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Illegal markets, violence, and local economic impacts:
evidence from gold mining in the Brazilian Amazon

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Tese apresentada ao Programa de Pós-Graduação em Economia da Universidade Federal de Juiz de Fora como requisito parcial à obtenção do título de Doutor em Economia.

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Orientadora: Profa. Dra. Flaviane de Souza Santigo.

Coorientador: Prof. Dr. Weslem Rodrigues Faria

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Em memória do meu avô, Álvaro Ferraz.

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RESUMO

Usando um conjunto rico de dados que abrange mais de 540 municípios no bioma Amazônico Brasileiro ao longo de 20 anos, investigamos os efeitos das mudanças econômicas e institucionais sobre o crime violento associado à mineração ilegal de ouro. Para identificar efeitos causais, exploramos a exogeneidade de um raro episódio de desregulamentação do mercado e de um *boom* nos preços internacionais do ouro, combinados com a distribuição relativamente aleatória de depósitos geológicos em áreas protegidas, onde a mineração é estritamente proibida. Empregando um desenho de diferenças em diferenças, documentamos que áreas mais expostas à mineração ilegal experimentaram aumentos na criminalidade violenta após a desregulamentação do mercado e o *boom* do preço do ouro. Em nossa análise dos mecanismos, encontramos apoio mais forte à hipótese da rapacidade, que postula que retornos mais altos da extração ilegal incentivam a pilhagem de depósitos de ouro e aumentam a violência local. Em consonância com essa hipótese, observamos um aumento significativo no uso da terra para a mineração de ouro (garimpo) em áreas mais expostas à mineração ilegal. Também documentamos uma deterioração nas condições do mercado de trabalho, refletida em quedas no emprego formal, bem como uma redução relativa na importância das receitas de royalties nos orçamentos municipais, fornecendo evidências de um papel complementar do mecanismo de custo de oportunidade. Em termos de política, nosso quadro teórico sugere que a violência associada à mineração ilegal de ouro pode ser mitigada tanto por meio de monitoramento centralizado quanto descentralizado. Embora ambos sejam teoricamente eficazes, a comparação entre os dois desenhos institucionais sugere que o monitoramento descentralizado pode envolver custos de implementação relativamente mais baixos, pois depende de incentivos privados ao longo da cadeia de produção.

Palavras-chave: mineração ilegal; violência; recursos naturais; monitoramento; Amazônia.

ABSTRACT

Using a rich set of data covering more than 540 municipalities in the Brazilian Amazon biome over 20 years, we investigate the effects of economic and institutional changes on violent crime associated with illegal gold mining. To identify causal effects, we exploit the exogeneity of a rare episode of market deregulation and a boom in international gold prices, combined with the random distribution of geological deposits in protected areas, where mining is strictly prohibited. Employing a difference-in-differences design, we document that areas more exposed to illegal mining experienced increases in violent crime following market deregulation and the gold price boom. In our analysis of mechanisms, we find stronger support for the rapacity hypothesis, which posits that higher returns from illegal extraction incentivize the plundering of gold deposits and increase local violence. Consistent with this hypothesis, we observe a significant increase in land use for gold mining (garimpo) in areas more exposed to illegal mining. We also document a deterioration in labor market conditions, reflected in declines in formal employment, as well as a relative reduction in the importance of royalty revenues in municipal budgets, providing evidence of a complementary role for the opportunity-cost mechanism. In policy terms, our theoretical framework suggests that violence associated with illegal gold mining can be mitigated through both centralized and decentralized monitoring. Although both are theoretically effective, the comparison between the two institutional designs suggests that decentralized monitoring may involve relatively lower implementation costs, as it relies on private incentives along the production chain.

Keywords: illegal mining; violence; natural resources; monitoring; Amazon.

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1 INTRODUCTION

The abundance of natural resources can generate strong incentives for illegal exploitation in contexts characterized by poorly defined property rights and weak institutions (Couttenier et al., 2017; Cust and Poelhekke, 2015; Ploeg, 2011). Under these circumstances, resource-rich regions tend to face high social costs, insofar as the rents derived from extraction can finance the acquisition of weapons, sustain the organization of criminal groups, and weaken the State's governance capacity.[1] Not surprisingly, the systematic appropriation of these rents by illegal agents undermines the security of local communities.

Due to persistent limitations in law enforcement, governments have increasingly turned to regulatory mechanisms that delegate part of the monitoring of natural resource extraction to private agents along the entire production chain. However, empirical evidence suggests that these policies may be ineffective and may lead to unintended consequences, such as increased violence (Stoop et al., 2019; Parker and Vadheim, 2017; Chimeli and Soares, 2017). Despite the importance of this issue for better public policy design, evidence on how institutional and economic changes affecting legality along the production chain influence violence in contexts of low state capacity remains scarce.

This thesis provides evidence on the effects of illegality in natural resource extraction in the Brazilian Amazon, a gold-rich region with levels of violence comparable to those of countries experiencing armed conflict.[2] For this, we use a rich set of municipality-level data spanning more than two decades (2000–2021) and exploit two plausibly exogenous sources of variation in economic and institutional conditions: (i) a deregulation of the raw gold market in 2013, which exempted private intermediaries from the obligation to verify the origin of metal; and (ii) a positive income shock stemming from the boom in international gold prices starting in 2003. This strategy allows us to identify the effects of illegal gold mining on violent crime and its impacts on local economies.[3]

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[1] Revenues from environmental crimes (e.g., fuel smuggling and illegal mining) finance 38% of violent conflicts and non-state armed activities worldwide (Nellemann et al., 2018).

[2] According to the Uppsala Conflict Data Program (UCDP), the Central African Republic recorded a mortality rate of 17.8 per 100,000 inhabitants due to armed conflicts in 2021, while Somalia had a rate of 13.2 per 100,000 inhabitants (Our World in Data, 2024). In that same year, the Brazilian Amazon reached a homicide rate of 33 per 100,000 inhabitants, five times higher than the global average.

[3] We define illegal mining as the violation of property rights, such as the extraction of gold from deposits in indigenous territories and conservation units (protected areas), where, by law, mining is strictly prohibited. For example, in areas along the Tapajós River Basin in Pará, more than 30% of miners extract gold and gemstones in protected areas (Risso et al., 2021).

The Amazon concentrates over 90% of Brazil's gold mining area, most of which consists of small-scale mining (*garimpo*), and is home to more than 24 million people potentially affected by the increase in violence associated with illegal mining activity (MapBiomas, 2024; Risso et al., 2021). In the past two decades, over 145,000 homicides have been recorded in the region, a figure comparable to the population of Cambridge, the United Kingdom (Ministério da Saúde, 2024).

The raw gold extracted in the Amazon region by garimpeiros enters the national market through local stores – Gold Purchase Points (*Pontos de Compra de Ouro*, PCOs) – authorized to operate as private intermediaries (Banco Central do Brasil, 2017). Until 2012, these intermediaries were legally required to verify sellers' documentation (e.g., licenses), ensure the gold's licit origin, and report suspicious transactions. However, a federal deregulation implemented in 2013 removed these obligations, reducing the risk of sanctions and facilitating the commercialization of illegally mined gold from protected areas. We examine how this institutional change – which naturally shifted demand from legal to illegal gold – affected violent crimes in areas with illegal mining. Additionally, we analyze the response of violence in illegal mining areas to a positive income shock resulting from the sharp increase in international gold prices after 2003, a period during which the metal's real price tripled.[4]

A recent and closely related study by Pereira and Pucci (2026) shows that the deregulation of the Brazilian gold market in 2013, by weakening decentralized monitoring, led to a significant increase in violent crime in areas exposed to illegal mining.[5] Taking this result as a consolidated starting point, this thesis contributes along four dimensions. First, it incorporates the international gold price boom as an additional exogenous shock. Second, it provides a more in-depth analysis of the underlying mechanisms, distinguishing between rapacity and opportunity-cost channels. Third, it examines broader local economic effects, including impacts on labor market outcomes and fiscal budgets. Fourth, it places the theoretical framework at the center of the empirical analysis, guiding identification, the interpretation of results, and the analysis of monitoring policies.

[4] The gold market is divided into two segments: upstream and downstream. The upstream market consists of small-scale miners (*garimpeiros*) who extract raw gold and sell it to local stores. The downstream market, in turn, consists of these stores (*Pontos de Compra de Ouro*, PCOs), which act as the initial purchasers of gold from the miners.

[5] While the authors focus on the Legal Amazon over the period 2006–2019, this thesis instead centers specifically on illegal mining within the Amazon biome and leverages a dataset spanning a longer time horizon (2000–2021).

Our central hypothesis is that market deregulation and the gold price boom have increased violence through the expansion of illegal gold mining in the Brazilian Amazon. Higher returns from illegal extraction encourage competition over deposits among rival mining groups, increase labor conflicts in mining areas, and expand exploratory incursions into the territories of local communities and Indigenous peoples. In the absence of well-defined property rights and formal dispute-resolution mechanisms, these conflicts tend to be settled through threats and violence (Mehlum et al., 2006; Idrobo et al., 2014; Chimeli and Soares, 2017; Fetzer and Marden, 2017; Pereira and Pucci, 2026).

To test this hypothesis, we employ a difference-in-differences strategy, comparing municipalities with gold deposits located in protected areas – where mining is prohibited and therefore illegal – with municipalities outside these areas, before and after market deregulation and the gold price boom. The identification is based on the exogeneity of these shocks and the plausibly random distribution of gold deposits in protected areas. Under the parallel-trends assumption, this approach allows us to isolate the causal effect of illegal gold mining on local violent crime.

Using this empirical strategy, we document a large, visually clear, and statistically significant increase in homicide rates in municipalities more exposed to illegal mining following market deregulation and the gold price boom. Consistent with Pereira and Pucci (2026), we estimate that the deregulation of the market is associated with an increase of approximately 8 homicides per 100,000 inhabitants. In comparison, a gold price boom comparable to that observed during the analyzed cycle implies an increase of 6–7 homicides per 100,000 inhabitants. These estimates indicate that, in the absence of these shocks, 1,218 and 1,908 homicides could have been avoided, respectively. This represents approximately 11% and 17% of homicides recorded in municipalities with illegal gold deposits. These results are robust to different specifications and do not reflect preexisting differences in trends.

The observed violence aligns with our hypothesis that market deregulation and the boom in gold prices have increased profits from illegal mining, thereby intensifying local conflicts over gold deposits and territorial control. By decomposing homicide rates, we document that the increase in violence is concentrated among male victims and black or indigenous individuals, occurs predominantly outside the home, and is not associated with police lethality. The means employed – primarily firearms and knives, and, to a lesser extent, physical assault, fire, or chemical agents – are also consistent with interpersonal conflicts and criminal disputes in the context of illegal natural resource exploitation in remote areas (Chimeli and Soares, 2017; Fetzer and Marden, 2017; Idrobo et al., 2014).

The analysis of the mechanisms reinforces this interpretation by providing evidence that the main transmission channel of market deregulation and the gold price boom is the expansion of illegal mining activity, characterizing a mechanism of rapacity. Consistent with this, we find that the rise in violence is strongly linked to the intensification of illegal extraction, as reflected in the disproportionate increase of land used for small-scale mining (*garimpo*) in municipalities most exposed to illegal gold mining. In contrast, we find no significant changes in land use for industrial gold mining. We also do not find evidence that the effects operate through the expansion of illicit parallel markets or through increased social disorganization. Nor is there evidence that illegal mining generates local economic or social benefits: there is no observed increase in per capita income, nor improvements in health indicators or urban infrastructure.

However, we document a significant deterioration in labor market conditions and fiscal capacity in municipalities more exposed to illegal gold mining. A decline in formal employment, combined with reductions in the share of royalty revenues - whether measured relative to total municipal revenue or to public expenditure - suggests both a reduction in the opportunity cost of crime and a weakening of the state's capacity to provide public goods and security. These results indicate that, while the primary transmission channel of the shocks is the intensification of conflicts directly associated with the increase in illegal gold extraction (rapacity), mechanisms related to the reduction of legal economic opportunities (opportunity cost) play a complementary role.

This thesis contributes to the literature examining the relationship between market illegality and violence by exploiting a rare, permanent, and exogenous institutional shock with broad economic, social, and environmental effects. While the existing literature focuses on supply and demand shocks in illicit markets (Castillo et al., 2020; Mejía and Restrepo, 2011; Angrist and Kugler, 2008), repressive policies (Dell, 2015), or prohibitive interventions (Stoop et al., 2019; Chimeli and Soares, 2017; Parker and Vadheim, 2017), we study a regulatory change that altered incentives for legality along the gold production chain. We document that a permanent reduction in the costs and risks associated with downstream illegal trade reshaped incentives for gold extraction in prohibited areas, leading to a persistent increase in violent crime and a deterioration of local environmental and economic conditions.

This work also provides a theoretical contribution by extending the model of Pereira and Pucci (2026) to incorporate the risks of arrest and penalties into the optimization problem faced by illegal gold miners. In line with Castillo et al. (2020), we interpret these risks as a measure of the state's capacity to protect property rights. The extended model indicates that violence linked to illegal mining can be reduced through two complementary mechanisms: (i) decentralized monitoring, holding downstream buyers accountable for the origin of the gold, and (ii) centralized monitoring, with the government investing in upstream law enforcement and environmental policing. Although both mechanisms are theoretically effective in the model, the comparison between the two institutional designs suggests that decentralized monitoring may involve lower relative implementation costs, as it relies on private incentives along the production chain. This result should be interpreted as an institutional inference derived from the theoretical framework, rather than a direct empirical assessment of costs and effectiveness.

This complementary perspective also speaks to the literature on property rights and violence (e.g., Castillo et al., 2020; De La Sierra, 2020; Chimeli and Soares, 2017; Fetzer and Marden, 2017; Dell, 2015) by demonstrating how different institutional arrangements shape incentives for the appropriation of natural resources in contexts of low state capacity. The work also advances the literature on mining and conflict by shifting the focus from the relationship between mineral wealth and violence to the analysis of institutional responses to illegal extractive activities (Berman et al., 2017; Idrobo et al., 2014; Maystadt et al., 2014). In contrast to studies on certification schemes (Berman et al., 2017), concession regimes (Maystadt et al., 2014), or trade restrictions (Stoop et al., 2019; Parker and Vadheim, 2017), we show that a regulatory intervention that exempts private intermediaries from responsibility for the origin of gold weakens decentralized monitoring and increases violence associated with illegal mining.

Moreover, this thesis contributes to the extensive literature examining the effects of natural resource wealth on violence and conflict (Berman et al., 2017; Caselli et al., 2015; Lei and Michaels, 2014; Maystadt et al., 2014; Dube and Vargas, 2013; Rohner, 2006; Collier and Hoeffler, 2005), particularly to the subset that focuses on criminal activities (Soares and Souza, 2025; Ishak and Méon, 2023; Axbard et al., 2021; Corvalan and Pazzona, 2019; Andrews and Deza, 2018; James and Smith, 2017). We show that a positive income shock (the gold price boom) intensifies violent crime in areas exposed to illegal gold mining, and that these effects operate through rapacity and opportunity cost channels. In particular, we found that when legal earnings are minimal or nonexistent, both mechanisms align, further increasing incentives for illegal activity.

The remainder of the thesis is organized as follows. Section 2 presents the institutional context of gold mining and violence in the Brazilian Amazon. Section 3 presents the theoretical model linking illegal gold mining to local violence. Section 4 describes the data and research design. Section 5 presents the main results. Section 6 explores the underlying economic mechanisms and discusses the interpretations. Section 7 presents the conclusions and policy recommendations.

2 INSTITUTIONAL BACKGROUND

This section presents the institutional context of gold mining in the Brazilian Amazon. Subsection 2.1 describes the geographic and operational characteristics of gold extraction, highlighting the link between illegality and local violence. Subsection 2.2 presents the legal and illegal gold markets. Finally, Subsection 2.3 discusses the international gold price boom and market deregulation, emphasizing how these shocks reshaped incentives for illegal mining.

2.1 ILLEGAL GOLD MINING AND VIOLENCE IN THE BRAZILIAN AMAZON

More than one-third of Brazil's gold production comes from the Amazon, one of the world's most important biomes (Agência Nacional de Mineração, 2021). Spanning nine states and approximately half of the national territory (Figure 1), the region constitutes Brazil's main gold frontier and hosts a large number of small-scale mining operations (*garimpos*).[6] Between 2000 and 2021, land used for gold mining nearly tripled, expanding by approximately 116,200 hectares (MapBiomas, 2024).[7] Notably, over 90% of this growth in gold mining occurred in municipalities containing protected areas, such as indigenous territories and conservation units, where this activity is strictly prohibited.

Small-scale mining, known as *garimpo*, represents the traditional form of gold extraction in the region. *Garimpos* are typically situated along riverbeds, floodplains, and

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[6] The Amazon is one of Brazil's largest biomes, covering more than 40% of the national territory. It comprises 559 municipalities, distributed across the states of Acre, Amapá, Amazonas, Pará, and Roraima, as well as parts of Maranhão, Mato Grosso, Rondônia, and Tocantins. In addition, the region hosts the world's largest tropical rainforest, spanning more than 4 million square kilometers, and contains approximately 20% of the planet's freshwater (IBGE, 2024).

[7] Equivalent to approximately 169,200 times the size of the Anfield football (soccer) field in Liverpool, England.

dense forest areas, employing techniques such as floating dredges, barges, suction pumps, hydraulic excavators, and backhoes. Furthermore, small-scale miners commonly use mercury to separate raw gold. These methods allow rapid development of new extraction sites with minimal capital investment and high mobility.[8] From an organizational perspective, they range from small groups of artisanal miners to complex networks involving financiers, local operators, and criminal organizations (Pereira and Pucci, 2026; Siqueira-Gay and Sánchez, 2021).

Most small-scale gold miners in the Amazon operate illegally, although it is possible to obtain a license (Sousa et al., 2011). These miners account for more than one-third of national gold production, although this likely understates their true contribution due to extensive informal activity. Brazil ranks among the world's ten largest gold producers, with annual production of approximately 100 metric tons, about 90% of which is exported. Recent estimates suggest that at least one quarter of this production originates from illegal sources (Sousa, 2023; Risso et al., 2021; Rodrigues, 2021).

