\tau)$. Then, by plugging 24 in 23 and using $(N_{m,I}^*)^2$ from 20 to simplify,

$$\begin{aligned}
\frac{\partial v_m^*}{\partial \mu} &= \frac{1}{2N_{m,I}^*(N_{m,I}^*)^2}\frac{\frac{\partial p_I^*}{\partial \mu} q(p_I^*)\{p_I q(p_I) - c(q(p_I))\}}{(1-\beta)g(1-\tau)} + \frac{N_{m,I}^* - 1}{N_{m,I}^*} q(p_I^*)\frac{\partial p_I^*}{\partial \mu} \\
&= q(p_I^*)\frac{\partial p_I^*}{\partial \mu}\left[\frac{1}{2N_{m,I}^*} + \frac{N_{m,I}^* - 1}{N_{m,I}^*}\right] = q(p_I^*)\frac{\partial p_I^*}{\partial \mu}\left[\frac{2N_{m,I}^* - 1}{2N_{m,I}^*}\right]
\end{aligned} \tag{25}$$

Because $\left[\frac{2N^*_{m,I}-1}{2N^*_{m,I}}\right] > 0$ 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 19,

$$\begin{aligned} \frac{\partial p^*_I}{\partial \mu} &= \frac{1-\alpha}{\alpha (N^*_{m,I})^2 q^2(p^*_I)} \left[-\frac{\partial N^*_{m,I}}{\partial \mu} q(1-\tau) N^*_{m,I} q(p^*_I) \right] + \\ &+ \frac{(1-\alpha)}{\alpha (N^*_{m,I})^2 q^2(p^*_I)} \left[-(N_m - N^*_{m,I}) q(1-\tau) \left(\frac{\partial N^*_{m,I}}{\partial \mu} q(p^*_I) + N^*_{m,I} q'(p^*_I) \frac{\partial p^*_I}{\partial \mu} \right) \right] - \gamma \end{aligned} \tag{26}$$

Then, plugging 24 in 27 and rearranging terms to isolate $\frac{\partial p^*_I}{\partial \mu}$ finally yields

$$\begin{aligned} \frac{\partial p^*_I}{\partial \mu} = -\gamma & \left[\frac{2(N^*_{m,I})^3 (1-\beta) \alpha g (1-\tau)}{2(N^*_{m,I})^3 (1-\beta) \alpha g (1-\tau) + (1-\alpha) q (1-\tau) N_M} \right] * \\ * & \left[\frac{\alpha N^*_{m,I} q^2(p^*_I)}{\alpha N^*_{m,I} q^2(p^*_I) + (1-\alpha)(N_m - N^*_{m,I}) q (1-\tau) q'(p^*_I)} \right] < 0 \end{aligned} \tag{27}$$

Finally, given $\frac{\partial p^*_I}{\partial \mu} < 0$, we have that

$$\frac{\partial v^*_m}{\partial \mu} < 0 \tag{28}$$

$$\frac{\partial N^*_{m,I}}{\partial \mu} < 0 \tag{29}$$

$$\frac{\partial p^*_I}{\partial \mu} < 0 \tag{30}$$

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 - Deforestation Analysis

C.1 Adjusting Errors for Spatial Correlation

Table 1 shows an alternative way to account for spatial correlation. Columns (1) and (5) display our baseline results, which account for spatial correlation by clustering errors at the municipal level. The other columns present standard errors obtained using the methodology in Conley (1999). To do this, we need to define distance thresholds within which we allow for spatial correlation. Thresholds are in terms of number of cells. For example, Columns (2) and (6) allow for spatial correlation between cells that are up to 6 kilometers apart (2 cells with 3 kilometers each).

Table 1: Effect of Deregulation on Gold Garimpo Deforestation (MapBiomas) in 3x3-km Grid Cells Exposed to Illegal Gold Mining, from 2007 to 2019

	Full Sample				Cells with Gold			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Illegal Gold Deposits	0.114	0.114	0.114	0.114	0.214	0.214	0.214	0.214
	(0.059)	(0.062)	(0.075)	(0.077)	(0.109)	(0.105)	(0.114)	(0.118)
Cell and Year FEs	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
All Covariates	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7,413,575	7,413,575	7,413,575	7,413,575	24,349	24,349	24,349	24,349
# Cell FE	570,275	570,275	570,275	570,275	1,873	1,873	1,873	1,873
# Year FE	13	13	13	13	13	13	13	13
Spatial Corr.	Munic.	2 Cells	4 Cells	8 Cells	Munic.	2 Cells	4 Cells	8 Cells

Notes: In Columns (1)-(4), sample includes all cells, regardless of the existence of gold deposits, and all specifications control for the presence of at least one gold deposit.In Columns (5)-(8), sample only includes cells with gold deposits. All specifications include the following covariates: share of protected areas in grid cell, share of tree coverage from Hansen et al (2013), log of distance to nearest road or waterway plus one, and log of distance to nearest city center plus one.Errors are clustered at municipal level in Columns (1) and (5), our baseline. Other columns include errors allowing for spatial correlation as in Conley (1999), with distance thresholds indicated in number of cells.

Results are significant at 5% level in Columns (5) and (6). They are significant at 10% level in the other columns.

C.2 Total Deforestation

Table 2: Effect of Deregulation on Total Deforestation (PRODES) in 3x3-km Grid Cells Exposed to Illegal Gold Mining, from 2007 to 2019

	Full Sample			Cells with Gold		
	(1)	(2)	(3)	(4)	(5)	(6)
IGD $\times$ $I(Year \geq 2013)$	-0.607	0.284	-0.027	-0.607	0.288	-0.086
	(0.148)	(0.043)	(0.174)	(0.196)	(0.097)	(0.438)
Cell and Year FEs	Yes	Yes	Yes	Yes	Yes	Yes
Share of Protected Areas		Yes	Yes		Yes	Yes
All Covariates			Yes			Yes
Observations	7,413,575	7,413,575	7,413,575	24,349	24,349	24,349
# Cell FE	570,275	570,275	570,275	1,873	1,873	1,873
# Year FE	13	13	13	13	13	13

Notes: All errors are clustered at cell and municipal levels to allow for serial and spatial correlation. In Columns (1)-(3), sample includes all cells, regardless of the existence of gold deposits. In Column (1)-(3), all specifications control for the presence of at least one gold deposit. In Columns (4)-(6), sample only includes cells with gold deposits. Columns (1) and (4) are the unconditional models. Column (2) and (5) control share of protected areas in grid cell. Columns (3) and (6) include the following covariates: share of protected areas in grid cell, share of tree coverage from Hansen et al (2013), log of distance to nearest road or waterway plus one, and log of distance to nearest city center plus one.

Table 3: Effect of Deregulation on Total Deforestation (MapBiomas) in 3x3-km Grid Cells Exposed to Illegal Gold Mining, from 2007 to 2019

	Full Sample			Cells with Gold		
	(1)	(2)	(3)	(4)	(5)	(6)
IGD $\times$ $I(Year \geq 2013)$	-0.809	0.004	-0.105	-0.809	-0.114	-0.190
	(0.270)	(0.059)	(0.118)	(0.168)	(0.173)	(0.340)
Cell and Year FEs	Yes	Yes	Yes	Yes	Yes	Yes
Share of Protected Areas		Yes	Yes		Yes	Yes
All Covariates			Yes			Yes
Observations	7,413,575	7,413,575	7,413,575	24,349	24,349	24,349
# Cell FE	570,275	570,275	570,275	1,873	1,873	1,873
# Year FE	13	13	13	13	13	13

Notes: All errors are clustered at cell and municipal levels to allow for serial and spatial correlation. In Columns (1)-(3), sample includes all cells, regardless of the existence of gold deposits. In Column (1)-(3), all specifications control for the presence of at least one gold deposit. In Columns (4)-(6), sample only includes cells with gold deposits. Columns (1) and (4) are the unconditional models. Column (2) and (5) control share of protected areas in grid cell. Columns (3) and (6) include the following covariates: share of protected areas in grid cell, share of tree coverage from Hansen et al (2013), log of distance to nearest road or waterway plus one, and log of distance to nearest city center plus one.

C.3 Alternative Cell Sizes

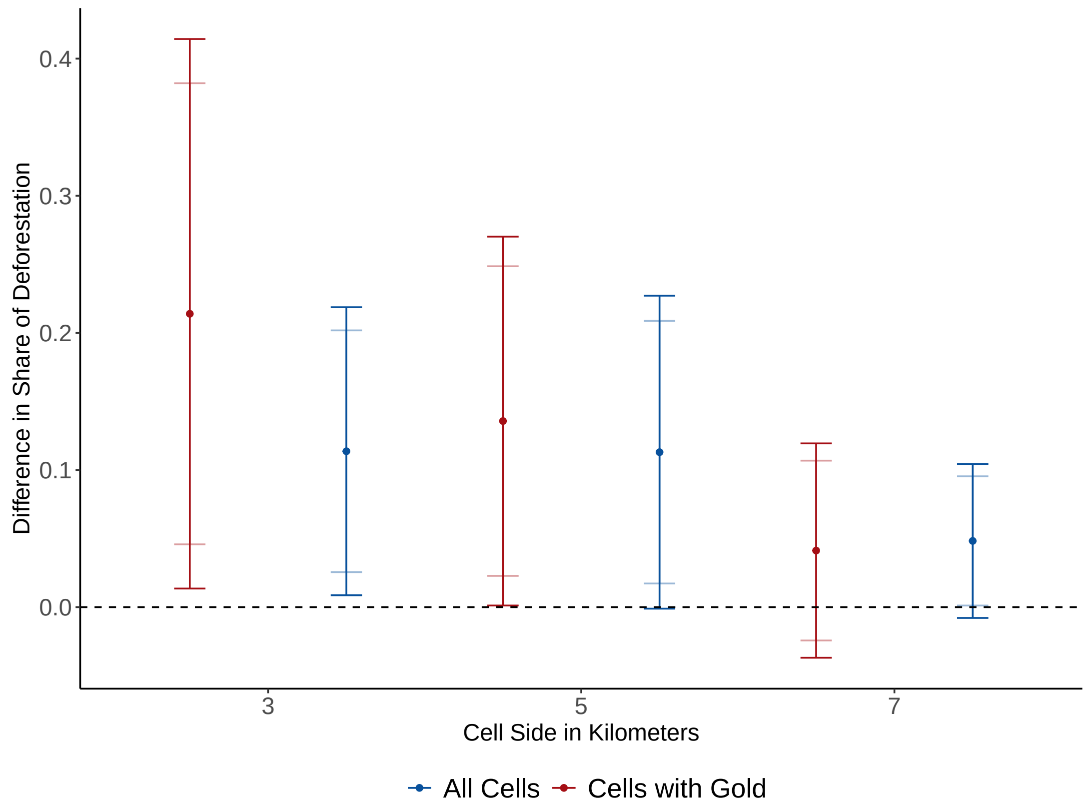

Figure 9: Estimated Effect of Deregulation on Share of Deforestation by Gold *Garimpo* using Alternative Cell Sizes (90% and 95% c.i.)

C.4 Extensive Margin Effects

Here, we show extensive margin effects on the deforested area associated with gold *garimpo* in each cell. The dependent variable is an indicator equal to zero as long as the cell has no sign of deforestation. It is equal to one in the first year presenting signs of deforestation and in all subsequent years.

Table 4: Effect of Deregulation on Exensive Margin of Gold Garimpo Deforestation (MapBiomas) in 3x3-km Grid Cells Exposed to Illegal Gold Mining, from 2007 to 2019

	Full Sample			Cells with Gold		
	(1)	(2)	(3)	(4)	(5)	(6)
IGD × $I(Year \geq 2013)$	-0.030	0.005	0.004	-0.030	0.009	0.010
	(0.010)	(0.001)	(0.001)	(0.006)	(0.003)	(0.007)
Cell and Year FEs	Yes	Yes	Yes	Yes	Yes	Yes
Share of Protected Areas		Yes	Yes		Yes	Yes
All Covariates			Yes			Yes
Observations	7,413,575	7,413,575	7,413,575	24,349	24,349	24,349
# Cell FE	570,275	570,275	570,275	1,873	1,873	1,873
# Year FE	13	13	13	13	13	13

Notes: All errors are clustered at cell and municipal levels to allow for serial and spatial correlation. In Columns (1)-(3), sample includes all cells, regardless of the existence of gold deposits. In Column (1)-(3), all specifications control for the presence of at least one gold deposit. In Columns (4)-(6), sample only includes cells with gold deposits. Columns (1) and (4) are the unconditional models. Column (2) and (5) control share of protected areas in grid cell. Columns (3) and (6) include the following covariates: share of protected areas in grid cell, share of tree coverage from Hansen et al (2013), log of distance to nearest road or waterway plus one, and log of distance to nearest city center plus one.

D Appendix D - Violence Analysis

D.1 Effect of Deregulation on Municipalities Exposed to Gold Mining

We show the effect of the deregulation for all municipalities with gold deposits, regardless of their location (i.e., inside or outside protected areas). We estimate Equation 31, where Y_{it} is the homicide rate in municipality i and year t, and GD_i, $D_{t \geq 2013}$ and X_{it} are as defined in Section 4).

$$Y_{it} = \beta_1 GD_i * D_{t \geq 2013} + X'_{it}\rho + \theta_i + \mu_t + \varepsilon_{it} \tag{31}$$

Table 1 shows small and mostly 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.