In addition to accounting for a substantial share of the gold produced and exported by Brazil, illegal mining in the Amazon region also imposes high environmental and social costs. It is estimated that each kilogram of gold extracted causes environmental damage of approximately R$ 1.7 million (US$ 315,000 in 2021), nearly ten times the gold's market value (Risso et al., 2021). The resulting deforestation threatens the livelihoods and security of local populations, including Indigenous peoples (Silva et al., 2023). As mining expands into protected areas, conflicts with communities resisting territorial invasion and environmental degradation are becoming increasingly frequent. In contexts characterized by already weak property rights and limited access to the legal system, intimidation and violence are widely used in conflict resolution.[9] Consistent with this dynamic, reported cases of violence against Indigenous peoples linked to territorial invasions and illegal extraction increased by 135% between 2018 and 2019 (Risso et al., 2021; Rangel, 2020).

Illegal gold mining also affects other parallel illicit markets. Mining areas often overlap with routes used for arms and drug trafficking, clandestine airstrips, and the

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[8] Security agencies and non-governmental organizations estimate that the initial capital investment required for garimpo operations in the Amazon ranges from approximately US$ 20,000 to US$ 650,000. Capital-intensive operations, such as "*Balsas de Garimpo*", require upfront investments of up to US$ 650,000, whereas "*Garimpos de Baixão*" typically require investments of up to US$ 280,000. Despite these entry costs, such operations are highly profitable in the region, with reported monthly revenues reaching US$225,000 (Instituto Escolhas, 2023).

[9] These conflicts arise from competition among *garimpeiros*, disputes over revenue sharing and labor arrangements within mining areas, confrontations with Indigenous communities over the control and protection of natural resources, and other factors.

circulation of illegal goods such as gemstones, narcotics, and timber. Reports further document labor practices analogous to slavery and the employment of children in mining areas (Ministério Público Federal, 2020). These dynamics have fostered the emergence of hybrid criminal organizations, including so-called "*narcogarimpos*", in which drug trafficking groups exploit gold mining and trade to launder proceeds from narcotics activities (Fórum Brasileiro de Segurança Pública, 2024).

This link between illegal mining and crime underscores the importance of the institutional design of the gold market. To better contextualize this dynamic, the next section presents the regulatory framework that distinguishes legal from illegal gold production in Brazil.

2.2 GOLD MARKET: LEGAL VS. ILLEGAL

Gold is considered legal in the Brazilian market when it is extracted under a license issued by the National Mining Agency (*Agência Nacional de Mineração*, ANM).[10] Small-scale miners must hold a *Permissão de Lavra Garimpeira* (PLG) to exploit irregularly distributed gold deposits. Industrial miners, in turn, must hold a *Concessão de Lavra* (CL), which imposes stricter requirements, including compliance with environmental regulations.

The primary difference between these regimes lies in the scale of production and their licensing requirements. In this sense, the PLG is subject to fewer requirements, as it does not require detailed prospecting reports, thereby limiting authorities' oversight of gold production and trade.[11] This institutional gap creates opportunities for gold illegally extracted from protected areas to be sold as if it originated from authorized sites, a practice known as "*lavra fantasma*". Not surprisingly, this framework has encouraged PLG applications to the mining regulatory agency. The number of PLG applications for gold mining in the Amazon region increased from approximately 500 in 2000–2012 to around 4,500 in 2013–2021. During this period, the agency granted 3,688 PLG licenses, of which 72% were for mineral extraction in the region (Agência Nacional de Mineração, 2024). Although it is difficult to quantify how many of these licenses are used for illicit activities, federal

[10] Figure A1 in the Appendix presents a detailed diagram of the gold regulatory chain and its links to violent crime and local economic outcomes. This diagram provides the foundation for the theoretical framework that is subsequently developed.

[11] The regulatory framework established by Law 7,805 in the 1980s was created for a different economic and technological context. The more permissive license for small-scale mining was based on Decree-Law 227/1968, which defined "*garimpagem*" as individual work using rudimentary tools, manual devices, or simple portable machinery. Historically, *garimpagem* was viewed as a short-term, labor-intensive extractive activity that involved vulnerable workers.

prosecutors and law enforcement authorities indicate that irregular use is common due to limited oversight (Ministério Público Federal, 2020).

However, most of Brazil's legally recognized gold production is associated with extraction under the PLG license. Of the 94 tons of gold produced in 2020, approximately 80% were declared under this licensing regime. Of this total, the Amazon accounted for nearly all production (Agência Nacional de Mineração, 2021).

Legally extracted gold by small-scale miners must be sold directly to PCOs – the first buyers. These stores operate in the market with government authorization and are supervised by the Central Bank of Brazil. Located near mining areas in the Amazon, PCOs initially purchase raw gold, which is then sent to refineries for processing into gold bars before entering the financial market. By recording these transactions, these private intermediaries help combat tax evasion and monitor the origin of gold production. In 2021, the Amazon region had 75 PCOs, distributed across 24 municipalities and linked to 8 different financial institutions (Banco Central do Brasil, 2017; 2026).

This institutional arrangement facilitates decentralized monitoring of gold production through compliance procedures implemented by PCOs to prevent irregularities and serious crimes. As the primary gateway for gold entering the Brazilian financial market, PCOs are required to verify sellers' personal information (*garimpeiros*), the validity of the mining license (PLG), the declared origin of the metal, and the quantity of gold before finalizing a transaction. Each transaction must be documented with a fiscal invoice, which is retained on-site for ten years and submitted to the institution's headquarters, the federal tax authority (*Receita Federal*), and the seller. This process aims to prevent tax evasion and ensure the legal origin of the gold (Pereira and Pucci, 2026).

In the absence of a gold certification system, verification of origin relies almost exclusively on self-declaration. This makes the market particularly vulnerable to illicit practices, such as "*esquentamento*" and "*lavra fantasma*", which facilitate the laundering of gold through commercial transactions with PCOs (Instituto Escolhas, 2022).[12] However, prior to 2013, these intermediaries were not exempt from risks and penalties if they became involved in illegal schemes, including imprisonment, fines, and revocation of authorization

[12] See the article from *G1 Pará* (accessed June 28, 2024), *"Como garimpeiros 'esquentaram' toneladas de ouro ilegal da Amazônia em esquema bilionário que abastecia o exterior"*, available at: https://g1.globo.com/pa/para/noticia/2023/02/15/como-garimpeiros-esquentaram-toneladas-de-ouro-ilegal-da-amazonia-em-esquema-bilionario-que-abastecia-o-exterior.ghtml.

to operate in the market.[13] These risks can be illustrated by operations carried out by the Federal Police. For example, in 2012, "*Operação Eldorado*" investigated and prosecuted a financial institution for gold laundering valued at approximately R$150 million.[14] Moreover, the sector's collective response further reinforced risks of liability and punishment: financial institutions lobbied lawmakers in National Congress to reduce their responsibility for verifying the origin of gold, culminating in the deregulation of the market in 2013. This reform would later become the weakest link in Brazil's gold production chain (Pereira and Pucci, 2026).

2.3 FROM BOOM TO DEREGULATION OF THE GOLD MARKET

This section presents two economic shocks that affected gold-mining areas in the Amazon region over the past two decades: (i) the boom in international gold prices and (ii) market deregulation. These shocks likely changed the incentives for illegal mining and affected local violence.

2.3.1 The Gold Price Boom

Gold is one of the most valuable and widely traded commodities in the world. Its price typically rises during periods of macroeconomic instability – such as financial crises, geopolitical tensions, and episodes of global uncertainty – when investors reallocate portfolios toward safe-haven assets. As a globally accepted store of value, gold differs from other precious metals and becomes particularly attractive during periods of financial distress (Białkowski et al., 2015).

Between 2000 and 2021, the international price of a troy ounce (approximately 31.1 grams) increased from US$ 279 to US$ 1,144, representing a rise of more than 300% (Figure 2). Domestic gold prices followed a similar trajectory, increasing by more than 230% over the same period. This sustained price increase reflects global macro-financial factors, including the 2008 financial crisis and rising demand for gold as a financial asset among

[13] Private intermediaries may be held accountable for their involvement in gold-laundering schemes and are subject to the sanctions provided for in Law No. 9,613/1998 (the Money Laundering Law). This law provides for prison sentences of three to ten years, in addition to fines, in cases where deliberate participation in such schemes is established or where there is a failure to report suspicious transactions to the competent authorities.

[14] See the article from *G1 Rondônia* (accessed January 21, 2026), *"PF deflagra operação contra extração ilegal em RO e outros seis estados"*, available at: https://g1.globo.com/ro/rondonia/noticia/2012/11/pf-deflagra-operacao-contra-extracao-mineral-em-ro-e-outros-seis-estados.html.

investors and central banks in emerging economies. China and India, in particular, account for more than half of global gold consumption.

The gold price boom raises expected mining revenues, incentivizing extraction in gold-rich regions such as the Brazilian Amazon. While higher prices encourage legal mining activities, they also promote illegal mining. As a result, competition over the control of gold deposits and their production (i.e., their profits) may intensify, potentially contributing to higher levels of local violence (Axbard et al., 2021; Idrobo et al., 2014).

2.3.2 Gold Market Deregulation

At the beginning of 2013, the federal government issued a Provisional Measure (*Medida Provisória*, MP) originally intended to establish a public assistance program for small farmers affected by droughts or floods. However, during its passage through the National Congress, legislators introduced an unrelated amendment establishing regulatory changes to the buying, selling, and transportation of gold in Brazil. These changes reduced verification requirements in ways that benefited lobbyists in the mining sector and financial institutions controlling the PCOs.[15]

The amendment was approved and subsequently enacted as part of Law No. 12,844. Under the new legal framework, once the information provided by the seller is duly recorded by legally authorized purchasing institutions (PCOs), both the legality of the gold and the good faith of the purchasing entity are presumed. In this regulatory framework, responsibility for the origin and legality of the gold rests exclusively with the seller (*garimpeiro*), effectively shielding purchasing institutions from legal liability.[16]

The introduction of this presumption-based system substantially reduced the risk of sanctions and penalties for PCOs. Although these intermediaries remained formally required to issue invoices and maintain transaction records, the reform weakened their incentives to report irregularities in gold purchases. As a result, the law effectively

[15] Law No. 12,844 introduced changes to the regulation of the gold market after strong political pressure from the National Gold Association (*Associação Nacional do Ouro*, ANORO) and financial institutions involved in gold trading in the Amazon region. The reform, introduced through a parliamentary amendment attached to unrelated legislation, reduced the liability of institutions that control PCOs. Approved in July 2013 after earlier unsuccessful attempts, the measure reflected an ongoing political debate that had been underway since late 2012 and was likely to have immediate effects on the raw gold market. Access the law at: https://www.planalto.gov.br/ccivil_03/_ato2011-2014/2013/lei/l12844.htm.

[16] According to federal prosecutors, this system of legal presumptions reflects the State's implicit acknowledgment that a substantial share of gold extracted in the Brazilian Amazon originates from illegal mining activities (Ministério Público Federal, 2020).

dismantled the decentralized monitoring mechanism, creating institutional loopholes that facilitate the purchase and laundering of illegal gold.

Since then, federal enforcement agencies have become increasingly reliant on centralized monitoring mechanisms and direct interventions, which have proven insufficient given the vastness of the Amazon region and persistent budgetary constraints. In this context, descriptive evidence indicates an increase in illegal mining, deforestation, and violence following market deregulation. For example, between 2004–2012 and 2013 – 2021, the total number of homicides in municipalities with gold mining activities in the Brazilian Amazon rose from 45,800 to 65,900 – an increase of approximately 45% (Ministério da Saúde, 2024).

This understanding was later corroborated by the Supreme Federal Court (*Supremo Tribunal Federal*, STF). In 2023, following a lawsuit filed by political parties, the Court temporarily suspended the provisions of Law No. 12,844 that presumed the legality of acquired gold and the good faith of purchasing entities. The STF argued that these provisions weakened the monitoring mechanisms for gold mining and imposed disproportionate costs on local communities, thereby undermining environmental protection and public safety. The suspension remains in effect until the federal government proposes a new regulatory framework and the National Congress approves it.

Overall, the 2013 reform reduced the expected cost of transacting illegal gold in the downstream market, while state enforcement had to intensify over illegal extraction in the upstream market.

3 THEORETICAL FRAMEWORK

This section extends an economic model to analyze how the gold price boom and market deregulation may affect local violent crime. The model examines interactions between agents operating in upstream and downstream gold markets. In the downstream market, private intermediaries (PCOs) compete to purchase both legal and illegal gold extracted by miners (*garimpeiros*). Meanwhile, miners compete for access to gold deposits and the revenues generated at each location.

We extend the theoretical model proposed by Pereira and Pucci (2026) by reformulating the problem faced by illegal miners. This reformulation incorporates the risk of arrest and financial penalties (fines). By doing so, the optimization problem of illegal miners aligns with the core ideas of crime economic models (e.g., Becker, 1968; Ehrlich, 1971; Silva et al., 2007), which posit that rational agents weigh the expected costs and benefits before engaging in illicit activities. Following Castillo et al. (2020), we interpret the risk of arrest and financial penalties as indicators of institutional quality. This formulation allows the model to explicitly account for both centralized and decentralized monitoring mechanisms.

3.1 A MODEL OF GOLD AND BLOOD

3.1.1 Economic Environment

We consider a small open economy in which the gold market is structured into upstream and downstream segments. In the downstream market, firms compete to purchase gold from both legal and illegal sources and resell it to financial-sector institutions at a final price. In turn, the upstream market comprises miners (garimpeiros) competing to extract and sell raw gold to downstream firms. Miners may choose between legal mining, which requires a license and payment of taxes, or illegal mining, which exposes them to the risk of arrest and fines. To acquire or defend control over clandestine mining areas, illegal miners often invest in weapons and resort to violence.

Specifically, we consider an economy where there are N municipalities indexed by $n \in N = \{1, 2, \ldots N\}$, J firms in the downstream market (PCOs) indexed by $j \in J = \{1, 2, \ldots, J\}$, and L legal miners (*garimpeiros legais*) and I illegal miners (*illegal garimpeiros*) in the upstream market indexed by $l \in L = \{1,2, \ldots, L\}$ and $i \in I = \{1,2, \ldots, I\}$, respectively. Thus, in each municipality there are G miners indexed by $g \in G = \{1,2, \ldots, G\}$.

3.1.2 Downstream Market

A *downstream market* firm maximizes its profit by choosing the quantities of legal and illegal gold to purchase, taking into account market prices and the expected penalties in case of seizure during an illicit transaction. Thus, the firm's optimization problem can be expressed by the following equation:

$$\max \Pi_J = p_S Q - p_L Q_L - [(1-\theta) p_I Q_I + \theta(p_I + f) Q_I], \text{ where } Q = \left(\alpha Q_L^{\frac{\sigma-1}{\sigma}} + (1-\alpha) Q_I^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} \quad (3.1)$$

where Q is the demand for gold, given by the sum of the demands for legal (Q_L) and illegal (Q_I) gold. Furthermore, we consider a demand function with constant elasticity of substitution (CES), where α and $(1 - \alpha)$ indicates the relative weights of legal and illegal gold in demand $\{\alpha \in (0,1)\}$, while σ is the substitution parameter (Arrow et al., 1961).[17] p_S is the final price paid by financial sector institutions (S) for gold, while p_L and p_I are the acquisition prices of the legal (L) and illegal (I) gold from the *garimpo*, respectively. The acquisition cost of legal gold is given by $p_L Q_L$.

Based on the models of Becker et al. (1968), Ehrlich (1971), and Pereira and Pucci (2026), we assume that downstream firms, when buying illegal gold, must consider at least two factors: first, the probability of being detected $\theta \in [0,1]$ in an illicit transaction by the authorities. Second, firms should consider penalties (e.g., fines and imprisonment) if caught in an illegal transaction (f). Therefore, we define the expected acquisition cost of illegal gold as $\theta(p_I + f)Q_I$ when an illicit transaction is identified, while $(1-\theta)\, p_I Q_I$ when no irregularities are detected.

To find the profit-maximizing conditions, we calculate the partial derivatives of Π_J with respect to the quantities demanded of legal and illegal gold. The resolution of the maximization problem provides the equilibrium prices:

$$p_L = \frac{p_S \alpha \left(\alpha Q_L^{\frac{\sigma-1}{\sigma}} + (1-\alpha) Q_I^{\frac{\sigma-1}{\sigma}} \right)^{\frac{1}{\sigma-1}}}{(Q_L)^{1/\sigma}} \tag{3.2}$$

$$p_I = \frac{p_S (1-\alpha) \left(\alpha Q_L^{\frac{\sigma-1}{\sigma}} + (1-\alpha) Q_I^{\frac{\sigma-1}{\sigma}} \right)^{\frac{1}{\sigma-1}}}{(Q_I)^{1/\sigma}} - \theta f \tag{3.3}$$

Equation (3.3) shows that when expected sanctions decrease ($-\theta f$), downstream market firms become more willing to pay for illegal gold. This, in turn, reflects the impact of market deregulation.

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[17] Given that it is a standard CES function, equation nests a *Cobb-Douglas* function when ($\sigma = 1$); a *Leontief* function with fixed input proportions when ($\sigma = 0$); and a linear production function with perfect substitution between legal and illegal gold when ($\sigma = \infty$). Pereira and Pucci (2026) consider the special case of the *Cobb–Douglas* function, implying a fixed unitary elasticity of substitution. In contrast, the specification adopted here is more general because it relaxes this restriction, allowing the elasticity of substitution between legal and illegal gold to be determined by the institutional context. This broadens the model's explanatory power without altering its qualitative implications, while only refining the mechanism through which regulatory and risk shocks are transmitted to market equilibrium. In this sense, the main contribution of the generalization is to allow the degree of substitution not to be imposed a priori, but to vary according to relevant institutional and economic factors, such as the intensity of enforcement, regulatory risk, and transaction costs associated with the illegal market.