Table 1: Effect of Deregulation on Homicide Rates in Municipalities Exposed to Legal and Illegal Gold Mining, from 2006 to 2019

	Homicide Rate		
Model:	(1)	(2)	(3)
Any Gold Deposit $\times$ $I(Year \geq 2013)$	0.62	2.4	3.0
	(1.8)	(1.7)	(1.5)
Munic FE (755)	Yes	Yes	Yes
Year FE (14)	Yes		
State-Year FE (126)		Yes	Yes
Covariates*Year			Yes
Observations	10,570	10,570	10,570
R^2	0.44	0.46	0.47
Within R^2	5.2×10^{-5}	0.0006	0.02

Notes: Municipalities with less than 200,000 people. Standard errors computed as in Conley (1999) with distance threshold of 100 kilometers. Covariates include the following: log of real gold prices; log of GDP per capita in 2005, share of agricultural GDP in 2005, log of municipal area, share of protected areas in municipality, rate of suicides and deaths in traffic, unemployment rate in 2000, highschool completion rate in 2000, log of life expectancy in 2000, access to electricity and sewage in 2000, log of distance to nearest road plus one, and log of distance to nearest waterway plus one. Gold prices are interacted with dummies GD and IGD, whereas other covariates are interacted with year fixed effecs.

D.2 Doubly Robust Difference-in-Differences

Table 2 and Figure 10 below presents the results considering the conditional parallel trends assumption, proposed by Sant'Anna and Zhao (2020) and implemented using the Doubly Robust Difference-in-Differences Estimator. In columns (1) and (2), we present the effect of the deregulation on municipalities that have gold deposits ($GD = 1$) compared to those that do not ($GD = 0$). Columns (3) and (4) display the estimates considering the municipalities exposed to illegal gold mining ($IGD = 1$) as treated. Because the Doubly Robust Difference-in-Differences Estimator does not allow us to include two separate treatments (GD and IGD), in Columns (5) and (6) we subset our sample to municipalities with gold deposits ($GD = 1$). Even-numbered columns include covariates, whereas odd-numbered columns do not. Overall, we find that our results are robust to assuming that parallel trends only hold conditional on predetermined covariates.

Table 2: Effect of Deregulation on Homicide Rates in Municipalities Exposed to Illegal Gold Mining, from 2006 to 2019

	Full Sample				Munic. with Gold	
	(1)	(2)	(3)	(4)	(5)	(6)
Illegal Gold Deposits			8.82	15.33	11.67	15.25
			(4.09)	(6.01)	(4.26)	(6.57)
Any Gold Deposit	0.53	2.59				
	(1.91)	(2.23)				
Munic. FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Covariates		Yes		Yes		Yes
Observations	10,570	10,570	10,570	10,570	2,002	2,002
# Munic. FE	755	755	755	755	143	143
# Year FE	14	14	14	14	14	14

Notes: All errors are clustered at the municipality level. Covariates include the following: log of GDP per capita in 2005, share of agricultural GDP in 2005, log of municipal area, share of protected areas in municipality, rate of suicides and deaths in traffic, unemployment rate in 2000, highschool completion rate in 2000, log of life expectancy in 2000, access to electricity and sewage in 2000, log of distance to nearest road plus one, and log of distance to nearest waterway plus one.

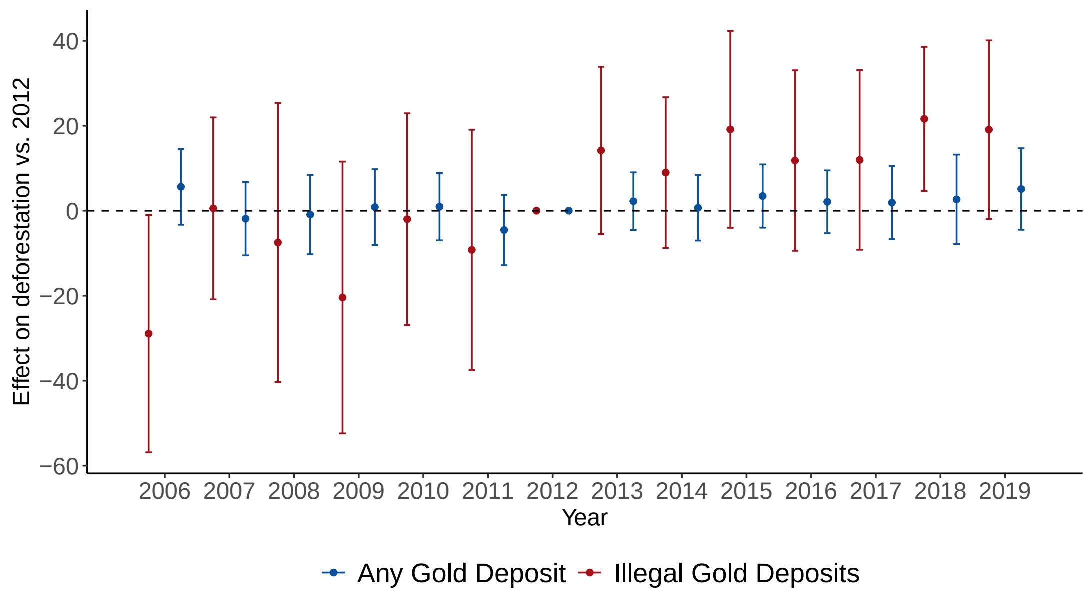

Figure 10: Average Difference in Homicide Rates Between Municipalities More and Less Exposed to Illegal Gold Mining, with Doubly Roubust Difference-in-Differences, Full Set of Controls and Errors Clustered at the Municipality Level (95% c.i.) - Municipalities with less than 200,000 People

D.3 Robustness Inference with Alternative Conley (1999) Distance Thresholds

Figure 11 shows how the confidence intervals for our main effect change for different Conley (1999) distance thresholds. Overall, even assuming quite generous distance ranges for spatial correlation, confidence intervals are not substantially affected.