3.1.3 Upstream Market

Legal miners. Miners must obtain a license from the mining regulatory agency to legally extract gold. We model this by assuming that miners face a probability $\phi \in [0, 1]$ of obtaining a license. The expected profit maximization problem is then given by:

$$\max \Pi_{g,n,L} \ (1 - \phi)\big(p_L q_{g,n,L} - c(q_{g,n,L}) - \tau q_{g,n,L}\big) - x \tag{3.4}$$

where $q_{g,n,L}$ is the quantity of legally extracted gold. c is the operational cost of mining as a function of the quantity of gold extracted $c(q_{g,n,L})$, x is the fixed cost and τ is a fee paid for the extraction of gold to the government. The operational cost of the miners $c\big(q_{g,n}\big)$ is considered increasing, convex and satisfies the following conditions: $\lim_{q_{g,n} \to 0} c^{'}(q_{g,n}) = \infty$ and $\lim_{q_{g,n} \to \infty} c^{'}(q_{g,n}) = 0$ (Castillo et al., 2020).

Deriving the profit function in relation to $q_{g,n,L}$ and considering the inverse of the derivative $c'^{-1}(.) = \mu(.)$ as the marginal cost of production, we obtain the optimal levels of gold extraction and profit for legal miners.

$$q^*_{g,n,L} = \mu(p_L - \tau) \tag{3.5}$$

$$\Pi^*_{g,n,L} = (1 - \phi)\left(p_L \mu(p_L - \tau) - c\big(\mu(p_L - \tau)\big) - \tau\mu(p_L - \tau)\right) - x \tag{3.6}$$

Illegal miners. The miners who decide to extract gold without a license face the risk of imprisonment and fines $\varphi \in [0,1]$. This maximization problem differs from that proposed by Pereira and Pucci (2026), who disregard the risks miners face when they decide to extract gold illegally. The new expected profit maximization problem for illegal miners is given by:

$$\max \Pi_{g,n,I} = (1 - \varphi)\big(p_I q_{g,n,I} - c(q_{g,n,I})\big) - x - \varphi m q_{g,n,I} \tag{3.7}$$

where $q_{g,n,I}$ is the quantity of illegally extracted gold, while m is the penalty if a miner is caught extracting gold illegally (e.g., fines and imprisonment). The probability of obtaining revenue by illegally extracting gold without being caught is $(1 - \varphi)$, and of not earning any revenue and still suffering a penalty is φ. By hypothesis, we assume that the penalty depends on the quantity of gold extracted (Becker et al., 1968; Ehrlich, 1971).

Deriving the profit function with respect to $q_{g,n,I}$, we obtain the optimal level of gold extraction and profit for illegal miners:

$$q^*_{g,n,I} = \mu\left(p_I - \frac{\varphi}{1-\varphi} m\right) \tag{3.8}$$

$$\Pi^*_{g,n,I} = (1-\varphi)\left(p_I\mu\left(p_I - \frac{\varphi}{1-\varphi}m\right) - c\left(\mu\left(p_I - \frac{\varphi}{1-\varphi}m\right)\right)\right) - x - \varphi\mu\left(p_I - \frac{\varphi}{1-\varphi}m\right)m \quad (3.9)$$

3.1.4 Law Enforcement Against Illegal Miners

The term φ can be interpreted as a measure of how much a centralizing authority can credibly protect property rights (Castillo et al., 2020). To ensure property rights, we assume that the government invests in control, monitoring, and policing to enforce environmental laws against illegal miners.

To illustrate, we can assume that φ is an increasing function of β, i.e., the greater the investment (β), the higher the probability of an illegal miner being caught. To model this relationship, we use a logistic function: $\varphi(\beta) = \frac{1}{1+e^{-\alpha(\beta-\beta_0)}}$. Here, α is a parameter that determines the sensitivity of the probability φ to the investments β, while β_0 is the level of investment from which the probability φ begins to increase significantly. The logistic specification is a reduced-form way to capture diminishing marginal returns to enforcement.

3.1.5 Investment in Weapons and Local Violence

Following Pereira and Pucci (2026) and Castillo et al. (2020), we assume that illegal miners from each municipality first decide how many resources to allocate to weaponry ($w_{g,n}$) to succeed in the competition for gold deposits. The underlying logic is that illegal gold miners (I) make backward-looking decisions about how much to invest in weaponry to appropriate or contest a share of the municipality's gold market revenue, often resorting to violence to achieve such success.

Therefore, there are *garimpeiros* (g) in each municipality (n) who simultaneously decide values of $w_{g,n} \geq 0$ to invest in weapons. Each miner holds a part of the total investment in weapons. As a result, each miner can obtain a fraction of the contestable earnings in the municipality from the following contest success function: $\omega_{g,n} = \frac{w_{g,n}}{\sum_{g' \in N_{n,I}} w_{g',n}}$, where $N_{n,I}$ is the number of illegal miners (Skaperdas, 2002).

Given the profit function, the investment maximization problem in weapons faced by all miners in the municipality can be expressed by the following equation:

$$\max_{w_{g,n}}\{\Pi^0_{g,n}\omega_{g,n} - w_{g,n} - x\}, \text{ with } \omega_n \geq 0 \text{ and } w_{g,n} \geq 0 \quad (3.10)$$

where the initial profit is assumed to be: $\Pi^0_{g,n} = p_I q_{g,n} - c(q_{g,n})$.

Introducing the contest success function into the investment problem (3.10) and the optimal production derived for illegal miners (3.8) into the initial profit function ($\Pi^0_{g,n}$), we obtain the equilibrium investment in weapons[18]:

$$w^*_{g,n} = \Pi^{0*}_{g,n}\left(\frac{N_{n,I}-1}{N^2_{n,I}}\right), \text{ where } \Pi^{0*}_{g,n} = p_I\mu\left(p_I - \frac{\varphi}{1-\varphi}m\right) - c\left(\mu\left(p_I - \frac{\varphi}{1-\varphi}m\right)\right). \tag{3.11}$$

Different from the equation proposed by Pereira and Pucci (2026), investments in armament now depend on the number of illegal miners in the municipality, the market price, operational costs, the probability of arrest, and the fines imposed if a miner is caught extracting gold illegally.[19] This new equation incorporates the fundamental elements of the standard crime economy models of Becker et al. (1968) and Ehrlich (1971).

The optimal profit of the illegal gold miner is obtained by introducing the contest success function and the equilibrium investment level (3.11) into the previously expressed maximization problem (3.10)[20]:

$$\Pi^*_{g,n,I} = \frac{1}{N^2_{n,I}}\left[p_I\mu\left(p_I - \frac{\varphi}{1-\varphi}m\right) - c\left(\mu\left(p_I - \frac{\varphi}{1-\varphi}m\right)\right)\right] - x \tag{3.12}$$

The aggregate level of violence related to gold mining in the municipality is given by the following equation (Castillo et al., 2020):

$$v^*_n = \sum_{I\in N_I} w^*_{g,n} = \left[p_I\mu\left(p_I - \frac{\varphi}{1-\varphi}m\right) - c\left(\mu\left(p_I - \frac{\varphi}{1-\varphi}m\right)\right)\right]\left(\frac{N_{n,I}-1}{N_{n,I}}\right) \tag{3.13}$$

Equation (3.13) shows that the level of violence results from the aggregation of weapons expenditures by illegal gold miners in the municipality.

3.1.6 Market Clearing Conditions

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[18] To differentiate $\omega_{g,n}$ with respect to $w_{g,n}$, we used the quotient derivation rule: $\frac{\partial \omega_{g,n}}{\partial w_{g,n}} = \frac{N_{n,I}w_{g,n} - w_{g,n}}{(N_{n,I}w_{g,n})^2}$. Considering this result and deriving the investment problem with respect to $w_{g,n}$ and equating to zero, we obtain the condition for maximizing the investment in weapons: $\frac{N_{n,I}w_{g,n} - w_{g,n}}{(N_{n,I}w_{g,n})^2} = \frac{1}{\Pi^0_{g,n}}$. To find the equilibrium result ($w^*_{g,n}$), isolate $w_{g,n}$.

[19] To illustrate this distinction more clearly, imagine that as illegal miners invest in weaponry, it becomes increasingly difficult for authorities to apprehend them for environmental crimes. This, in turn, further incentivizes these miners to invest even more in arms. Consequently, this process may lead to increased local violence.

[20] $\Pi^*_{g,n,I} = \Pi^{0*}_{g,n,I}\frac{w^*_{g,n}}{N_{n,I}w^*_{g,n}} - \Pi^{0*}_{g,n,I}\left(\frac{N_{m,I}-1}{N^2_{n,I}}\right) - x.$

The market equilibrium for the quantity of raw gold is achieved when the downstream market demand for gold (Q) balances the gold supply from the miners (g) in the upstream market, given by the aggregation of the quantities of legal (q_L) and illegal (q_I) gold in each municipality (n). Considering the poor state of transportation infrastructure and the vast territorial extension of municipalities in the Amazon region, it is reasonable to assume that there is no significant migration of miners between localities. Therefore, the total number of miners in a given municipality corresponds to the sum of both legal and illegal gold miners ($N_n = N^*_{n,L} + N^*_{n,I}$).[21] Under this assumption, the market equilibrium quantities are as follows (Castillo et al., 2020):

$$Q^*_I = \sum_n \sum_g q^*_{g,n,I} = \mu\left(p^*_I - \frac{\varphi}{1-\varphi}m\right)N^*_{n,I} \tag{3.14}$$

$$Q^*_L = \sum_n \sum_g q^*_{g,n,L} = \mu(1-\tau)(N_n - N^*_{n,I}) \tag{3.15}$$

$$Q^* = \left(\alpha\big(\mu(1-\tau)(N_n - N^*_{n,I})\big)^{\frac{\sigma-1}{\sigma}} + (1-\alpha)\left(\mu\left(p^*_I - \frac{\varphi}{1-\varphi}m\right)N^*_{n,I}\right)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} \tag{3.16}$$

where the price of legal gold is normalized ($p^*_L = 1$) for the solution of the model.

The miners' profits (3.17 and 3.18), the investment in weapons (3.19), and the local violence level (3.20) with the equilibrium prices are:

$$\Pi^*_{g,n,L} = (1-\phi)\Big(\mu(1-\tau) - c\big(\mu(1-\tau)\big) - \tau\mu(1-\tau)\Big) - x \tag{3.17}$$

$$\Pi^*_{g,n,I} = \frac{1}{N^{*2}_{n,I}}\left[p^*_I\mu\left(p^*_I - \frac{\varphi}{1-\varphi}m\right) - c\left(\mu\left(p^*_I - \frac{\varphi}{1-\varphi}m\right)\right)\right] - x \tag{3.18}$$

$$w^*_{g,n} = \left[p^*_I\mu\left(p^*_I - \frac{\varphi}{1-\varphi}m\right) - c\left(\mu\left(p^*_I - \frac{\varphi}{1-\varphi}m\right)\right)\right]\left(\frac{N^*_{n,I}-1}{N^{*2}_{n,I}}\right) \tag{3.19}$$

$$v^*_n = \left[p^*_I\mu\left(p^*_I - \frac{\varphi}{1-\varphi}m\right) - c\left(\mu\left(p^*_I - \frac{\varphi}{1-\varphi}m\right)\right)\right]\left(\frac{N^*_{n,I}-1}{N^*_{n,I}}\right) \tag{3.20}$$

To find the equilibrium price of illegal gold (p^*_I) and close the main equations of the model, we substitute the results from equations (3.14) and (3.15) into equations (3.2) and (3.3) and isolate the resale price of gold (p^I_S and p^L_S).[22] Next, we rearrange and isolate the equilibrium price of illegal gold (3.21).

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[21] This approach abstracts from heterogeneity among miners, entry costs, and other mobility frictions.

[22] $p^L_S = p^I_S = \dfrac{\big(\mu(1-\tau)(N_n - N^*_{n,I})\big)^{\frac{1}{\sigma}}}{\alpha\left(\alpha\big(\mu(1-\tau)(N_n - N^*_{n,I})\big)^{\frac{\sigma-1}{\sigma}} + (1-\alpha)\left(\mu\left(p^*_I - \frac{\varphi}{1-\varphi}m\right)N^*_{n,I}\right)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{1}{\sigma-1}}} = \dfrac{(p^*_I + \theta f)\left(\mu\left(p^*_I - \frac{\varphi}{1-\varphi}m\right)N^*_{n,I}\right)^{\frac{1}{\sigma}}}{(1-\alpha)\left(\alpha\big(\mu(1-\tau)(N_n - N^*_{n,I})\big)^{\frac{\sigma-1}{\sigma}} + (1-\alpha)\left(\mu\left(p^*_I - \frac{\varphi}{1-\varphi}m\right)N^*_{n,I}\right)^{\frac{\sigma-1}{\sigma}}\right)^{\frac{1}{\sigma-1}}}.$

$$p_I^* = \frac{(1-\alpha)}{\alpha}\left[\frac{(N_n - N_{n,I}^*)}{N_{n,I}^*}\frac{\mu(1-\tau)}{\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)}\right]^{\frac{1}{\sigma}} - \theta f \tag{3.21}$$

Equating the profit of legal miners (3.17) and illegal miners (3.18), we can determine the point at which miners become indifferent between operating legally or illegally in the gold market ($\Pi_{g,n,I}^* = \Pi_{g,n,L}^*$).[23] We obtain the equilibrium number of illegal miners (3.20) by rearranging the miners' profit equations.

$$N_{n,I}^* = \sqrt{\frac{1}{(1-\phi)}\frac{\left[p_I^*\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right) - c\left(\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\right)\right]}{\left(\mu(1-\tau) - c(\mu(1-\tau)) - \tau\mu(1-\tau)\right)}} \tag{3.22}$$

3.1.7 Predictions

In this section, we present the main predictions of the theoretical model. The mathematical proofs are presented in Appendix B2.

Prediction 1. *An increase in the risk of a downstream market firm being caught in an illicit trade transaction* ($\theta' > \theta$) *negatively affects illegal miners* ($N_{n,I}^{*\prime} < N_{n,I}^*$) *and violent crimes* ($\upsilon_n^{*\prime} < \upsilon_n^*$). *Therefore, in a market deregulation scenario, i.e., less monitoring in gold trading* ($\theta' < \theta$), *we expect an inverse response from these variables of interest.*

Prediction 2. *A positive shock in gold prices* ($p_I^{*\prime} > p_I^*$) *increases the number of illegal miners* ($N_{n,I}^{*\prime} > N_{n,I}^*$) *and violent crimes* ($\upsilon_n^{*\prime} > \upsilon_n^*$).[24] *In other words, an increase in the price raises the returns to illegal mining, and this intensifies conflicts in areas where enforcement is limited.*

Prediction 3. *When governmental authorities can credibly guarantee property rights* ($\varphi \Rightarrow 1$), *the number of illegal miners* ($N_{n,I}^* \Rightarrow 0$) *and the associated local violence levels approach zero* ($\upsilon_n^* \Rightarrow 0$).[25] *The main prediction is that with effective law enforcement, the*

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[23] $\frac{1}{N_{n,I}^2}\left[p_I^*\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right) - c\left(\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\right)\right] - x = (1-\phi)\left(\mu(1-\tau) - c\left(\mu(1-\tau)\right) - \tau\mu(1-\tau)\right) - x.$

[24] The boom in gold prices increases the expected returns from illegal mining, thereby intensifying the incentives to plunder gold reserves. Since gold is a high-value and easily appropriable asset, higher prices attract new miners to illegal extraction activities. This process heightens competition for mining sites, transportation routes, and protection, leading to increased violence (Dube and Vargas, 2013).

[25] The proof is simple, because the derivative is zero: $\frac{\partial \upsilon_n^*}{\partial \varphi} = 0$ and $\frac{\partial N_{n,I}^*}{\partial \varphi} = 0$. Therefore, miners who extract gold illegally face a higher risk of imprisonment and punishment when the government expands its capacity for environmental law enforcement. As a result, both the number of illegal gold miners and the incidence of violent crime are expected to decrease.

economic incentives for illegal gold mining ultimately become negligible. This is because the risk of being caught and punished outweighs the potential benefits of illegal mining in this new model version. Specifically, this indicates that authorities can combat illegality in the gold market and violence with both centralized ($\varphi' > \varphi$) and decentralized ($\theta' > \theta$) monitoring.

4 DATA AND RESEARCH DESIGN[26]

This section describes the data sources, defines the key variables used in the analysis, and presents our empirical strategy.

4.1 DATA SOURCES AND DEFINITIONS

Our main empirical analysis uses microdata on homicides from 2000 to 2021. This time interval was chosen due to the stabilization of changes in the territorial boundaries of the Amazon biome beginning in 2000 and the availability of data for empirical analysis. The geographical unit of analysis is the municipality. To ensure robust results, we consider only the 546 municipalities that comprised the Brazilian Amazon before the most recent update of the territorial boundaries. By restricting our analysis to the biome, we ensure greater balance in the environmental and sociodemographic characteristics of the municipalities.[27]

Homicide microdata. The data on homicides are derived from annual death certificates for external causes. We have access to microdata from Brazil's Ministry of Health (Ministério da Saúde, 2024), which includes detailed information such as the date of death, cause of death, type of aggression, sex, race, age, and the places of residence and occurrence. Local registration offices issue death certificates based on medical reports that assess the cause of death and the identity of the deceased. By law, no burial may occur in Brazilian territory without an official death certificate.

Using the International Classification of Diseases (ICD-10), we counted homicides by place of occurrence, including all deaths due to assault (X85–Y09) and legal interventions (Y35–Y36). In total, we observed more than 148,000 homicides in the Amazon between 2000 and 2021. We then converted these counts into municipality-year homicide rates by dividing

[26] Appendix G contains the statement describing how artificial intelligence was used in this work.
[27] In 2000, the Amazon region had 546 municipalities. However, in 2019, the Brazilian Institute of Geography and Statistics (IBGE) revised the boundaries of Brazilian biomes, adding 13 municipalities to the Amazon region, bringing the total to 559. In robustness tests, we use the complete sample.

the total number of deaths due to assault and legal interventions by the total population. Several previous studies have adopted a similar approach to calculate homicide rates for Brazilian municipalities (e.g., Soares and Souza, 2025; Ishak, 2022; Dix-Carneiro et al., 2018; Chimeli and Soares, 2017).

To test alternative hypotheses, we also accounted for deaths from traffic accidents, defined as all deaths from transport accidents (V01–V99), and suicides, defined as all deaths from self-inflicted injuries (X60–X84). In addition, we accounted for deaths from drug use, defined as all deaths from mental and behavioral disorders due to the use of psychoactive substances (F10–F19). We then calculated mortality rates for traffic accidents, suicides, and drug use in a manner analogous to homicide rates. To standardize, we express all rates per 100,000 inhabitants. We also calculated the proportion of suicides involving firearms. These variables are used as proxies for social disorganization and illegal markets, such as the drug and firearms trades.

Gold and protected areas microdata. The Geological Survey of Brazil (Serviço Geológico do Brasil – SGB, 2024) provides microdata on mineral resources. Each entry in the database corresponds to a georeferenced point indicating the location of a mineral deposit within a municipality and its mineralogical composition. These deposits, identified by the SGB, result from geological processes that occurred over millions of years. Based on this geological information, we identified the known gold deposits in Brazil (Figure 3). Although found throughout the country, most gold deposits are concentrated in the Amazon biome. Of the more than 4,400 gold deposits distributed across Brazilian territory, approximately 54.2% are in the Amazon. In contrast, of the more than 31,400 deposits containing other mineral substances, only 11.7% are located in this biome.

Although we have access to the location of the geological gold deposits in the Amazon, we do not have information about their productivity. Due to the complexity of mining operations and the high drilling costs, many geological gold reserves have been only superficially explored. To overcome this inherent limitation due to the lack of production data, we consider a municipality as a gold producer if it has at least one deposit containing this mineralogical substance within its territory. Of the 546 municipalities that comprise our main sample, approximately a quarter are considered gold producers (132 municipalities). [28]

[28] When we consider the complete sample (559 municipalities), the number of municipalities in the Amazon with gold deposits increases to 134.

However, it is still necessary to identify the illegality of gold production in the municipalities. To this end, we note that gold mining in the region frequently occurs within Indigenous territories and conservation units, where mining activity is strictly prohibited by law. This does not imply that mining outside protected areas is necessarily legal, but only that it is not categorically prohibited and remains subject to regulatory compliance. Evidence from the *Rede Amazônica de Informações Socioambientais Georreferenciadas* (RAISG, 2020) indicates that illegal mining is heavily concentrated in these protected areas and has expanded rapidly in recent years. According to their estimates, more than 85% of illegal mining activity is currently located within protected areas of the Amazon. Therefore, gold deposits located within protected areas constitute an appropriate strategy for identifying illegal gold mining.

Previous studies have also used this intention-to-treat strategy to identify illegal gold mining (e.g., Idrobo et al., 2014). An advantage of this approach in the Brazilian Amazon is that the process of creating and regularizing protected areas is well structured, and there is no evidence of incentives linked to the presence of mineral deposits. Additionally, we have access to georeferenced microdata from the National Indian Foundation (Fundação Nacional do Índio – FUNAI, 2024) and the Ministry of the Environment (Ministério do Meio Ambiente – MMA, 2024), which contain the boundaries of Indigenous territories and conservation units where mining is restricted.

FUNAI is the Brazilian government entity responsible for demarcating lands occupied for many generations by indigenous peoples, who coexist in balance with nature and the local ecosystem. These territories are demarcated and receive presidential approval after a rigorous identification process, which includes anthropological and land studies. In turn, the MMA established the conservation units at the beginning of the 2000s to preserve biodiversity and ensure an ecologically balanced environment for society. Specifically, the demarcation of conservation units serves as a societal tool to ensure the preservation of natural ecosystems, thereby combating environmental degradation. Although the demarcation process by government bodies may involve some arbitrariness, there is no evidence that the demarcation of protected areas is correlated with the distribution of mineral deposits in the Amazon. In other words, the presence of a gold deposit in an area where mining activity is prohibited is purely incidental.

By combining microdata on the demarcation of Indigenous territories and conservation units with geospatial data on mineral resources, we identify gold deposits that intersect strictly protected areas within the Amazon biome (Figure 4). Of the more than

2,400 mapped gold deposits, approximately 21% are located in areas where mining is prohibited – 16.5% within Indigenous territories and 4.5% within conservation units designated as restricted to mining activities. Among the 134 municipalities in the Amazon region that host gold deposits, 45 have deposits that overlap with protected areas, suggesting the potential presence of illegal gold mining. In contrast, the remaining 89 municipalities have gold deposits located outside these protected areas, where mining is permitted.

Gold Price Data. The World Bank (2024) provides the monthly historical series of international gold prices, expressed in US dollars per troy ounce. This series was converted to annual averages and adjusted to 2000 using the Consumer Price Index (CPI-US). In addition, for comparative analysis, we calculated the national price of gold using the Central Bank of Brazil's commercial exchange rate. We adjusted the values based on the General Price Index – Internal Availability (IGP-DI) from the Getúlio Vargas Foundation (*Fundação Getúlio Vargas*, FGV) for the same base year.[29]

Census Data. The Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística – IBGE, 2000) conducts the Brazilian population census, which reports demographic characteristics – such as gender, age, and race – as well as socioeconomic information, including educational attainment, employment status, occupation, and income. We use these data for two purposes: first, to flexibly control for the initial levels of population density and urbanization in the municipalities of the Amazon region; and second, in robustness exercises, to control for a series of other initial demographic characteristics of the municipality.

Other Data. We collected additional data to strengthen the interpretation of our results and to evaluate alternative hypotheses. These data include gross income (IBGE, 2025); employment and wages of formal-sector workers (Base de Dados, 2025); land use and forest cover (MapBiomas, 2024); maternal and child health indicators (Ministério da Saúde, 2025); and municipal budgets and royalty revenues (STN, 2024; IPEA, 2025). We also obtained information on the location of PCOs (Banco Central do Brasil, 2026) and on natural mahogany areas in the Amazon region (Lentini et al., 2003). Appendix C provides a detailed description of all variables and a statistical summary.

[29] The evolution of gold prices is presented in Figure 2.

4.1.1 Descriptive Data Analysis

Figure 5 shows the evolution of homicide rates over the past two decades. As illustrated in Figure 5.A, prior to the gold price boom in the early 2000s, homicide rates in the Amazon region were very similar to those observed in the rest of Brazil. From 2004 onward, following the gold price boom, homicide rates in the Amazon began to rise more rapidly. This divergence intensified after the deregulation of the gold market in 2013: while homicide rates declined in the rest of Brazil, they continued to rise steadily in the Amazon. Between 2000 and 2021, the homicide rate in the Amazon more than doubled, increasing from 13.7 to 27.7 homicides per 100,000 inhabitants.

Figure 5.B further details these trends in the Amazon region by comparing municipalities with gold deposits located in protected areas (where mining is illegal), municipalities with deposits in non-protected areas (where mining is permitted), and municipalities without gold deposits. Up to mid-2013, homicide rates followed similar trajectories across these groups. After market deregulation, however, there was a sharp increase in homicides in the municipalities most exposed to illegal mining. In contrast, homicide rates remained relatively stable in municipalities less exposed to illegal mining and in those without gold deposits. Between 2000 and 2021, homicide rates in the most exposed municipalities increased by more than 150%, suggesting a potential link between illegal gold mining and local violence.

Figure 6 presents the evolution of land use associated with gold garimpo in the Brazilian Amazon. Although international gold prices began rising in 2003, a substantial expansion of garimpo-related land use became evident only in the mid-2010s, with further acceleration following market deregulation. This pattern is particularly pronounced in municipalities more exposed to illegal mining, whereas municipalities without gold deposits exhibit largely stable land-use trends throughout the period.

Taken together, the descriptive evidence presented so far suggests that the gold price boom and market deregulation may have increased local violence by expanding illegal mining activity.

Statistical Summary. Before introducing the research design, Table 1 presents summary statistics on homicide rates and key sociodemographic characteristics for municipalities in the Amazon region. Municipalities more exposed to illegal gold mining (treated units) exhibit an average homicide rate of 30.7 per 100,000 inhabitants, compared to 26.8 in less exposed municipalities (control units) and 18.7 in municipalities without gold deposits. Using data from the 2000 Demographic Census, we also examined a broad set of basic population characteristics, including gender composition, race, educational attainment, and income inequality. Overall, the statistics indicate that municipalities with higher and lower exposure to illegal gold mining are comparable in terms of their sociodemographic characteristics.

4.2 RESEARCH DESIGN

Using a difference-in-differences empirical strategy, this study investigates the effects of illegal gold mining on violent crime in the Amazon biome. Identification exploits two plausibly exogenous sources of variation in local economic and institutional conditions: (i) the deregulation of the raw gold market in 2013, which exempted private intermediaries from verifying the origin of gold; and (ii) a positive income shock stemming from the boom in international gold prices beginning in 2003. As discussed in the theoretical section, both shocks likely increased the attractiveness and profitability of illegal gold mining. In light of the theoretical model, these shocks, by expanding illegal gold mining, are expected to have increased local violence. The next section presents the empirical specification used to test theoretical predictions 1 and 2 (Section 3.1.7) and outlines the conditions required for causal identification.

4.2.1 Specification

To estimate the impact of illegal gold mining on violent crime, we exploit exogenous variation in international gold prices and the recent market deregulation using the following empirical specification[30]:

$$H_{it} = \beta(\mathbb{G}_i \times \mathbb{I}_i \times \mathbb{S}) + \delta(\mathbb{G}_i \times \mathbb{S}) + \boldsymbol{X}'_{it}\Omega + \textstyle\sum_{z \in Z} \Phi_z \, (z \times \mathbf{FE}_t) + \mathbf{FE}_i + \mathbf{FE}_{st} + \xi_{it} \qquad (4.1)$$

where H_{it} is the homicide rate of municipality i in the year $t \in \{2000, 2001, \dots, 2021\}$, $\mathbb{G}_i$ is a dummy variable indicating whether the municipality has any gold deposit, while $\mathbb{I}_i$ is a dummy variable indicating whether the municipality contains a gold deposit located inside a protected area (illegal gold deposit). $\mathbb{S} = \{\log(\mathbb{P}_{t-1}), \mathbb{D}\}$ refers to the lagged international

[30] This empirical strategy is based on the work of Pereira and Pucci (2026).

gold price $\left(\log(\mathbb{P}_{t-1})\right)$ or the deregulation of the gold market ($\mathbb{D}$) — a dummy variable indicating whether the year is 2013 or later.[31] We add controls for municipality ($\mathbf{FE}_i$) and state-year ($\mathbf{FE}_{st}$) fixed effects, along with an interaction term between population density and the municipal urbanization rate in 2000 (z) and a linear time trend, $\sum_{z\in Z}\Phi_z\,(z\times\mathbf{FE}_t)$. $\boldsymbol{X}'_{it}$ is a vector of exogenous covariates discussed below.[32] Finally, ξ_{it} represents a random error term clustered at the municipal level to address serial and spatial autocorrelation in the data.[33]

The empirical model employs a difference-in-differences framework, comparing municipalities with illegal gold deposits (located within protected areas) to those with gold deposits outside protected areas, both before and after the price boom and market deregulation. Specifically, we compare municipalities that are more or less exposed to illegal gold mining. In this context, the parameter β captures the differential effect on homicide rates in municipalities more exposed to illegal gold mining, conditional on the presence of a gold deposit. If these shocks led to a disproportionate increase in homicide rates in more exposed municipalities, we would expect a positive estimate of this parameter.

Identification. Our main identification hypothesis is that, in the absence of the gold price boom and market deregulation, municipalities with higher and lower exposure to illegal gold mining would have experienced similar changes in homicide rates. Although the validity of this hypothesis depends on an assumption that cannot be directly tested, we offer two reasons to believe it is plausible. First, the classification of municipalities into treatment and control groups is based on the presence of geological gold deposits located inside or outside protected areas, which have existed for millions of years and therefore predate the shocks under analysis. Consequently, the assignment of municipalities to treatment and control groups is independent of both treatment exposure and homicide rates. Second, as noted above, protected areas were established predominantly at the beginning of the sample period, primarily to preserve Amazonian ecosystems. More importantly, there is no

[31] This strategy treats the international price of gold ($\mathbb{P}_{t-1}$) as an exogenous source of variation in local incomes, following a similar approach to that adopted by This strategy treats the international price of gold ($\mathbb{P}_{t-1}$) as an exogenous source of variation in local incomes, following a similar approach to that adopted by Acemoglu et al. (2013), Dube and Vargas (2013), and Soares and Souza (2025).

[32] The vector of covariates is used only in the market deregulation specification to control for heterogeneous gold price effects across mining areas. Specifically, the vector consists of interactions between the log international gold price ($\mathbb{P}_t$) and indicators for legal ($\mathbb{G}_i$) and illegal ($\mathbb{I}_i$) gold-mining areas.

[33] In robustness tests, we also calculated standard errors at the microregion and mesoregion levels.

evidence of any systematic correlation between the preexistence of geological gold deposits and the government's designation of these areas. Therefore, whether a gold deposit is located inside or outside a protected area is essentially random.

In this context, only differential trends in unobservable factors between treated and control municipalities could potentially threaten the validity of our strategy. By focusing on municipalities within the Amazon biome, we increase comparability across these areas, thereby reducing the likelihood of differential pre-treatment trends. In addition, we include differential time trends for population density and the urbanization rate to account for the fact that more densely populated and urbanized municipalities tend to exhibit higher homicide rates. However, some factors may still invalidate our estimates. First, failing to account for the heterogeneous effects of the boom in international gold prices before market deregulation could bias the results. We address this concern by including the international gold price as an exogenous control variable in the estimation of the market deregulation effect. Second, potential bias may arise from the concentration of gold deposits in protected areas in certain states within the Amazon region. We mitigate this issue by including state-year fixed effects.

Parallel Trends. Although it is not possible to directly test the first part of the identification hypothesis, we can examine how these shocks affect homicide rates over time in order to validate the central hypothesis of our study and gain a better understanding of the dynamics of the outcomes. This approach allows us to assess the parallel trends assumption and to determine whether these shocks lead to transitory or persistent effects on homicide rates.[34]

5 EFFECTS ON VIOLENT CRIMES

[34] To estimate the dynamic effects (event-study) of our difference-in-differences model, we employ the following specification:

$$H_{it} = \alpha + \sum_{t=2000}^{2021} \beta_t 1\{\tau = t\}.(\mathbb{G}_i \times \mathbb{I}_i \times \mathbb{S}) + \sum_{t=2000}^{2021} \delta_t 1\{\tau = t\}.(\mathbb{G}_i \times \mathbb{S}) + \boldsymbol{X}_{it}^{'}\Omega + \sum_{z \in Z} \Phi_z (z \times \mathbf{FE}_t) + \mathbf{FE}_i + \mathbf{FE}_{st} + \xi_{it}$$

where the terms $1\{\tau = t\}$ are year dummy variables. The dynamic responses of homicide rates in municipalities more and less exposed to illegal gold mining to shocks are captured by the trajectories of the coefficients β_t and δ_t, respectively. To avoid collinearity, we omit the period immediately preceding the shock.

This section presents the main empirical results on the impacts of market deregulation and the gold price boom on violent crime in municipalities more exposed to Illegal gold mining in the Brazilian Amazon.

5.1. MAIN RESULTS

As discussed in the section on institutional context, the market deregulation introduced a system of presumptions that exempts initial buyers from the obligation to verify the origin of gold, thereby encouraging these private intermediaries to purchase gold illegally extracted from the Amazon biome. This institutional change was preceded by the gold price boom, which may also have triggered a "gold rush" and encouraged illegal mining. Based on Predictions 1 and 2 of the theoretical model, these shocks are expected to increase local conflicts over control of gold deposits in protected areas where the resource is abundant, but extraction is illegal. In this sense, we expect to observe a disproportionate increase in homicide rates in municipalities more exposed to illegal mining, which is captured by the parameter β in the empirical equation.

The empirical results presented below add new evidence to the literature that examines the effects of illegality on local violence. Pereira and Pucci (2026) provide evidence that municipalities more exposed to illegal gold mining in the Brazilian Legal Amazon experienced increases in homicide rates following the deregulation of the gold market in 2013. We take this finding as a starting point and extend the empirical analysis by investigating not only the impact of the deregulation shock, but also the underlying mechanisms driving the increase in violence, the role of the international gold price shock, and the broader local economic consequences of illegal mining in the Amazon biome. Regarding the gold price boom, we are in dialogue with Idrobo et al. (2014), who exploit variation in international prices and show that illegal gold mining led to higher levels of violence in Colombia.

Dynamic Estimates. We begin by presenting the full trajectory of the homicide rate responses in municipalities with gold deposits inside (illegal deposits) and outside (any deposits) protected areas of the Amazon biome, before and after the market deregulation and the gold price boom. Figure 7 plots the coefficients β_t and δ_t and their respective 95% confidence intervals from estimation Equation (4.1) for each year between 2000 and 2021. The event-study results make it clear that there are no differential trends in homicide rates between municipalities more and less exposed to illegal mining prior to market deregulation

(Figure 7.A) or the gold price boom (Figure 7.B). The pre-treatment period coefficients – left of the dashed red line – are close to zero and statistically insignificant. This absence of systematic trends reinforces the credibility of our identification strategy. In the absence of these shocks, municipalities more and less exposed to illegal gold mining would have followed parallel trajectories in homicide rates.

However, after market deregulation and the gold price boom, the estimated coefficients for the post-treatment period – shown to the right of the dashed red line – indicate that homicide rates increased progressively only in municipalities with illegal gold deposits, becoming statistically significant over time. In contrast, municipalities with any gold deposits show no deviation from the pre-treatment homicide rate trajectory; i.e., they did not experience any statistically significant change in the post-treatment period. Under the parallel trends assumption, we document a disproportionate Increase in homicide rates in areas more exposed to illegal gold mining after market deregulation and the gold price boom.