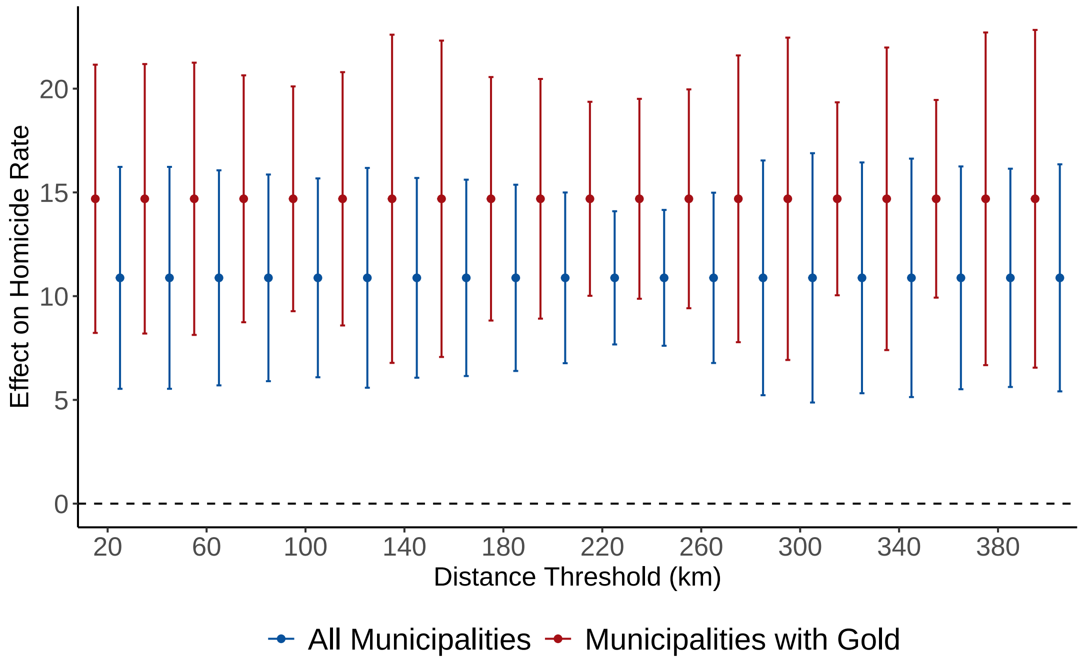

Figure 11: Confidence Intervals (95%) for Main Effect Using Alternative Conley (1999) Distance Thresholds

D.4 Presence of Other *Garimpo* Minerals

In this exercise, we delve deeper into the concern that *garimpeiros* might engage in violent competition for a variety of minerals, not just limited to gold. Table 3 employs a similar approach to our investigation of the effects of the regulatory change on places exposed to illegal gold mining. We explore whether municipalities' exposure to illegal mining of other *garimpo* minerals can also account for the rise in violence post-2013. To do this, we initially compile a list of the most common *garimpo* minerals in the Brazilian Amazon, including Cassiterite, Diamond, Niobium (Nb), Tantalum (Ta), Quartz, and Other Gems (encompassing Amethyst, Topaz, and Tourmaline). We then use a similar Difference-in-Differences approach, replacing *GD* and *IGD* with dummies specific to these other minerals. The first two columns present results for all *garimpo* minerals combined. The odd-numbered columns display estimates for the sample of municipalities with fewer than 200,000 inhabitants. The even-numbered columns showcase results for municipalities not exposed to illegal gold mining ($IGD = 0$).

The findings suggest that other *garimpo* minerals are not responsible for the increase in violence post-2013. Firstly, although the pointwise estimates for the interaction of deposits within protected areas and the post-2013 indicator are positive for the sample of municipalities with fewer than 200,000 inhabitants, they are not statistically significant. Secondly, these pointwise estimates substantially diminish (and even turn negative) when we narrow down the sample to municipalities not exposed to illegal gold mining ($IGD = 0$). Therefore, the positive coefficients seen in odd-numbered columns are driven by municipalities exposed to illegal gold deposits rather than other types of *garimpo* minerals, confirming our expectation that the gold regulatory change in 2013 only produced violence in places exposed to gold.

Table 3: Effect of Deregulation on Homicide Rates in Municipalities Exposed to Illegal Mining of Other Minerals, from 2006 to 2019

	Other Garimpo Minerals (Grouped)		Cassiterite		Diamond		Niobium and Tantalum		Quartz and Other Gems	
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Other Illegal Dep. $\times I(Year \geq 2013)$	4.7	-3.5								
	(3.8)	(4.2)								
Other Dep. $\times I(Year \geq 2013)$	0.43	-0.90								
	(2.2)	(2.0)								
Illegal Cassiterite Dep. $\times I(Year \geq 2013)$			8.4	2.9						
			(5.8)	(5.4)						
Cassiterite Dep. $\times I(Year \geq 2013)$			0.76	-6.3						
			(4.1)	(3.9)						
Illegal Diamond Dep. $\times I(Year \geq 2013)$					0.82	-12.1				
					(6.0)	(4.8)				
Diamond Dep. $\times I(Year \geq 2013)$					2.2	2.4				
					(2.8)	(2.4)				
Illegal Nb and Ta Dep. $\times I(Year \geq 2013)$							9.8	-31.9		
							(12.3)	(6.6)		
Nb and Ta Dep. $\times I(Year \geq 2013)$							6.9	11.0		
							(3.9)	(6.2)		
Illegal Quartz and Gems Dep. $\times I(Year \geq 2013)$									14.5	5.7
									(7.1)	(10.1)
Quartz and Gems Dep. $\times I(Year \geq 2013)$									-3.9	-4.9
									(3.2)	(3.4)
Munic FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State-Year FE (126)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Covariates*Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
# Munic FE	755	708	755	708	755	708	755	708	755	708
Observations	10,570	9,912	10,570	9,912	10,570	9,912	10,570	9,912	10,570	9,912
R^2	0.47	0.45	0.47	0.45	0.47	0.45	0.47	0.45	0.47	0.45
Within R^2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

Notes: Municipalities with less than 200,000 people. Standard errors computed as in Conley (1999) with distance threshold of 100 kilometers. Covariates include the following: log of real gold prices; log of GDP per capita in 2005, share of agricultural GDP in 2005, log of municipal area, share of protected areas in municipality, rate of suicides and deaths in traffic, unemployment rate in 2000, highschool completion rate in 2000, log of life expectancy in 2000, access to electricity and sewage in 2000, log of distance to nearest road plus one, and log of distance to nearest waterway plus one. Gold prices are interacted with dummies GD and IGD, whereas other covariates are interacted with year fixed effecs. Other Illegal Deposits and Other Deposits refer to municipalities with presence of *garimpo* minerals. Odd-numbered columns present the results considering the full sample of municipalities. Even-numbered columns subset sample to municipalities with no gold deposits inside protected areas.

D.5 Full Sample of Municipalities

Here, we present the results of the paper, but we do not limit our sample to municipalities with less than 200,000 people. Our effects are robust to considering this larger sample.