Baseline Estimates. The dynamic estimates provide clear visual evidence that market deregulation and the gold price boom led to substantial increases in violent crime in municipalities with illegal gold deposits. We summarize the magnitude of these effects in Table 2. Panel A presents the effects of market deregulation, while Panel B shows the impact of the gold price boom. Since our focus is on the effects of these shocks in areas with illegal gold mining, we concentrate our analysis on the coefficient (β) associated with illegal gold deposits.

Column (1) presents the estimated effect of market deregulation (or the gold price boom) on homicide rates in municipalities with illegal gold deposits, conditional on the presence of any gold deposit, as well as municipality and state-year fixed effects. In the case of market deregulation, we also control for international gold prices. These variables allow us to account for unobservable, time-invariant characteristics that influence the outcomes of interest, while also capturing the impact of state-level policies and economic factors that similarly affect all municipalities within the same state in the Amazon region. This approach is particularly relevant in the Brazilian context, as state governments have autonomy to implement distinct public policies, including in the areas of security and the environment. Moreover, state-year fixed effects help mitigate concerns about omitted-variable bias arising from the potential spatial concentration of gold deposits in protected areas across some states of the Amazon region. The coefficient of interest for market deregulation is estimated at 8.3 in Panel A, with a standard error of 3.3. In contrast, the coefficient of interest for the price boom is estimated at 5.7 in Panel B, with a standard error of 3.0.

Column (2) of Panels A and B reports the results from our preferred specification, which includes an interaction between a time trend and initial levels of population density and urbanization rate as an additional control. The magnitude of the coefficient for the price boom is slightly larger (6.4), while that for market deregulation remains virtually unchanged. It is important to note, however, that the standard errors also remain virtually unchanged in both models.

These estimates indicate that, following market deregulation, Amazonian municipalities with higher exposure to illegal gold mining recorded an increase of 8.3 homicides per 100,000 inhabitants compared to less exposed municipalities. This effect is statistically significant, representing approximately 40% of the average homicide rate during the sample period. Moreover, we document that a 200% increase in the international price of gold [log(3)] – a magnitude comparable to the price cycle observed between 2003 and 2021 – is associated with an increase of 6.3–7.1 homicides per 100,000 inhabitants in municipalities most exposed to illegal gold mining, representing more than 34% of the average homicide rate.[35] In aggregate terms, our estimates imply that, in the absence of market deregulation and the gold price boom, approximately 1,218 and 1,908 homicides would have been avoided, respectively (Appendix Table D1). This represents approximately 11% and 17% of the homicides recorded in municipalities with illegal gold deposits.

As expected, the results are not driven by municipalities with any gold deposits – i.e., where gold extraction is permitted. The estimates indicate that in municipalities where gold deposits are located outside protected areas (and therefore less exposed to illegal mining), there are no statistically significant changes in homicide rates following market deregulation and the gold price boom.

5.2. HOMICIDES DECOMPOSITION

Table 3 presents a detailed analysis of the results by decomposing homicide rates according to victim characteristics, location of occurrence, and type of weapon. The outcome variable

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[35] Between 2003 and 2021, the international price of gold increased by approximately 212%. To interpret the estimated results, we consider a scenario with a 200% increase in gold prices, which allows us to simulate a valuation cycle similar to that observed during the analyzed period (World Bank, 2024).

is divided into eleven categories: total (column 1); males (column 2); youths aged 15 to 39 (column 3); black and indigenous (column 4); outside of home (column 5); public street (column 6); firearms or knives (column 7); physical aggression (column 8); fire or chemical substance (column 9); police intervention (column 10); and unspecified (column 11). Column (1) replicates the results of the baseline specification related to market deregulation (Panel A) and the price boom (Panel B).

The results in Panel A indicate that the market deregulation disproportionately affected vulnerable groups: most victims were men (91%), black or indigenous (76%), and young individuals aged 15–39 (41%).[36] Approximately three-quarters of the homicides occurred outside the home (76%), suggesting links to disputes over mining areas, while only about one-fifth took place in public streets (21%). Firearms and knives predominated (60%), indicating violent conflicts; other forms of violence (such as the use of chemicals, fire, or physical assault) accounted for less than 4%. There was no statistically significant effect on homicides involving young victims, incidents occurring in public streets, or deaths resulting from physical assault, nor was there evidence of an increase in police lethality (2%), thereby weakening the hypothesis of state repression in areas affected by illegal mining. Other causes (e.g., land disputes) cannot be ruled out, as nearly one-quarter of the estimated effect is concentrated in undetermined or poorly reported cases (23%).

The results are also similar for the gold price boom. In Panel B, the increase in homicide rates is concentrated among black or indigenous victims (91%), males (80%), and young individuals (44%); although the effect on young individuals is not statistically significant. Most cases occurred outside the home (76%), while about one-fifth occurred on public streets (20%) – this last result, however, is not statistically significant. The predominance of firearms and knives (54%), although statistically insignificant, suggests that the price shock intensifies violent disputes. The residual share of homicides resulting from physical assault (5%) and from the use of fire or chemical agents (2%) points to a more diffuse pattern of violence. The absence of an increase in police lethality (3%) reinforces the interpretation that the effect stems from the reconfiguration of economic incentives generated by higher gold prices, rather than from increased police intervention. However, approximately 30% of cases have undetermined causes, which preclude ruling out the influence of other latent factors.

[36] Appendix Table E1 presents a decomposition of homicides among young men (ages 18–39), a group particularly vulnerable to violence in Brazil.

The decomposition aligns with prior evidence documenting interpersonal violence linked to the illegal extraction of natural resources (e.g., gold and mahogany) in remote areas where institutions are fragile and property rights are poorly defined (Idrobo et al., 2014; Chimeli and Soares, 2017). The concentration of homicides among vulnerable groups—occurring predominantly outside the home and involving firearms or knives—further supports the interpretation that both market deregulation and the gold price boom intensify violence associated with illegal mining, rather than reflecting a broader surge in urban crime or increased state repression.

5.3 ADDRESSING POTENTIAL CONFOUNDING FACTORS

Table 4 presents a series of robustness checks designed to address potential confounding factors that could compromise the main results. Column (1) presents the baseline estimates for market deregulation (Panel A) and the gold price boom (Panel B).

Other *Garimpo* Minerals. A first concern is that the documented increase in violence may reflect the expansion of illegal extraction of minerals other than gold in the Amazon. If illegal gold deposits largely overlap with deposits of other minerals, the baseline estimates could capture a broader increase in illegal mining activity unrelated to market deregulation or a gold price boom.

Columns (2) and (3) address this concern by isolating the role of illegal gold mining. In column (2), we include a mineral-specific time trend for other minerals, capturing mining activity associated with non-gold deposits in the Amazon. In column (3), we replicate our exposure measure using only deposits of non-gold minerals. Across both exercises, the coefficient on illegal gold mining remains large and statistically significant for both shocks. In contrast, the coefficients associated exclusively with other minerals are small and statistically indistinguishable from zero. These results indicate that the observed increase in violence is specifically driven by illegal gold mining, rather than by a generalized expansion of illegal mineral extraction.

Conflicts in Protected Areas. In the Brazilian Amazon, violence can arise from various local disputes, including conflicts over territorial control and natural resources. In the context of mining, confrontations between *garimpeiros* and local populations – such as Indigenous communities and other traditional groups – are common. An additional concern, therefore, is that the estimated effects might capture conflicts associated with protected areas rather than illegal gold mining itself.

Columns (4) and (5) address this issue. Column (4) restricts the sample to municipalities that contain protected areas, exploiting variation only within this subsample. Column (5) introduces an interaction between the presence of protected areas and gold deposits, combined with exposure to market deregulation and the gold price boom. In this specification, municipalities contain both gold deposits and protected areas, but there is no spatial overlap between them. The estimated effect of illegal gold mining remains robust, while the additional term associated with protected areas is small and statistically insignificant. These findings suggest that the observed increase in violence is not driven by conflicts inherent to protected areas, but by illegal gold mining activity.

Mahogany area. Illegal exploitation of other high-value natural resources may also contribute to violence in the Amazon. In particular, illegal logging and the trade in mahogany have been linked to illicit rents and violent conflict (Chimeli and Soares, 2017).[37] A further concern, therefore, is that the estimated effects attributed to illegal gold mining may reflect a broader pattern of violence associated with illegal natural resource extraction.

Columns (6) and (7) examine this possibility. Column (6) includes a municipality-specific time trend for locations that simultaneously host gold deposits and areas of natural mahogany occurrence. Column (7) adds an interaction between gold deposits, mahogany presence, and exposure to market deregulation or the gold price boom. This specification does not require spatial overlap between gold and mahogany, but allows for differential effects in areas where another high-value illegal activity is present. In all cases, the coefficients associated with illegal gold mining remain robust, while the interaction terms are small and statistically insignificant. Therefore, this evidence indicates that the observed increase in violence is not driven by a broader dynamic of illegal resource extraction, but rather by illegal gold mining.

Alternative channel. Although not a primary threat to identification, it is relevant to assess whether market deregulation and the gold price boom increase violence through

[37] The commercialization of Brazilian mahogany, a valuable hardwood from the Amazon, began to face government restrictions in the late 1990s, culminating in its ban in 2001. Chimeli and Soares (2017) found evidence that these measures fostered the emergence of an illegal mahogany extraction market in the Amazon, which contributed to increased violence in extractive activity areas.

higher income circulation – such as thefts and violent disputes along gold trade routes – rather than exclusively through conflicts around gold deposits (Pereira and Pucci, 2026).

Columns (8) and (9) explore this alternative channel. Column (8) excludes municipalities hosting PCOs, six of which also contain gold deposits in protected areas. Column (9) introduces an interaction between PCO presence and exposure to illegal gold mining. The results show that the effects of illegal gold mining remain robust following the deregulation shock. In contrast, for the gold price boom, the coefficient becomes statistically insignificant once the interaction is included, suggesting that part of this effect may operate through increased income circulation and violent crime along commercialization routes. This result should be interpreted with caution, as the estimate, while large in magnitude, is not statistically significant.

5.4. OTHER ROBUSTNESS CHECKS

Sensitivity Analysis. We conducted a series of sensitivity analyses to assess the robustness of our main results, most of which are summarized in Figure 8 and presented in detail in Appendix Table D2. The figure shows that our findings remain robust even after controlling for a broad set of pre-shock socioeconomic characteristics that could also account for increases in homicide rates, including the illiteracy rate; the proportion of males, black individuals, and young people (ages 18–29); income inequality (Theil index); and dummy variables for metropolitan area status and other illegal extraction activities, such as natural mahogany occurrence areas. Including this diverse set of controls yields estimates for the parameter associated with illegal gold mining (β) and standard errors that are nearly identical to those obtained from our more parsimonious baseline specification, both for market deregulation (Panel A) and for the price boom (Panel B).

Inference. In our baseline estimates, standard errors are clustered at the municipal level, which is our unit of spatial analysis. However, given the dynamics of violence and mineral extraction in the Amazon region, we cannot rule out the presence of an unknown spatial correlation in the residuals. Table D3 in the Appendix shows that the main results remain statistically significant and robust even when standard errors are adjusted for spatial autocorrelation at broader territorial levels, such as microregions and mesoregions. We also assess the statistical significance of our estimates using alternative inference procedures, including a wild bootstrap that corrects for biases associated with small cluster sizes.

Subsamples. Table D4 in the Appendix documents the robustness of our findings to different sample treatment procedures. Specifically, we consider: (i) winsorization, excluding zero values for the homicide rate; (ii) the inclusion of municipalities that experienced changes in their territorial boundaries (non-constant municipalities); (iii) the exclusion of municipalities located in metropolitan areas; and (iv) the exclusion of very populous municipalities (over 200,000 inhabitants). Estimates based on these alternative samples are very similar to those obtained in the baseline, reinforcing the robustness of our results for both market deregulation (Panel A) and the gold price boom (Panel B).

Gold Deposits. We also conducted a robustness check by restricting the sample to municipalities with gold deposits in the Amazon Biome (Appendix Table D5). Specifically, we compared only municipalities that are more or less exposed to illegal gold mining. Due to the smaller sample size, we used only municipality and year fixed effects to ensure sufficient cross-sectional variation for identifying the causal effect. Even with this more restricted sample, the main results remain statistically significant, reinforcing the robustness of our conclusions.

Horse Race Test. We also conducted an additional robustness check using a "horse race" approach (Appendix Table D6). In this exercise, we simultaneously include both the market deregulation and gold price boom in the empirical equation. The aim is to assess whether the effect of market deregulation on violent crime in municipalities more exposed to illegal gold mining remains robust when compared with our other exogenous source of variation related to the gold market – the contemporaneous and lagged international gold prices. The estimates show that, although the magnitude of the coefficient of interest for market deregulation varies across specifications, it remains strong, consistent, and statistically significant even after including the price shocks.

6 MECHANISMS AND INTERPRETATION

In this section, we explore explanations for the increase in violent crime that we document. In particular, we assess the role of rapacity associated with illegal gold mining, the expansion of illicit parallel markets, and social disorganization. We also consider alternative hypotheses beyond those examined in the previous section, including a potential opportunity-cost mechanism that could likewise yield a positive estimate of β.[38]

6.1 LAND USE FOR GOLD MINING

The main economic mechanism proposed in the literature to explain our results is rapacity associated with illegal gold mining (Idrobo et al., 2014; Dube and Vargas, 2013). Since illegal gold production is not directly observable, we use high-resolution annual data from the MapBiomas (2024) to measure land use allocated to gold mining. In the Amazon, this activity is strongly correlated with deforestation, as a large share of mining sites are located in remote forested areas (Silva et al., 2023; Risso et al., 2021). To isolate illegal mining activity, we analyze land use for gold extraction in (i) all municipalities in the Amazon and (ii) a subsample of municipalities containing protected areas. Our main variable of interest is the area dedicated to gold garimpo, although we also present results for industrial mining.

Table 5 presents the estimation results. Columns (1) through (4) show that both market deregulation and the gold price boom significantly increase the area devoted to gold garimpo in municipalities with both higher and lower exposure to illegal mining; however, the effects are disproportionately larger in more exposed municipalities.[39] These patterns persist in the subsample of municipalities containing protected areas. In contrast, we find no evidence that these shocks have significant effects on land use for industrial mining in municipalities more exposed to illegal mining. Positive effects emerge only in less exposed municipalities (i.e., those with any gold deposits), suggesting an expansion of industrial mining frontiers in those areas.

Figure 8 presents the dynamic estimates of land use devoted to gold garimpo in each sample. The event-study analyses indicate that, prior to treatment, municipalities with higher and lower exposure to illegal mining exhibit parallel trends, with coefficients that are close to zero and statistically insignificant. Following the shocks, land use for gold garimpo increases sharply in both groups, with somewhat stronger growth in municipalities more exposed to illegal mining.

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[38] Economic theory identifies two main mechanisms through which income shocks can influence violent crime. First, changes in wages or opportunities for legal income alter the opportunity cost of involvement in illegal activities, affecting the supply of labor available for violent conflicts. Second, shocks that increase the value of contestable rents raise the expected returns to rapacity, intensifying violent competition for their appropriation (Dube and Vargas, 2013).

[39] Municipalities more exposed to illegal mining concentrate approximately 54% of the total gold mining area in the Amazon biome, while less exposed municipalities account for about 40%.

Although the results do not allow for definitive conclusions, they point to a significant increase in land use for gold garimpo in areas more exposed to illegal mining, while showing no statistically significant effect on industrial mining. This distinction is important in our context, as illegal and informal activities occur predominantly through small-scale gold mining (*garimpo*). The evidence is consistent with the literature for Brazil (Pereira and Pucci, 2026; Siqueira-Gay and Sánchez, 2021) and other Latin American countries (Álvarez-Berríos et al., 2021; Swenson et al., 2011), which documents the expansion of illegal mining in remote regions such as the Amazon biome. Taken together, these findings suggest that the increase in local violence following market deregulation and the gold price boom is driven by the expansion of illegal gold mining - the rapacity channel.

Considerations. Results based on land-use data for gold mining (garimpo) as a proxy for illegal gold production should be interpreted with caution due to several limitations. For example, not all mapped areas reflect direct extraction; many include supporting infrastructure (camps, roads, and airstrips), whose expansion is slower than production. Moreover, these areas persist over time, retaining signs of human intervention for several years (MapBiomas, 2024).

Another important issue is the association between gold mining and deforestation in the Amazon. Although mining accounts for a relatively small share of forest deforestation (approximately 2%), this may imply a spurious correlation with changes in environmental policies during the period analyzed (Ferreira, 2026). To assess this possibility, we replicate our estimates using natural forest cover loss – an annual measure of deforestation provided by MapBiomas (2024). The results in Appendix Table F1 show that, unlike land use for garimpo, deforestation does not increase disproportionately in municipalities more exposed to illegal mining following market deregulation and the gold price boom. In the specific case of the price boom, we observe only a modest increase in deforestation in municipalities less exposed to illegal mining, reinforcing the interpretation that these shocks may also stimulate the opening of new mining fronts in non-protected areas.

6.2 ILLEGAL MARKETS AND SOCIAL DISORGANIZATION

When analyzing the mahogany market in the Amazon region, Chimeli and Soares (2017) show that the Brazilian government's ban on trade in the early 2000s did not eliminate extraction but merely shifted it to the illegal market, intensifying violent conflicts and fostering the emergence of parallel illicit markets. Similarly, we show that both market deregulation and the gold price boom not only increased violent crime in areas of illegal gold mining but also intensified the expansion of illegal extraction activities.