D.5.1 Descriptive Statistics for All Municipalities

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

	Without Deposits	Deposits Outside P.A.	Deposits Inside P.A.
Observations	622	99	48
Population (‘000)	30.2	31.6	39.0
	(105.1)	(62.5)	(61.8)
Homicide Rate	16.0	24.3	27.0
	(20.1)	(23.8)	(27.0)
GDP per capita (‘000 BRL)	14.3	16.1	19.0
	(15.3)	(7.7)	(22.8)
% agricultural GDP	26.5	22.8	18.2
	(14.9)	(13.1)	(16.2)
Area (‘000 km2)	4.7	6.5	32.3
	(8.6)	(8.4)	(34.8)
Sh. Protected Area	0.1	0.1	0.5
	(0.2)	(0.2)	(0.3)
Other Deaths Rates	23.4	28.0	25.8
	(29.9)	(41.1)	(22.5)
Unemployment	0.1	0.1	0.1
	(0.1)	(0.1)	(0.1)
Highschool Compl. Rate	0.1	0.1	0.1
	(0.1)	(0.1)	(0.1)
Life Expectancy	65.6	67.1	67.6
	(3.2)	(2.3)	(2.1)
Electricity	0.7	0.7	0.6
	(0.2)	(0.2)	(0.2)
Sewage	0.3	0.4	0.4
	(0.2)	(0.2)	(0.2)
Dist. Road (km)	32.3	22.8	30.6
	(45.9)	(34.2)	(43.8)
Dist. River (km)	32.7	46.2	41.9
	(36.4)	(38.1)	(54.9)

Notes: Table shows means and standard errors (in parenthesis) for multiple variables between 2006 and 2012 (pre-period) in all municipalities. GDP per capita is measured in 2019 prices. Other Deaths are suicides and deaths in traffic. ‘Without Deposits’ are all municipalities without gold deposits. ‘Deposits Outside P.A.’ refers to municipalities with at least one gold deposit, but none inside protected areas. ‘Deposits Inside P.A.’ refers to all municipalities in which at least one gold deposit is inside a protected area. Variables are at the municipality-year level.

Table 4: Descriptive Statistics of Brazilian Amazon Municipalities According to Presence and Location of Gold Deposits, 2006-2012

D.5.2 Benchmark results

Figure 12 and Table 5 present the main results for the full sample of municipalities in the Legal Amazon. As in Table 5, Columns (4) to (6) of Table 5 show the estimates considering the sample of municipalities with gold deposits.

Table 5: Effect of Deregulation on Homicide Rates in Municipalities Exposed to Illegal Gold Mining, from 2006 to 2019

	Homicide Rate					
	Full Sample			Munic. with Gold		
Model:	(1)	(2)	(3)	(4)	(5)	(6)
Illegal Gold Deposits × $I(Year \geq 2013)$	11.7	8.4	10.8	11.7	10.2	14.8
	(3.5)	(2.7)	(2.4)	(3.5)	(3.0)	(2.6)
Any Gold Deposit × $I(Year \geq 2013)$	-3.7	-0.68	-0.23			
	(1.4)	(1.5)	(1.5)			
Munic FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE (14)	Yes			Yes		
State-Year FE (126)		Yes	Yes		Yes	Yes
Covariates*Year			Yes			Yes
# Munic FE	769	769	769	147	147	147
Observations	10,766	10,766	10,766	2,058	2,058	2,058
R^2	0.47	0.49	0.50	0.51	0.55	0.59
Within R^2	0.005	0.003	0.02	0.02	0.01	0.10

Notes: All municipalities. Standard errors computed as in Conley (1999) with distance threshold of 100 kilometers. Covariates include the following: log of real gold prices; log of GDP per capita in 2005, share of agricultural GDP in 2005, log of municipal area, share of protected areas in municipality, rate of suicides and deaths in traffic, unemployment rate in 2000, highschool completion rate in 2000, log of life expectancy in 2000, access to electricity and sewage in 2000, log of distance to nearest road plus one, and log of distance to nearest waterway plus one. Gold prices are interacted with dummies GD and IGD, whereas other covariates are interacted with year fixed effecs.

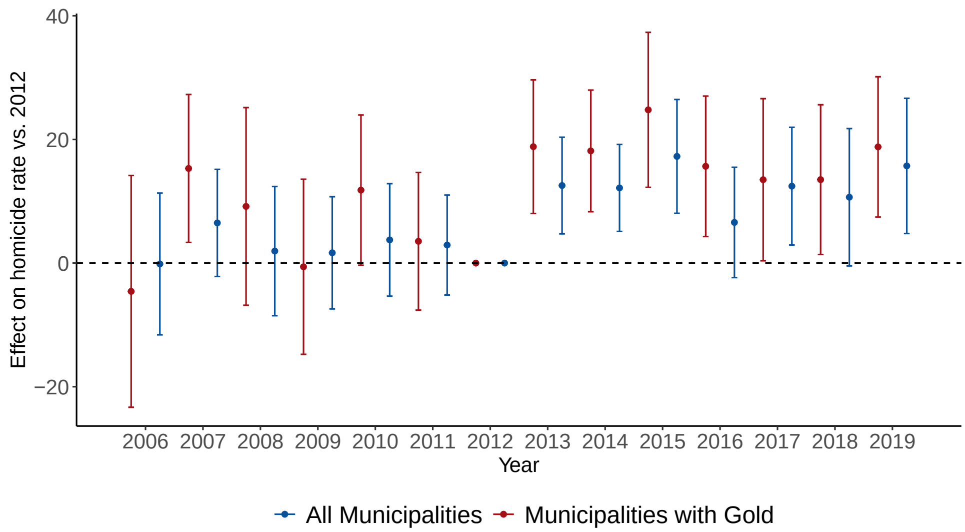

Figure 12: Average Difference in Homicide Rates Between Municipalities More and Less Exposed to Illegal Gold Mining, with Full Set of Controls (95% c.i.)

Notes: Standard errors computed as in Conley (1999) with distance threshold of 100 kilometers.

D.5.3 Decomposition of Homicides

Table 6: Decomposition of Effect of Deregulation on Homicide Rates in Municipalities Exposed to Illegal Gold Mining, from 2006 to 2019

	Total	Homicide Rate - Men					Other Homicides		
	Homicide Rate	Men	Men 20-49	Men At Home	Men Out of Home	Firearm or Knife	CPT	Police	Indet.
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Illegal Gold Deposits × $I(Year \geq 2013)$	10.8	9.2	5.0	0.52	8.6	8.6	0.02	0.11	0.80
	(2.4)	(2.2)	(1.7)	(0.90)	(2.0)	(2.1)	(0.04)	(0.13)	(0.99)
Any Gold Deposit × $I(Year \geq 2013)$	-0.23	-0.17	0.18	0.27	-0.44	-0.14	-0.01	0.02	-0.22
	(1.5)	(1.4)	(0.99)	(0.62)	(1.2)	(1.7)	(0.01)	(0.05)	(0.79)
Munic FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	10,766	10,766	10,766	10,766	10,766	10,766	10,766	10,766	10,766
R^2	0.50	0.49	0.43	0.22	0.48	0.48	0.22	0.11	0.18
Within R^2	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02

Notes: All municipalities. Standard errors computed as in Conley (1999) with distance threshold of 100 kilometers. Covariates include the following: log of real gold prices; log of GDP per capita in 2005, share of agricultural GDP in 2005, log of municipal area, share of protected areas in municipality, rate of suicides and deaths in traffic, unemployment rate in 2000, highschool completion rate in 2000, log of life expectancy in 2000, access to electricity and sewage in 2000, log of distance to nearest road plus one, and log of distance to nearest waterway plus one. Gold prices are interacted with dummies GD and IGD, whereas other covariates are interacted with year fixed effecs. Dependent variable is the homicide rate (per 100,000 inhabitants). Homicides by Firearm or Knives also include homicides by other cutting instruments. CPT is an indicator variable equal to one when there are deaths in the countryside due to land conflicts according to the Comissão Pastoral da Terra. Police and Indet. are homicide rates committed by the police or by an indeterminate actor.

D.5.4 Heterogeneities and Other Outcomes

Tables 7 to 11 below show that results presented in Section 6.3 also hold when considering the full sample of municipalities.

Table 7: Heterogenous Effect of Deregulation and the Availability of Gold Deposits Outside Protected Areas as of 2012

	Homicide Rate			
	Full Sample		Munic. with Gold	
Model:	(1)	(2)	(3)	(4)
Illegal Gold Deposits × $I(Year \geq 2013)$	10.8	10.6	14.8	15.6
	(2.4)	(3.1)	(2.6)	(4.0)
Gold Dep. w/o Permit × $I(Year \geq 2013)$		-3.2		-2.9
		(2.6)		(3.4)
Illegal Gold Deposits × Gold Dep. w/o Permit × $I(Year \geq 2013)$		0.21		-3.5
		(7.5)		(7.9)
Any Gold Deposit × $I(Year \geq 2013)$	-0.23	1.0		
	(1.5)	(1.6)		
Munic FE	Yes	Yes	Yes	Yes
State-Year FE (126)	Yes	Yes	Yes	Yes
Covariates	Yes	Yes	Yes	Yes
# Munic FE	769	769	147	147
Observations	10,766	10,766	2,058	2,058
R^2	0.50	0.50	0.59	0.59
Within R^2	0.02	0.02	0.10	0.11

Notes: All municipalities. Standard errors computed as in Conley (1999) with distance threshold of 100 kilometers. Covariates include the following: log of real gold prices; log of GDP per capita in 2005, share of agricultural GDP in 2005, log of municipal area, share of protected areas in municipality, rate of suicides and deaths in traffic, unemployment rate in 2000, highschool completion rate in 2000, log of life expectancy in 2000, access to electricity and sewage in 2000, log of distance to nearest road plus one, and log of distance to nearest waterway plus one. Gold prices are interacted with dummies GD and IGD, whereas other covariates are interacted with year fixed effecs.

Table 8: Effect of Deregulation on Homicide Rates in Municipalities Exposed to Illegal Gold Mining, from 2006 to 2019 - Heterogeneities

	Baseline	Intensive Margin	Other Garimpo Minerals		Presence of PAs		Treat. Defined in 2006	Presence of PCOs	
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
IGD × Post2013	10.8		9.6	10.5	10.2	10.5	11.7	10.2	9.4
	(2.4)		(2.7)	(2.4)	(2.6)	(2.5)	(2.7)	(2.7)	(2.7)
Share IGD × Post2013		11.6							
		(5.8)							
IGD × Post2013 × PCO									6.6
									(8.9)
Other Illegal Dep. × Post2013				1.1					
				(3.8)					
GD × Post2013 × PA						1.7			
						(3.1)			
GD × Post2013	-0.23	1.2	0.20	-0.18	-0.49	-1.2	-0.45	-0.31	-0.63
	(1.5)	(1.5)	(1.7)	(1.7)	(2.5)	(2.1)	(1.6)	(1.7)	(1.6)
GD × Post2013 × PCO									5.8
									(6.0)
Post2013 × PA						1.3			
						(1.2)			
Other Dep. × Post2013				-0.24					
				(2.2)					
Munic FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State-Year FE (126)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Covariates	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
# Munic FE	769	769	769	769	398	769	754	748	769
Observations	10,766	10,766	10,766	10,766	5,572	10,766	10,556	10,472	10,766
R^2	0.50	0.50	0.50	0.50	0.56	0.50	0.50	0.49	0.50
Within R^2	0.02	0.02	0.03	0.02	0.05	0.02	0.02	0.02	0.02

Notes: All municipalities. Standard errors computed as in Conley (1999) with distance threshold of 100 kilometers. Abbreviations: IGD - Illegal Gold Deposits; GD - Gold Deposits; PA - Protected Area; Other Illegal Dep. - Munics with deposits of other garimpo minerals inside PAs; Column (1) presents baseline results. Column (2) considers the share of illegal gold deposits as intensive margin type of treatment. Column (3) adds year dummies interacted with variables indicating the presence of other *garimpo* minerals inside or outside PAs. Column (4) adds post-2013 dummy interacted with variables indicating the presence of other *garimpo* minerals inside or outside PAs. Column (5) displays results for the sample of municipalities with at least one protected area. Column (6) introduces the interaction of two dummies: PA for protected areas and GD for gold deposits. Column (7) uses only gold deposits and protected areas registered up to 2006 to define treatment. Columns (8) and (9) assess whether results vary depending on the existence of PCOs in a municipality. Column (8) considers only municipalities without PCOs, while column (9) explicitly introduces a dummy variable indicating the presence of a PCO.

Table 9: Effect of Deregulation on Crime Rates in Pará Municipalities Exposed to Illegal Gold Mining, from 2010 to 2019

	Body Injury	Body Injury Fatal	Sexual Assault	Sexual Assault Fatal	Robbery	Robbery Fatal
Model:	(1)	(2)	(3)	(4)	(5)	(6)
Illegal Gold Deposits $\times$ $I(Year \geq 2013)$	42.4	0.67	10.0	-0.03	261.0	1.0
	(52.5)	(0.32)	(4.4)	(0.02)	(136.3)	(0.56)
Any Gold Deposit $\times$ $I(Year \geq 2013)$	-4.9	0.03	1.3	-0.01	-61.5	0.12
	(31.9)	(0.14)	(4.3)	(0.02)	(65.1)	(0.37)
Munic FE (143)	Yes	Yes	Yes	Yes	Yes	Yes
Year FE (10)	Yes	Yes	Yes	Yes	Yes	Yes
Covariates*Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,430	1,430	1,430	1,430	1,430	1,430
R^2	0.79	0.18	0.55	0.17	0.94	0.32
Within R^2	0.19	0.07	0.11	0.07	0.20	0.16

Notes: All municipalities of the state of Pará. Standard errors computed as in Conley (1999) with distance threshold of 100 kilometers. 'Fatal' denotes whether crime led to victims' death. Dependent variables are the crime rates per 100,000 inhabitants and each column shows the results for a different type of crime. Covariates are the same as those used in baseline results.