However, it is possible that these shocks affected violence through alternative channels, such as the expansion of parallel illicit activities (e.g., illegal trafficking of arms and drugs) and social disorganization (Risso, 2021; Castillo et al., 2020). To empirically investigate these mechanisms, we use indicators commonly employed in the economic literature (e.g., Soares and Souza, 2025): the mortality rate from overdose and the proportion of suicides involving firearms as indicators of illicit parallel markets; and the mortality rate from traffic accidents as an indicator of social disorganization. Although these measures are indirect proxies, they are widely used in the literature to capture the presence of illicit markets and social disorganization.

The results presented in Table 6 provide no evidence that these channels explain the documented increase in violence. Neither market deregulation (Panel A) nor the price boom (Panel B) shows a statistically significant effect on these indicators. Thus, the observed increases in violent crime in areas of illegal mining do not appear to result from the expansion of parallel illicit markets or from rising social disorganization.

6.3 ALTERNATIVE HYPOTHESES: INCOME, LABOR MARKET, FISCAL BUDGETS, AND OTHER CONDITIONS

In this section, we investigate alternative mechanisms that may help explain positive estimates of β, with particular emphasis on an opportunity-cost channel. The shocks analyzed – market deregulation and the gold price boom – may increase the relative returns to illegal gold mining compared to legal activities, thereby reducing the opportunity cost of engaging in criminal behavior. This mechanism would operate, for example, if municipalities with illegal gold deposits that are more exposed to these shocks experience a contraction in economic activity, a deterioration in labor market conditions, or fiscal constraints that undermine the provision of public goods (Soares and Souza, 2025; Ishak and Méon, 2023; Ferraz et al., 2022; Axbard et al., 2021; Dube and Vargas, 2013).[40]

[40] Positive income shocks in contestable markets tend to intensify the reallocation of labor toward illegal activities by expanding the scope of appropriable rents and weakening mechanisms of state containment, regulation, and enforcement. In this context, it is reasonable to assume that market deregulation and the price boom have adversely affected the economies of municipalities with illegal gold deposits, thereby intensifying violent crime (Dube and Vargas, 2013; Idrobo et al., 2014).

To empirically assess the relevance of this channel, we examine a comprehensive set of outcomes, including aggregate income, formal-sector employment and wages, municipal finances, and other socioeconomic indicators such as health and urban infrastructure. Taken together, these dimensions allow us to evaluate whether the observed increase in violent crime reflects a decline in legal economic opportunities or a weakening of state capacity in areas more exposed to illegal gold mining.

Income. We begin by examining whether the shocks translate into changes in aggregate income or in the reallocation of sectoral income. Table 7 presents estimates for per capita income and for the sectoral composition of income, measured by the shares of agriculture, industry, and services.

The results show that neither market deregulation (Panel A) nor the gold price boom (Panel B) has statistically significant effects on per capita income or on the sectoral composition of income in municipalities more exposed to illegal gold mining. These findings indicate the absence of measurable economic gains or sectoral reallocation across legal activities following these shocks. In particular, the lack of aggregate income growth weakens explanations based on generalized prosperity or distributive conflicts over expanding legal economic rents.

By contrast, in municipalities less exposed to illegal mining, the gold price boom is associated with a decline in the share of agriculture and an increase in the share of industry, consistent with sectoral reallocation toward formal mining activities.

Labor Market. While aggregate income remains largely unaffected, the labor market results reveal substantial adverse effects in municipalities more exposed to illegal gold mining. Table 8 shows that market deregulation (Panel A) is associated with a statistically significant reduction in formal employment, with the impact concentrated in sectors unrelated to mineral extraction. Moreover, this shock is associated with significant declines in employment for both high- and low-skilled workers. In turn, the effects of the increase in the gold price (Panel B) are more limited. Still, the price shock contributes to worsening labor market conditions, as it is associated with reductions in skilled employment in municipalities more exposed to illegal mining. In contrast, in less exposed municipalities, the price shock increases employment in the mining sector.

Overall, these findings point to a deterioration of legitimate labor market opportunities in areas with illegal gold deposits. This pattern is consistent with a reduction in the opportunity cost of engaging in illegal activities, such as gold mining in protected areas, as the returns to formal employment become relatively less attractive.

Fiscal Budgets. Next, we examine whether the shocks affect municipal fiscal outcomes. The estimates reported in Table 9 show that market deregulation (Panel A) leads to a statistically significant reduction in the share of royalty revenues relative to total revenues in municipalities more exposed to illegal gold mining. Market deregulation also reduces the share of royalty revenues relative to total public expenditures in these municipalities.

By contrast, in municipalities less exposed to illegal mining, both market deregulation and the gold price boom (Panel B) increase royalty revenues and their share of total revenues. In these areas, the gold price boom is also associated with an increase in the relative importance of royalty revenues in municipal budgets. Despite the larger share of royalty revenues in the budgets of less exposed areas, there is no evidence that these gains translate into greater fiscal effort toward social investments, such as spending on education, health, or personnel.

Therefore, these results indicate that municipalities more exposed to illegal gold mining capture a smaller share of mining-related revenues through formal royalty channels. This pattern is consistent with a relative weakening of fiscal capacity in these areas, which may constrain their ability to expand public expenditures or strengthen state presence in response to adverse social conditions, including rising violence.

Other Conditions. Finally, we examine whether the shocks lead to changes in more sensitive socioeconomic conditions – such as health outcomes and urban infrastructure – that could also mediate the relationship between illegal mining and violent crime. Table 10 shows that neither market deregulation (Panel A) nor the gold price boom (Panel B) has statistically significant effects on key health indicators, including low birth weight, fetal mortality, and infant mortality, in municipalities more exposed to illegal gold mining. However, we find an increase in the crude birth rate following market deregulation in areas more exposed to illegal mining. Moreover, we find no evidence that these shocks lead to improvements in urban infrastructure, as there is no observed increase in infrastructure area in municipalities more exposed to illegal mining.

These results suggest that the shocks do not generate measurable improvements in basic socioeconomic conditions in areas more exposed to illegal gold mining.

6.4 DISCUSSION

Figure 10 presents a summary of the results obtained from analyzing the mechanisms. Taken together, the evidence is consistent with the central role of a rapacity mechanism associated with illegal gold mining (garimpo). Although this evidence already appears in a suggestive form in Pereira and Pucci (2026), it gains greater robustness and clarity here, as we are able to explicitly distinguish between types of mining (industrial vs. garimpo). In particular, our results point directly to the expansion of illegal garimpo activity as a key driver of the increase in violence in areas more exposed to illegal mining.

In addition, we rule out a broad set of alternative explanations. We find no evidence that the increase in violence is driven by the expansion of parallel illicit markets (e.g., drug and arms trafficking), rising social disorganization, or greater lethality associated with police activity. Likewise, there is no support for interpretations based on a deterioration in aggregate economic activity (aggregate income), broader reductions in public investment (e.g., health, education, or personal), or changes in other local conditions, such as health and urban infrastructure.

In contrast, we document a deterioration in formal labor market conditions and a relative weakening of fiscal capacity in municipalities more exposed to illegal mining. These results suggest that, although rapacity constitutes the main channel through which market deregulation and the gold price boom translate into higher levels of violence, the opportunity cost mechanism also plays a complementary role. As legitimate economic opportunities become scarcer and state capacity weakens, incentives to engage in illegal activities increase.

In sum, the mechanisms can be organized into three groups: (i) stronger evidence for the rapacity channel, operating through the expansion of illegal gold mining (garimpo); (ii) complementary evidence for the opportunity cost mechanism; and (iii) a lack of empirical support for alternative explanations, such as the expansion of parallel illicit markets, social disorganization, and a deterioration in overall economic activity (e.g., aggregate income). Relative to Pereira and Pucci (2026), this additional body of evidence- particularly the distinction between types of mining and the systematic analysis of competing mechanisms - allows us to move from suggestive evidence to a clearer interpretation of the transmission channels through which market deregulation shocks and the gold price boom affect violent crime in areas more exposed to illegal mining.

7 CONCLUSIONS

In this thesis, we analyze the effects of illegality in natural resource extraction on lethal violence in the Brazilian Amazon, using a municipal-level data panel spanning more than two decades. We exploit two plausibly exogenous sources of variation in economic and institutional conditions – the deregulation of the raw gold market in 2013 and the boom in international gold prices beginning in 2003 – combined with the random distribution of geological gold deposits in protected areas, where mining is prohibited. Using this empirical strategy, we identify how shocks that increase the profitability of Illegal gold mining affect violence in contexts characterized by weak property rights and low state capacity.

The results indicate that both shocks are associated with substantial increases in homicide rates in municipalities more exposed to Illegal gold mining. At the same time, no statistically significant effects are observed in municipalities with lower exposure. The estimated magnitudes are economically relevant: market deregulation is associated with an increase of approximately 8 homicides per 100,000 inhabitants, whereas a gold price boom comparable to that observed during the period analyzed (200%) implies an increase of between 6-7 homicides per 100,000 inhabitants. In aggregate terms, our estimates imply that, in the absence of market deregulation and the gold price boom, approximately 1,218 and 1,908 homicides would have been avoided, respectively. This represents approximately 11% and 17% of the homicides recorded in municipalities with illegal gold deposits. Dynamic evidence corroborates the validity of the empirical strategy by indicating the absence of differential pre-trends between the treatment and control groups and by showing that the effects emerge gradually after the shocks and persist over time.

The nature of the observed violence is consistent with the hypothesis that higher returns from illegal mining intensify local conflicts over gold deposits and territorial control. The homicide decomposition analysis reveals that the rise in violence is concentrated among male victims and black or indigenous individuals, occurs predominantly outside the home, and is not associated with police lethality. The means employed – primarily firearms and knives, and, to a lesser extent, physical assault, fire, or chemical agents – are consistent with interpersonal conflicts and criminal disputes in the context of illegal gold mining. Qualitatively similar results to those associated with market deregulation are found for the gold price boom, albeit with a more diffuse pattern of violence.

The analysis of mechanisms reinforces this interpretation, indicating that the primary transmission channel of these shocks is the expansion of illegal mining activity, consistent with a rapacity mechanism. This result is evidenced by the disproportionate increase in the area allocated to gold *garimpo* in municipalities more exposed to illegal mining following market deregulation and the boom in gold prices. In contrast, we find no evidence that the effects operate through the expansion of parallel illicit markets or through greater social disorganization. Moreover, the results show that illegal mining does not generate local economic or social gains. There is no increase in per capita income, nor improvements in health indicators or urban infrastructure.

However, we document a significant deterioration in formal labor market conditions and fiscal capacity in municipalities more exposed to illegal gold mining. The decline in employment, together with evidence that more exposed municipalities capture a smaller share of mining-related revenues through formal royalty channels – reflected in the reduced importance of royalty revenues in local budgets – points to both a reduction in the opportunity cost of engaging in illicit activities and a diminished capacity of the state to provide public goods and security. These results indicate that, although the main channel is the intensification of conflicts directly associated with the increase in illegal gold extraction (rapacity channel), mechanisms related to the decline in legal economic opportunities also play a complementary role in the increase in violence (opportunity cost channel).

However, some limitations should be acknowledged. First, despite the use of high-resolution land-use and land-cover data, the measurement of illegal gold production remains imperfect. Second, it is not possible to directly observe the strategic interactions among the different groups involved in illegal mining. Third, the analysis focuses on lethal violence and therefore does not fully capture other relevant dimensions of coercion, conflict, and informal governance in the affected territories. Despite these limitations, the findings of this thesis provide clear evidence that institutional changes along the gold production chain can generate substantial social costs in contexts of low state capacity.

7.1 POLICY RECOMMENDATION

This thesis provides guidance for designing public policies to regulate natural resource markets in contexts of low state capacity. While the literature and regulatory practice emphasize origin certification and licensing systems as central tools to curb illegal extraction and related conflicts (e.g., Berman et al., 2017; Parker and Vadheim, 2017), these measures may be insufficient without effective accountability mechanisms along the entire production chain.

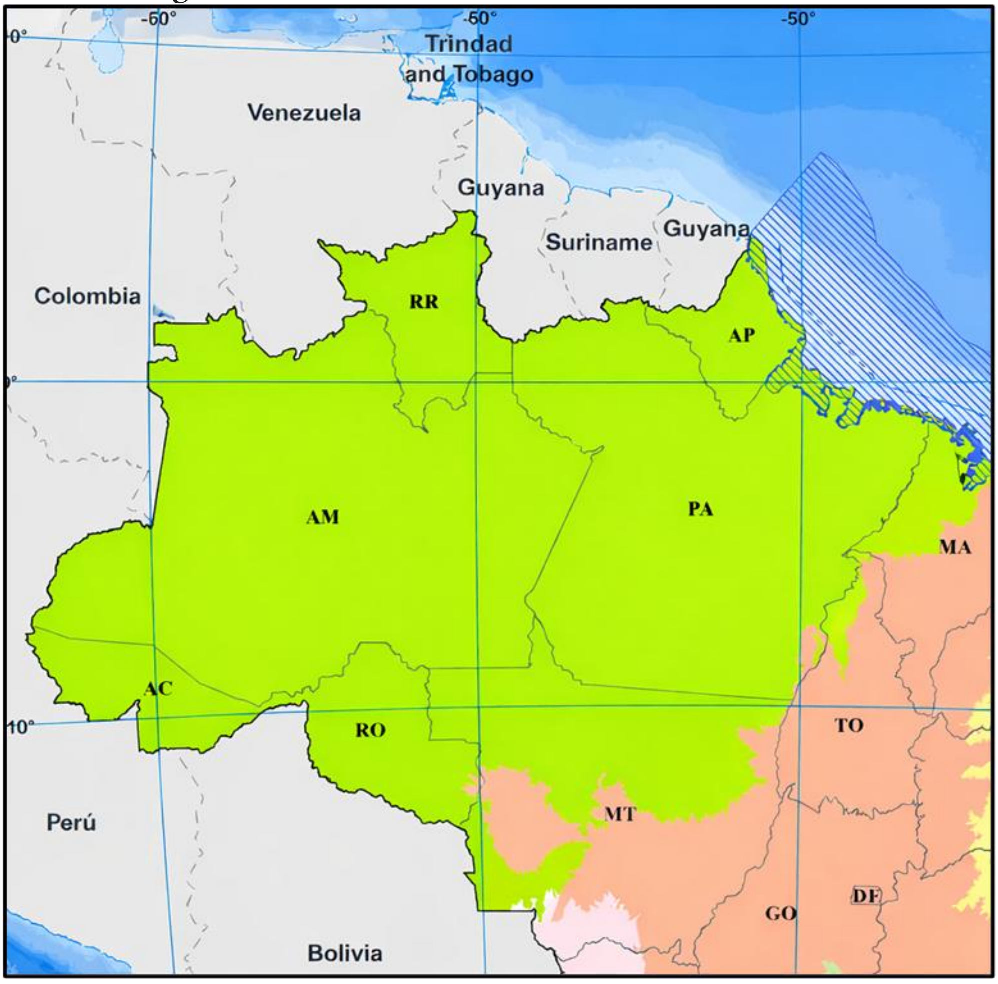
Specifically, removing the legal liability of private intermediaries for the origin of gold – i.e., first buyers in the Brazilian raw gold market – weakens decentralized monitoring and significantly reduces the expected costs of illegal activity. Even under a formal licensing system, the ability to trade gold without effective origin verification creates incentives for the expansion of illegal mining, intensifying territorial disputes, violent conflict, and environmental degradation (Siqueira-Gay and Sánchez, 2021). Deregulation may also amplify the effects of positive shocks, such as increases in international gold prices, in areas with illegal mining, thereby exacerbating violence.

In this context, holding first buyers legally liable for purchasing illegal gold is a central tool for deterring such activities and their consequences, including increased violence. Assigning responsibility to intermediaries strengthens incentives for origin verification and internalizes legal risks that would otherwise fall on the most vulnerable actors in the production chain. This mechanism enhances decentralized monitoring and reduces reliance on direct state enforcement, which is especially costly and limited in remote regions such as the Amazon.

These insights extend beyond the gold market. In other sectors where legal and illegal activities coexist (e.g., timber extraction and trade), policies based exclusively on certification or licensing tend to fail in the absence of effective accountability for intermediate and final buyers. In such contexts, assigning liability on the demand side can incentivize the selection of legal inputs, generating positive effects throughout the production chain (Pereira and Pucci, 2026).

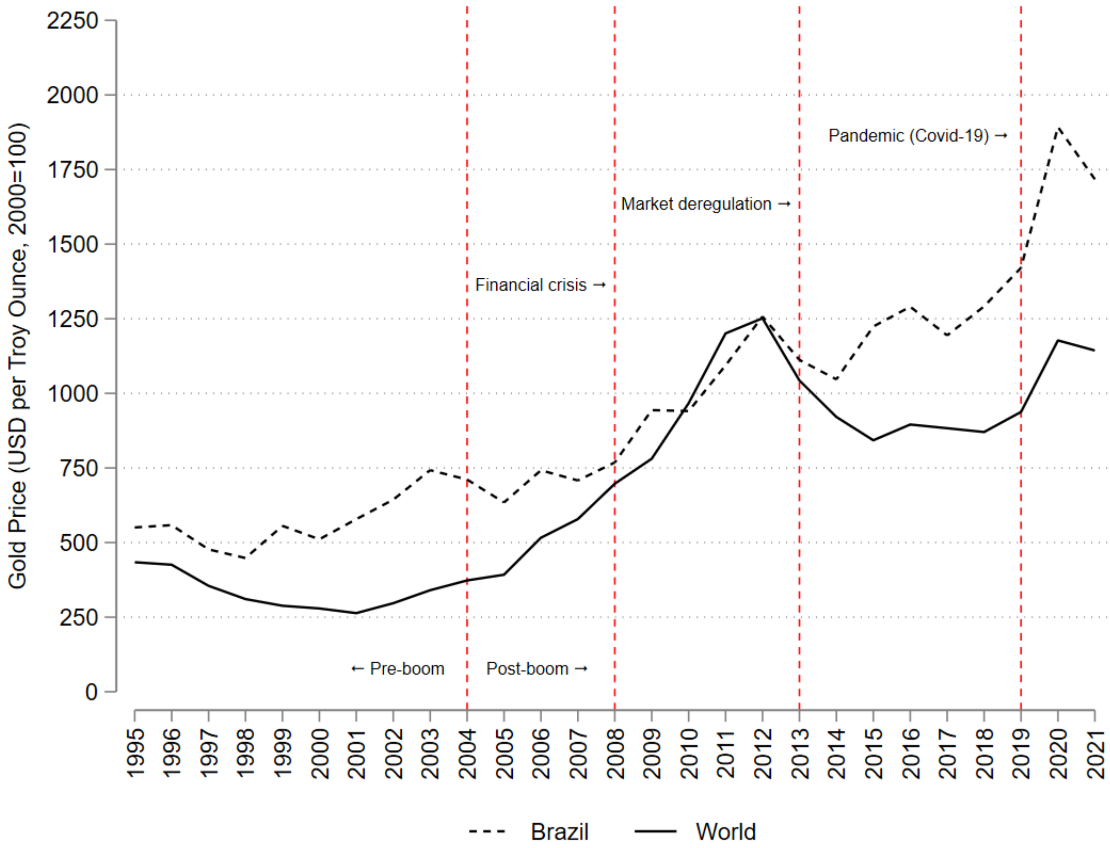
Overall, this thesis highlights the risks associated with regulatory policies that weaken private monitoring mechanisms under the justification of reducing transaction costs or stimulating economic activity. In environments characterized by weak property rights and limited enforcement capacity, the institutional design of the production chain is crucial for curbing illegality and violence. Accordingly, effective regulatory strategies should align private incentives with legality by combining certification systems with clear accountability mechanisms for buyers, thereby reducing the profitability of illegal activities and their associated social and environmental costs.

Figure 1. Delimitation of the Amazon Biome in Brazil



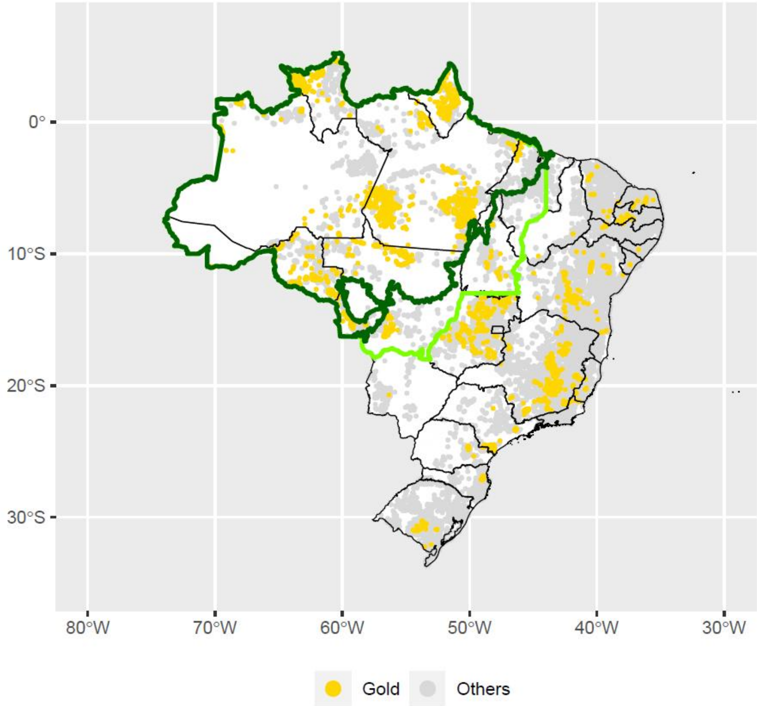
Source: Elaborated by the author (2026), with data from the IBGE (2024).
Notes: The Amazon biome corresponds to the entire green area shown in the figure. The region covers approximately half of Brazil's territory, encompassing the states of Acre (AC), Amapá (AP), Amazonas (AM), Pará (PA), Rondônia (RO), and Roraima (RR), as well as parts of the states of Maranhão (MA), Tocantins (TO), and Mato Grosso (MT).

Figure 2. Trend in the international gold price (1995–2021)



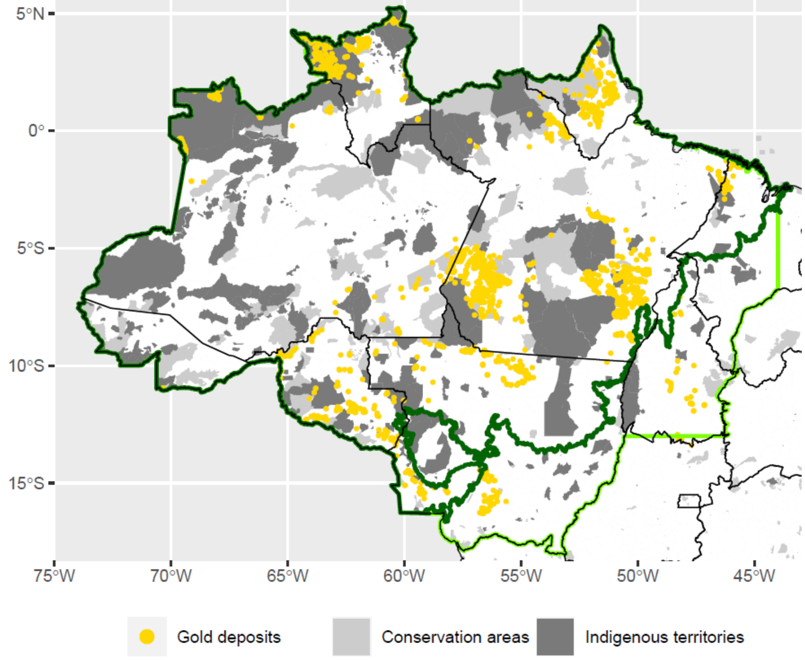
Source: Elaborated by the author (2026), with data from the World Bank (2024).

Figure 3. Gold deposits in Brazil



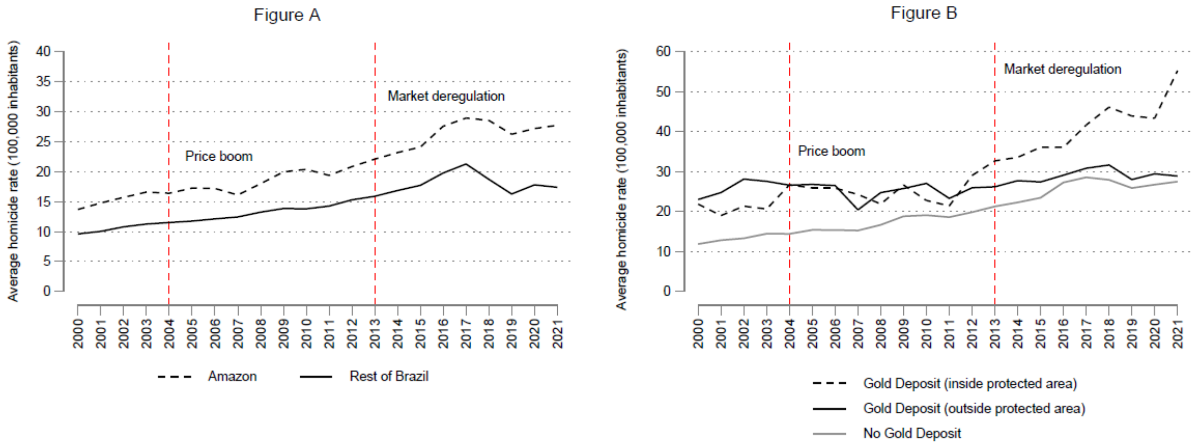
Source: Elaborated by the author (2026), with data from the *Serviço Geológico Brasileiro* (SGB, 2024).
Notes: The dark green line delineates the Amazon biome (study area), while the light green line delineates the Legal Amazon region.

Figure 4. Gold deposits and protected areas in the Brazilian Amazon



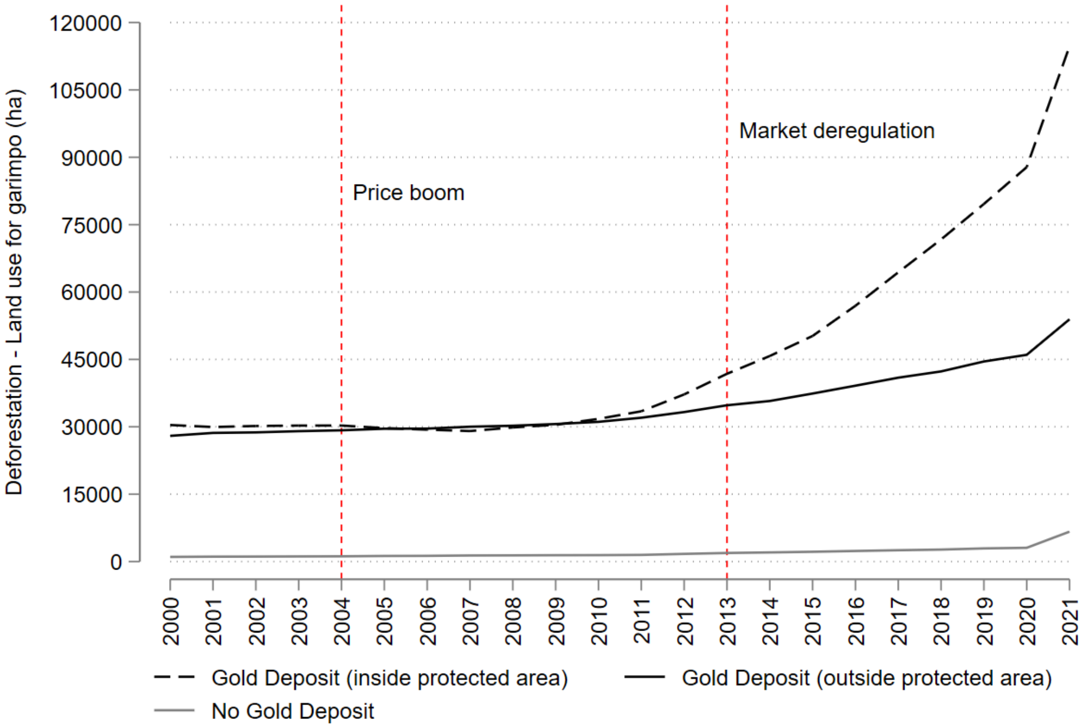
Source: Elaborated by the author (2026), with data from the *Serviço Geológico Brasileiro* (SGB, 2024), *Fundação Nacional dos Povos Indígenas* (FUNAI, 2024) and *Ministério do Meio Ambiente* (MMA, 2024).
Notes: The dark green line delineates the Amazon biome (study area), while the light green line delineates the Legal Amazon region.

Figure 5. Trends in homicide rates in the Amazon (2000–2021)



Source: Elaborated by the author (2026), with data from the *Ministério da Saúde* (2024).
Notes: Municipalities with gold deposits located in protected areas (illegal gold deposits) make up the treatment group, while municipalities with gold deposits outside protected areas (any gold deposit) constitute the control group.

Figure 6. Trend in land use for gold garimpo in the Amazon (2000-2021)



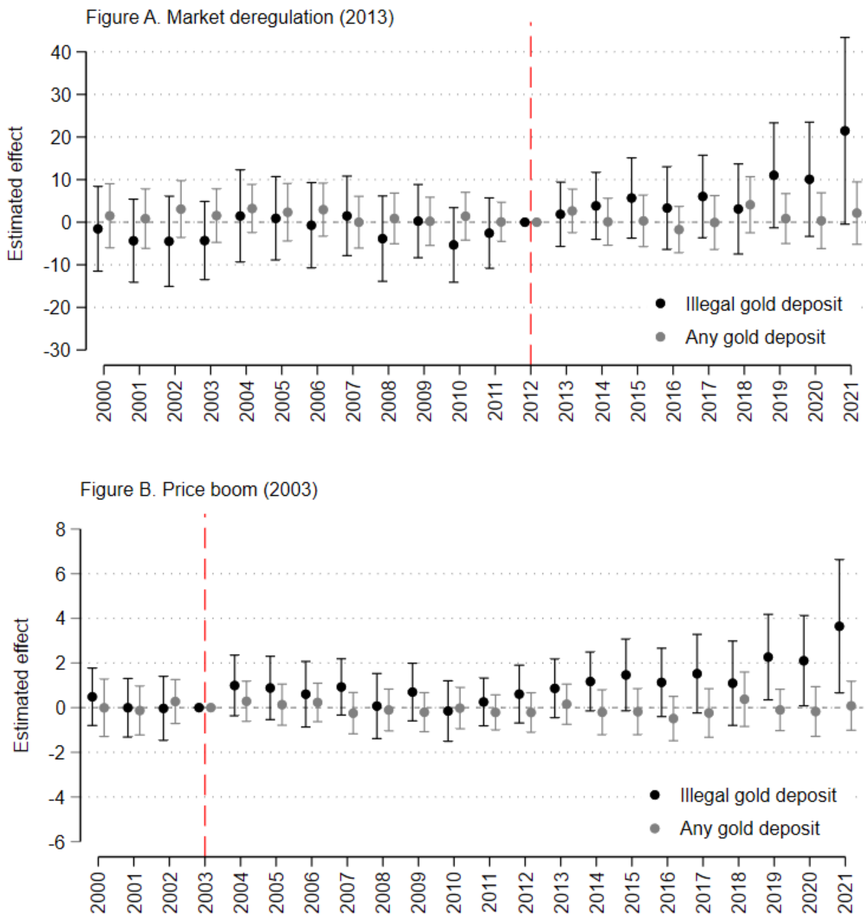
Source: Elaborated by the author (2026), with data from the MapBiomas (2024).
Notes: Municipalities with gold deposits located in protected areas (illegal gold deposits) make up the treatment group, while municipalities with gold deposits outside protected areas (any gold deposit) constitute the control group.

Table 1. Descriptive statistics

	Treatment group *Inside protected area*		**Control group** *Outside protected area*		*Rest of the Amazon*	
	Illegal gold deposit (N = 44)		Any gold deposit (N = 88)		No gold deposit (N = 414)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Homicide rate (100,000 inhabitants)	30.72	33.17	26.81	24.43	18.71	21.46
Municipal Characteristics						
Population density	2.32	4.10	7.77	8.06	35.83	166.02
Urbanization rate	44.14	23.14	54.39	20.56	49.60	20.91
Illiteracy rate	21.25	1.68	21.55	1.69	21.24	1.76
Male population share	27.08	8.81	23.86	8.35	30.81	11.46
Black population share	53.02	1.79	52.83	1.64	52.02	1.45
Young population share (18-29 yrs.)	71.93	13.08	63.02	14.36	70.71	13.25
Share of workers in public safety jobs	0.96	2.09	0.38	0.81	0.36	0.75
Income inequality (Theil Index)	0.59	0.15	0.58	0.11	0.56	0.14
Dummy for metropolitan region	0.14	0.34	0.02	0.15	0.13	0.34
Dummy for mahogany areas	0.55	0.50	0.61	0.49	0.26	0.44

Source: Elaborated by the author (2026).
Notes: Municipalities with gold deposits inside protected areas (illegal gold deposits) make up the treatment group, while municipalities with gold deposits outside protected areas (any gold deposit) constitute the control group. Municipalities without gold deposits were included in the sample solely for compositional and scaling purposes. The sociodemographic characteristics of the municipalities are based on the 2000 Census (IBGE).

Figure 7. Effects of deregulation and price boom on violence in municipalities exposed to illegal gold mining (2000–2021) – Event study



Source: Elaborated by the author (2026).
Notes: The figure shows the average difference in homicide rates between municipalities more and less exposed to illegal gold mining (Table 2). The 95% confidence interval was calculated using standard errors clustered at the municipal level. The dashed red line represents the year prior to the shock (market deregulation or price boom).

Table 2. Effects of deregulation and price boom on violence in municipalities exposed to illegal gold mining (2000–2021)

	Homicide rate	
	(1)	(2)
Panel A. Market deregulation		
Illegal gold deposit x Post-2012	8.337	8.311
	[3.323]**	[3.300]**
Any Gold deposit x Post-2012	0.371	0.268
	[1.843]	[1.849]
R-sq	0.493	0.504
Panel B. Price boom		
Illegal gold deposit x log(lagged gold price)	5.714	6.443
	[3.008]*	[2.994]**
Any Gold deposit x log(lagged gold price)	-1.050	-0.933
	[1.773]	[1.787]
R-sq	0.491	0.502
Dep. Variable mean	20.983	20.983
Number of observations	12012	12012
Number of municipalities	546	546
Municipality FE	Yes	Yes
State x Year FE	Yes	Yes
Time trend x Basic controls (2000)	No	Yes

Source: Elaborated by the author (2026).

Notes: The dependent variable is the homicide rate per 100,000 inhabitants. Basic control variables include population density and the urbanization rate in 2000. Panel A adds gold prices interacted with dummy variables for illegal gold deposits and for any gold deposit as additional controls. Estimations are performed using ordinary least squares (OLS), with standard errors clustered at the municipal level. *, **, ***, significance at the 10%, 5%, and 1% levels, respectively.