Table 10: Effect of Deregulation on Covariates in Municipalities Exposed to Illegal Gold Mining, from 2006 to 2019

Model:	Suicide Rate (1)	Traffic Deaths Rate (2)	(log) GDP (3)	Share Agric. GDP (4)	(log) Pop. (5)
Illegal Gold Deposits × $I(Year \geq 2013)$	-0.35	-2.7	-0.04	-1.4	-0.01
	(1.0)	(2.7)	(0.04)	(0.85)	(0.01)
Any Gold Deposit × $I(Year \geq 2013)$	0.56	1.3	0.01	0.45	-0.01
	(0.65)	(1.8)	(0.02)	(0.51)	(0.006)
Munic FE (769)	Yes	Yes	Yes	Yes	Yes
State-Year FE	Yes	Yes	Yes	Yes	Yes
# State-Year FE	126	126	108	108	126
Observations	10,766	10,766	9,228	9,228	10,766
R^2	0.21	0.41	0.94	0.91	0.99
Within R^2	0.02	0.02	0.03	0.03	0.13

Notes: All municipalities. Standard errors computed as in Conley (1999) with distance threshold of 100 kilometers. Covariates include the following: log of real gold prices; log of GDP per capita in 2005, share of agricultural GDP in 2005, log of municipal area, share of protected areas in municipality, rate of suicides and deaths in traffic, unemployment rate in 2000, highschool completion rate in 2000, log of life expectancy in 2000, access to electricity and sewage in 2000, log of distance to nearest road plus one, and log of distance to nearest waterway plus one. Gold prices are interacted with dummies GD and IGD, whereas other covariates are interacted with year fixed effecs. All models include the interaction of year fixed effects with constant covariates' levels, excluding covariate in the left-hand side.

Table 11: Effect of Deregulation on Other Death Rates in Municipalities Exposed to Illegal Gold Mining, from 2006 to 2019

Model:	Infect Parasite (1)	Neoplasm (2)	Circulatory (3)	Respiratory (4)	Digestive (5)
Illegal Gold Deposits $\times$ $I(Year \geq 2013)$	-0.97	1.3	2.3	-0.15	0.21
	(1.1)	(1.5)	(2.7)	(1.7)	(1.0)
Any Gold Deposit $\times$ $I(Year \geq 2013)$	-0.24	-1.7	1.1	-0.31	-0.92
	(0.55)	(1.1)	(2.0)	(0.98)	(0.74)
Munic FE (769)	Yes	Yes	Yes	Yes	Yes
State-Year FE (126)	Yes	Yes	Yes	Yes	Yes
Covariates	Yes	Yes	Yes	Yes	Yes
Observations	10,766	10,766	10,766	10,766	10,766
R^2	0.55	0.55	0.58	0.47	0.51
Within R^2	0.02	0.03	0.02	0.02	0.02

Notes: All municipalities. Standard errors computed as in Conley (1999) with distance threshold of 100 kilometers. Covariates include the following: log of real gold prices; log of GDP per capita in 2005, share of agricultural GDP in 2005, log of municipal area, share of protected areas in municipality, rate of suicides and deaths in traffic, unemployment rate in 2000, highschool completion rate in 2000, log of life expectancy in 2000, access to electricity and sewage in 2000, log of distance to nearest road plus one, and log of distance to nearest waterway plus one. Gold prices are interacted with dummies GD and IGD, whereas other covariates are interacted with year fixed effecs.

D.6 Benchmark Results for Alternative Population Thresholds

Table 12 shows that results are robust to further restricting the sample to municipalities with less than 100,000 and 50,000 inhabitants.

Table 12: Effect of Deregulation on Homicide Rates in Munic. Exposed to Illegal Gold Mining(2006-2019)

	Homicide Rate							
	Full Sample				**Munic. with Gold**			
Pop. Threshold	All	200k	100k	50k	All	200k	100k	50k
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Illegal Gold Deposits × $I(Year \geq 2013)$	10.8	10.9	10.9	9.7	14.8	14.7	14.5	13.4
	(2.4)	(2.4)	(2.6)	(2.9)	(2.6)	(2.8)	(3.0)	(3.5)
Any Gold Deposit × $I(Year \geq 2013)$	-0.23	0.25	0.29	0.98				
	(1.5)	(1.6)	(1.6)	(1.8)				
Munic FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State-Year FE (126)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Covariates*Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
# Munic FE	769	755	738	680	147	143	140	123
Observations	10,766	10,570	10,332	9,520	2,058	2,002	1,960	1,722
R^2	0.50	0.47	0.46	0.42	0.59	0.58	0.57	0.56
Within R^2	0.02	0.02	0.02	0.02	0.10	0.10	0.11	0.12

Notes: Standard errors computed as in Conley (1999) with distance threshold of 100 kilometers. Covariates include the following: log of real gold prices; log of GDP per capita in 2005, share of agricultural GDP in 2005, log of municipal area, share of protected areas in municipality, rate of suicides and deaths in traffic, unemployment rate in 2000, highschool completion rate in 2000, log of life expectancy in 2000, access to electricity and sewage in 2000, log of distance to nearest road plus one, and log of distance to nearest waterway plus one. Gold prices are interacted with dummies GD and IGD, whereas other covariates are interacted with year fixed effecs. *p<.1; **p<.05; ***p<.01.

D.7 Sample of Municipalities with Gold Deposits

In this section, we replicate the main heterogeneities and robustness exercises done for the municipal-level analysis, but we restrict the sample to municipalities with at least one gold deposit.

D.7.1 Decomposition of Homicides

Table 13: Decomposition of Effect of Deregulation on Homicide Rates in Municipalities Exposed to Illegal Gold Mining, from 2006 to 2019

	Total	Homicide Rate - Men					Other Homicides		
	Homicide Rate	Men	Men 20-49	Men At Home	Men Out of Home	Firearm or Knife	CPT	Police	Indet.
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Illegal Gold Deposits × $I(Year \geq 2013)$	14.7	12.5	8.7	0.33	12.1	12.6	0.01	-0.002	0.28
	(2.8)	(2.5)	(2.3)	(1.3)	(2.4)	(2.5)	(0.06)	(0.15)	(1.7)
Munic FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,002	2,002	2,002	2,002	2,002	2,002	2,002	2,002	2,002
R^2	0.58	0.56	0.51	0.41	0.55	0.54	0.32	0.37	0.35
Within R^2	0.10	0.11	0.11	0.08	0.11	0.09	0.10	0.19	0.08

Notes: Municipalities with less than 200,000 people and with gold deposits. Standard errors computed as in Conley (1999) with distance threshold of 100 kilometers. Covariates include the following: log of real gold prices; log of GDP per capita in 2005, share of agricultural GDP in 2005, log of municipal area, share of protected areas in municipality, rate of suicides and deaths in traffic, unemployment rate in 2000, highschool completion rate in 2000, log of life expectancy in 2000, access to electricity and sewage in 2000, log of distance to nearest road plus one, and log of distance to nearest waterway plus one. Gold prices are interacted with dummies GD and IGD, whereas other covariates are interacted with year fixed effecs. Dependent variable is the homicide rate (per 100,000 inhabitants). Homicides by Firearm or Knives also include homicides by other cutting instruments. CPT is an indicator variable equal to one when there are deaths in the countryside due to land conflicts according to the Comissão Pastoral da Terra. Police and Indet. are homicide rates committed by the police or by an indeterminate actor.

D.7.2 Heterogeneities and Other Outcomes

Table 14: Effect of Deregulation on Homicide Rates in Municipalities Exposed to Illegal Gold Mining, from 2006 to 2019 - Heterogeneities

	Baseline	Intensive Margin	Other Garimpo Minerals		Presence of PAs		Treat. Defined in 2006	Presence of PCOs	
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
IGD × Post2013	14.7		12.6	13.9	14.2	14.7	13.7	13.5	12.0
	(3.4)		(3.7)	(3.6)	(3.5)	(3.4)	(3.7)	(4.3)	(4.3)
Post2013 × Share IGD		14.1							
		(8.0)							
IGD × PCO × Post2013									9.0
									(9.8)
Other Illegal Dep. × Post2013				2.1					
				(5.3)					
Post2013 × PA						7.7			
						(4.4)			
Other Dep. × Post2013				1.5					
				(3.6)					
Munic FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Covariates	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
# Munic FE	143	143	143	143	105	143	129	128	143
# State-Year FE	126	126	126	126	112	126	126	126	126
Observations	2,002	2,002	2,002	2,002	1,470	2,002	1,806	1,792	2,002
R^2	0.58	0.57	0.59	0.58	0.61	0.58	0.59	0.56	0.58
Within R^2	0.10	0.10	0.12	0.11	0.15	0.11	0.13	0.10	0.11

Notes: Municipalities with less than 200,000 people and gold deposits. Standard errors computed as in Conley (1999) with distance threshold of 100 kilometers. Abbreviations: IGD - Illegal Gold Deposits; PA - Protected Area; Other Illegal Dep. - Munics with deposits of other garimpo minerals inside PAs; Column (1) presents baseline results. Column (2) considers the share of illegal gold deposits as intensive margin type of treatment. Column (3) adds year dummies interacted with variables indicating the presence of other *garimpo* minerals inside or outside PAs. Column (4) adds post-2013 dummy interacted with variables indicating the presence of other *garimpo* minerals inside or outside PAs. Column (5) displays results for the sample of municipalities with at least one protected area. Column (6) introduces the interaction of two dummies: PA for protected areas and GD for gold deposits. Column (7) uses only gold deposits and protected areas registered up to 2006 to define treatment. Columns (8) and (9) assess whether results vary depending on the existence of PCOs in a municipality. Column (8) considers only municipalities without PCOs, while column (9) explicitly introduces a dummy variable indicating the presence of a PCO.

Table 15: Effect of Deregulation on Crime Rates in Pará Municipalities Exposed to Illegal Gold Mining, from 2010 to 2019

	Body Injury	Body Injury Fatal	Sexual Assault	Sexual Assault Fatal	Robbery	Robbery Fatal
Model:	(1)	(2)	(3)	(4)	(5)	(6)
Illegal Gold Deposits × $I(Year \geq 2013)$	85.7	0.62	8.3	-0.06	299.5	1.2
	(66.3)	(0.24)	(6.9)	(0.02)	(163.0)	(0.66)
Munic FE (33)	Yes	Yes	Yes	Yes	Yes	Yes
Year FE (10)	Yes	Yes	Yes	Yes	Yes	Yes
Covariates*Year	Yes	Yes	Yes	Yes	Yes	Yes
Observations	330	330	330	330	330	330
R^2	0.88	0.40	0.77	0.39	0.93	0.56
Within R^2	0.46	0.32	0.40	0.29	0.55	0.50

Notes: Municipalities with less than 200,000 people, with gold deposits and in the state of Pará. Standard errors computed as in Conley (1999) with distance threshold of 100 kilometers. 'Fatal' denotes whether crime led to victims' death. Dependent variables are the crime rates per 100,000 inhabitants and each column shows the results for a different type of crime. Covariates are the same as those used in baseline results.

Table 16: Effect of Deregulation on Covariates in Municipalities Exposed to Illegal Gold Mining, from 2006 to 2019

Model:	Suicide Rate (1)	Traffic Deaths Rate (2)	(log) GDP (3)	Share Agric. GDP (4)	(log) Pop. (5)
Illegal Gold Deposits × $I(Year \geq 2013)$	-0.35	-5.7	-0.07	-1.7	-0.02
	(1.5)	(3.7)	(0.05)	(0.84)	(0.01)
Munic FE (143)	Yes	Yes	Yes	Yes	Yes
State-Year FE	Yes	Yes	Yes	Yes	Yes
# State-Year FE	126	126	108	108	126
Observations	2,002	2,002	1,716	1,716	2,002
R^2	0.41	0.36	0.90	0.94	0.99
Within R^2	0.10	0.09	0.10	0.08	0.23

Notes: Municipalities with less than 200,000 people and gold deposits. Standard errors computed as in Conley (1999) with distance threshold of 100 kilometers. Covariates include the following: log of real gold prices; log of GDP per capita in 2005, share of agricultural GDP in 2005, log of municipal area, share of protected areas in municipality, rate of suicides and deaths in traffic, unemployment rate in 2000, highschool completion rate in 2000, log of life expectancy in 2000, access to electricity and sewage in 2000, log of distance to nearest road plus one, and log of distance to nearest waterway plus one. Gold prices are interacted with dummies GD and IGD, whereas other covariates are interacted with year fixed effecs. All models include the interaction of year fixed effects with constant covariates' levels, excluding covariate in the left-hand side.

Table 17: Effect of Deregulation on Other Death Rates in Municipalities Exposed to Illegal Gold Mining, from 2006 to 2019

	Infect Parasite	Neoplasm	Circulatory	Respiratory	Digestive
Model:	(1)	(2)	(3)	(4)	(5)
Illegal Gold Deposits $\times$ $I(Year \geq 2013)$	-2.6	-1.3	0.02	-0.41	0.78
	(1.7)	(3.4)	(4.5)	(2.5)	(1.1)
Munic FE (143)	Yes	Yes	Yes	Yes	Yes
State-Year FE (126)	Yes	Yes	Yes	Yes	Yes
Covariates	Yes	Yes	Yes	Yes	Yes
Observations	2,002	2,002	2,002	2,002	2,002
R^2	0.64	0.68	0.70	0.61	0.64
Within R^2	0.08	0.10	0.09	0.10	0.09

Notes: Municipalities with less than 200,000 people and gold deposits. Standard errors computed as in Conley (1999) with distance threshold of 100 kilometers. Covariates include the following: log of real gold prices; log of GDP per capita in 2005, share of agricultural GDP in 2005, log of municipal area, share of protected areas in municipality, rate of suicides and deaths in traffic, unemployment rate in 2000, highschool completion rate in 2000, log of life expectancy in 2000, access to electricity and sewage in 2000, log of distance to nearest road plus one, and log of distance to nearest waterway plus one. Gold prices are interacted with dummies GD and IGD, whereas other covariates are interacted with year fixed effecs.