Table 3. Decomposition of homicides by victim profile, location of occurrence, and weapon type (2000-2021)

	Homicide rate										
		Victim profile			*Location of occurrence*			*Weapon types*		*Other homicides*	
	Total	Male	Young (15-39)	Black and Indigenous	Outside of home	Public street	Firearms and Knives	Physical aggression	Fire and chemicals	Police interventions	Unspecified
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Panel A. Market deregulation											
Illegal gold deposit x Post-2012	8.311	7.566	3.448	6.299	6.288	1.771	5.155	0.062	0.226	0.182	1.878
	[3.300]**	[3.037]**	[2.203]	[2.881]**	[2.869]**	[1.451]	[2.699]*	[0.267]	[0.105]**	[0.149]	[0.818]**
Any Gold deposit x Post-2012	0.268	-0.018	0.254	0.835	0.128	0.252	-0.031	0.022	-0.089	0.019	0.185
	[1.849]	[1.741]	[1.395]	[1.540]	[1.525]	[1.041]	[1.685]	[0.114]	[0.041]**	[0.081]	[0.217]
R-sq	0.504	0.496	0.471	0.497	0.477	0.413	0.480	0.115	0.063	0.120	0.303
Panel B. Price boom											
Illegal gold deposit x log(lagged gold price)	6.443	5.144	2.817	5.849	4.912	1.296	3.507	0.293	0.127	0.206	2.049
	[2.994]**	[2.703]*	[1.996]	[2.509]**	[2.552]*	[1.269]	[2.602]	[0.171]*	[0.066]*	[0.127]	[0.897]**
Any Gold deposit x log(lagged gold price)	-0.933	-0.849	-0.633	-0.610	-0.269	-0.741	-1.069	0.000	-0.103	-0.029	0.208
	[1.787]	[1.651]	[1.225]	[1.424]	[1.491]	[0.871]	[1.613]	[0.096]	[0.057]*	[0.057]	[0.224]
R-sq	0.502	0.495	0.471	0.496	0.476	0.413	0.480	0.115	0.063	0.120	0.302
Dep. Variable mean	20.983	19.033	13.955	16.891	16.429	7.849	18.070	0.494	0.050	0.081	0.840
Number of observations	12012	12012	12012	12012	12012	12012	12012	12012	12012	12012	12012
Number of municipalities	546	546	546	546	546	546	546	546	546	546	546
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State x Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time trend x Basic Controls (2000)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Source: Elaborated by the author (2026).

Notes: The dependent variable is the homicide rate per 100,000 inhabitants. Basic control variables include population density and the urbanization rate in 2000. Panel A adds gold prices interacted with dummy variables for illegal gold deposits and for any gold deposit as additional controls. Estimations are performed using ordinary least squares (OLS), with standard errors clustered at the municipal level. *, **, ***, significance at the 10%, 5%, and 1% levels, respectively.

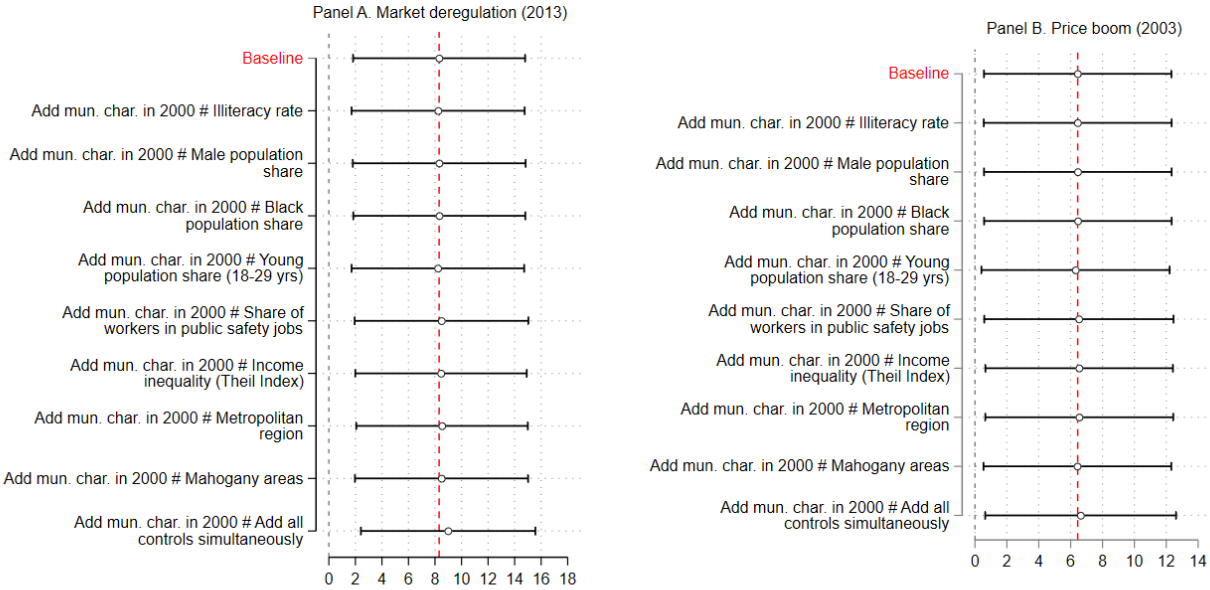
Table 4. Effects of deregulation and price boom on violence in municipalities exposed to illegal gold mining (2000–2021) – Heterogeneities

	Baseline	Other garimpo minerals		Protected area		Mahogany area		Presence of PCOs	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Panel A. Market deregulation									
Illegal gold deposit x Post-2012	8.311	8.048	8.543	7.370	7.441	8.252	8.260	7.648	7.142
	[3.300]**	[3.467]**	[3.703]**	[3.479]**	[3.447]**	[3.290]**	[3.287]**	[3.589]**	[3.616]**
Any Gold deposit x Post-2012	0.268	0.052	0.012	1.185	-1.625	-1.344	-1.142	0.463	0.294
	[1.849]	[1.832]	[1.853]	[2.278]	[3.201]	[2.093]	[2.259]	[1.926]	[1.849]
Other illegal deposits x Post-2012			-1.064						
			[2.339]						
Other deposits x Post-2012			0.039						
			[0.069]						
Illegal gold deposit x Post-2012 x PCOs									7.319
									[8.859]
Any Gold deposit x Post-2012 x Protected areas					2.772				
					[3.618]				
Any Gold deposit x Post-2012 x Mahogany area							2.426		
							[3.372]		
R-sq	0.504	0.504	0.504	0.539	0.504		0.504	0.498	0.504
Panel B. Price boom						0.505			
Illegal gold deposit x log(lagged gold price)	6.443	6.183	6.589	5.485	5.689	6.431	6.431	6.292	5.079
	[2.994]**	[3.034]**	[3.126]**	[3.156]*	[3.158]*	[3.004]**	[3.001]**	[3.170]**	[3.125]
Any Gold deposit x log(lagged gold price)	-0.933	-1.147	-1.146	0.668	-2.572	-1.277	-1.277	-2.211	-0.904
	[1.787]	[1.853]	[1.849]	[2.151]	[2.847]	[2.039]	[2.037]	[1.899]	[1.786]
Other illegal deposits x log(lagged gold price)			-0.793						
			[1.874]						
Other deposits x log(lagged gold price)			0.032						
			[0.047]						
Illegal gold deposit x log(lagged gold price) x PCOs									8.537
									[7.278]
Any Gold deposit x log(lagged gold price) x Protected areas					2.400				
					[3.193]				
Any Gold deposit x log(lagged gold price) x Mahogany area							0.592		
							[2.862]		
R-sq	0.502	0.503	0.503	0.537	0.503	0.504	0.502	0.497	0.503
Number of observations	12012	12012	12012	7282	12012	12012	12012	11484	12012
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State x Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time trend x Basic Controls (2000)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Source: Elaborated by the author (2026).

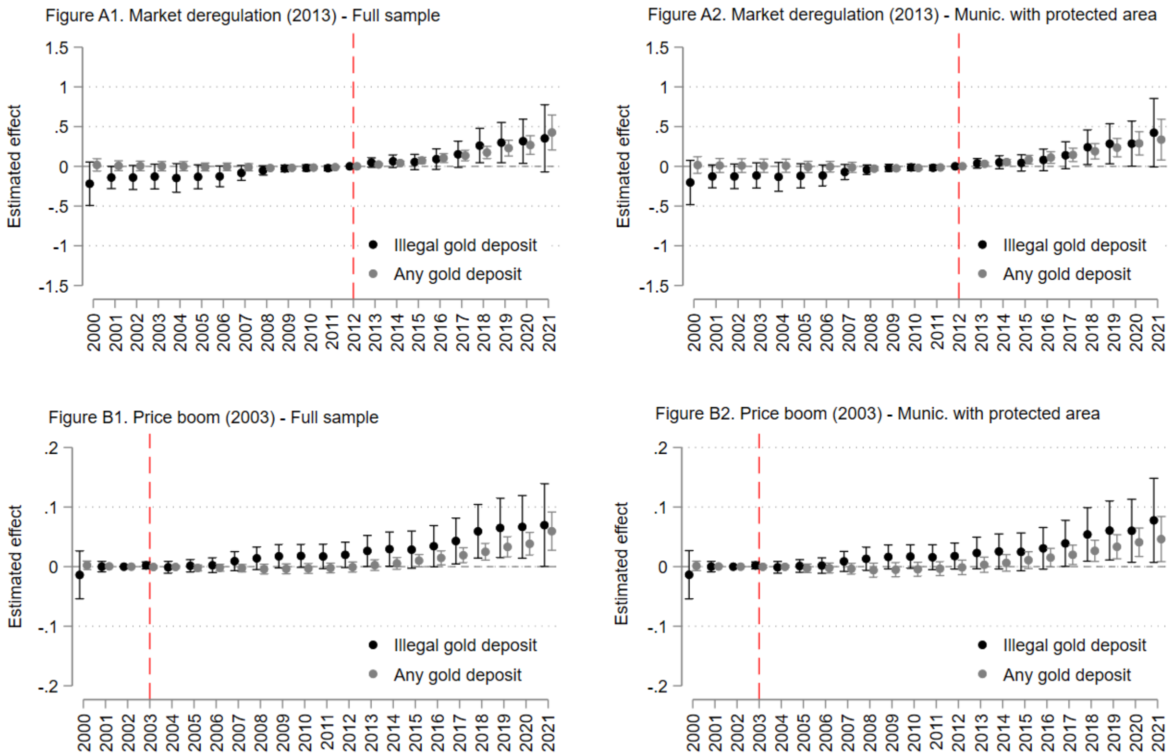
Notes: The dependent variable is the homicide rate per 100,000 inhabitants. Basic control variables include population density and the urbanization rate in 2000. Panel A adds gold prices interacted with dummy variables for illegal gold deposits and for any gold deposit as additional controls. Estimations are performed using ordinary least squares (OLS), with standard errors clustered at the municipal level. *, **, ***, significance at the 10%, 5%, and 1% levels, respectively.

Figure 8. Effects of deregulation and price boom on violence in municipalities exposed to illegal gold mining (2000–2021) – Sensitivity analysis



Source: Elaborated by the author (2026).
Notes: The figure presents estimates of the parameter β with 95% confidence intervals, using standard errors clustered at the municipal level. Line 1 corresponds to the baseline results reported in Table 2, while Line 10 simultaneously incorporates all pre-treatment controls. Table D2 in the Appendix provides the detailed estimates.

Figure 9. Effects of deregulation and price boom on land use for garimpo in municipalities exposed to illegal gold mining (2000–2021) — Event study



Source: Elaborated by the author (2026).

Notes: The figure shows the average difference in land use for garimpo between municipalities more and less exposed to illegal gold mining (see Table 5). The 95% confidence intervals were calculated using standard errors clustered at the municipal level. The dashed red line represents the year prior to the shock (market deregulation or price boom).

Table 5. Effects of deregulation and price boom on land use gold mining in municipalities exposed to illegal gold mining (2000–2021) – Rapacity mechanism

	Gold mining area in hectares (in log)					
	Full Sample			Munic. with protected area		
	Total	Garimpo	Industrial	Total	Garimpo	Industrial
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A. Market deregulation						
Illegal gold deposit x Post-2012	0.165	0.202	-0.044	0.147	0.189	-0.056
	[0.091]*	[0.092]**	[0.028]	[0.094]	[0.094]**	[0.038]
Any Gold deposit x Post-2012	0.178	0.164	0.039	0.188	0.170	0.052
	[0.036]***	[0.034]***	[0.024]*	[0.046]***	[0.044]***	[0.034]
R-sq	0.980	0.979	0.973	0.980	0.979	0.972
Panel B. Price boom						
Illegal gold deposit x log(lagged gold price)	0.179	0.236	0.045	0.161	0.224	0.053
	[0.093]*	[0.096]**	[0.098]	[0.095]*	[0.097]**	[0.105]
Any Gold deposit x log(lagged gold price)	0.128	0.102	0.055	0.129	0.096	0.047
	[0.036]***	[0.032]***	[0.027]**	[0.047]***	[0.042]**	[0.032]
R-sq	0.980	0.978	0.973	0.979	0.978	0.972
Number of observations	12012	12012	12012	7282	7282	7282
Number of municipalities	546	546	546	331	331	331
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes
State x Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Time trend x Basic controls (2000)	Yes	Yes	Yes	Yes	Yes	Yes

Source: Elaborated by the author (2026).

Notes: The dependent variable is land use for gold mining. Basic control variables include population density and the urbanization rate in 2000. Panel A adds gold prices interacted with dummy variables for illegal gold deposits and for any gold deposit as additional controls. Estimations are performed using ordinary least squares (OLS), with standard errors clustered at the municipal level. *, **, ***, significance at the 10%, 5%, and 1% levels, respectively.

Table 6. Effects of deregulation and price boom on deaths from overdose, traffic accidents, and firearm suicides in municipalities exposed to illegal gold mining (2000–2021) – Illegal market and social disorganization

	Illegal Market		*Social Disorganization*
	Overdose death rate	Share of firearm suicides	Traffic accident death rate
	(1)	(2)	(3)
Panel A. Market deregulation			
Illegal gold deposit x Post-2012	0.421	0.013	0.147
	[0.353]	[0.233]	[2.188]
Any Gold deposit x Post-2012	-0.379	-0.056	0.143
	[0.290]	[0.173]	[1.575]
R-sq	0.201	0.103	0.432
Panel B. Price boom			
Illegal gold deposit x log(lagged gold price)	0.121	-0.233	0.349
	[0.298]	[0.183]	[1.761]
Any Gold deposit x log(lagged gold price)	-0.185	0.148	0.323
	[0.243]	[0.155]	[1.384]
R-sq	0.201	0.102	0.432
Number of observations	12012	12012	12012
Number of municipalities	546	546	546
Municipality FE	Yes	Yes	Yes
State x Year FE	Yes	Yes	Yes
Time trend x Basic controls (2000)	Yes	Yes	Yes

Source: Elaborated by the author (2026).

Notes: The dependent variables are mortality rates from overdose, traffic accidents, and the proportion of suicides involving firearms. Basic control variables include population density and the urbanization rate in 2000. Panel A adds gold prices interacted with dummy variables for illegal gold deposits and for any gold deposit as additional controls. Estimations are performed using ordinary least squares (OLS), with standard errors clustered at the municipal level. *, **, ***, significance at the 10%, 5%, and 1% levels, respectively.

Table 7. Effects of deregulation and price boom on aggregate income in municipalities exposed to illegal gold mining (2000–2021) – Opportunity cost mechanism

	Aggregate income			
	GDP per capita (in log)	GDP share		
		Agriculture	Manufacturing	Services
	(1)	(2)	(3)	(4)
Panel A. Market deregulation				
Illegal gold deposit x Post-2012	-0.017	0.891	-0.646	-0.206
	[0.058]	[0.697]	[0.887]	[0.716]
Any Gold deposit x Post-2012	0.009	-0.317	0.230	0.073
	[0.031]	[0.478]	[0.560]	[0.365]
R-sq	0.905	0.875	0.726	0.863
Panel B. Price boom				
Illegal gold deposit x log(lagged gold price)	-0.003	-0.041	-0.065	0.082
	[0.064]	[0.882]	[0.892]	[0.614]
Any Gold deposit x log(lagged gold price)	0.064	-1.521	1.469	0.051
	[0.042]	[0.578]***	[0.669]**	[0.427]
R-sq	0.905	0.875	0.726	0.863
Number of observations	12012	12012	12012	12012
Number of municipalities	546	546	546	546
Municipality FE	Yes	Yes	Yes	Yes
State x Year FE	Yes	Yes	Yes	Yes
Time trend x Basic controls (2000)	Yes	Yes	Yes	Yes

Source: Elaborated by the author (2026).

Notes: The dependent variable is aggregate income. Basic control variables include population density and the urbanization rate in 2000. Panel A adds gold prices interacted with dummy variables for illegal gold deposits and for any gold deposit as additional controls. Estimations are performed using ordinary least squares (OLS), with standard errors clustered at the municipal level. *, **, ***, significance at the 10%, 5%, and 1% levels, respectively.

Table 8. Effects of deregulation and price boom on employment and wages for formal workers in municipalities exposed to illegal gold mining (2000–2021) – Opportunity cost mechanism (cont.)

	Labor market (in log)							
	Employment	Mineral extraction employment	Non-mineral extraction employment	Unskilled employment	Skilled employment	Real wages	Real wages unskilled	Real wages skilled
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A. Market deregulation								
Illegal gold deposit x Post-2012	-0.139	-0.037	-0.148	-0.128	-0.178	-0.022	0.000	-0.047
	[0.060]**	[0.171]	[0.064]**	[0.060]**	[0.094]*	[0.018]	[0.017]	[0.099]
Any Gold deposit x Post-2012	-0.001	0.109	0.017	0.013	-0.002	-0.015	0.003	-0.001
	[0.043]	[0.119]	[0.047]	[0.044]	[0.073]	[0.012]	[0.013]	[0.080]
R-sq	0.877	0.810	0.877	0.875	0.868	0.514	0.432	0.424
Panel B. Price boom								
Illegal gold deposit x log(lagged gold price)	-0.038	-0.051	-0.042	-0.020	-0.282	-0.024	-0.017	-0.158
	[0.093]	[0.210]	[0.091]	[0.094]	[0.111]**	[0.040]	[0.038]	[0.184]
Any Gold deposit x log(lagged gold price)	-0.017	0.531	-0.032	0.002	0.046	0.024	0.025	-0.003
	[0.064]	[0.140]***	[0.062]	[0.066]	[0.068]	[0.020]	[0.019]	[0.110]
R-sq	0.877	0.809	0.877	0.875	0.868	0.514	0.432	0.424
Number of observations	12012	12012	12012	12012	12012	12012	12012	12012
Number of municipalities	546	546	546	546	546	546	546	546
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State x Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time trend x Basic controls (2000)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Source: Elaborated by the author (2026).

Notes: The dependent variables are employment and wages of formal workers. Basic control variables include population density and the urbanization rate in 2000. Panel A adds gold prices interacted with dummy variables for illegal gold deposits and for any gold deposit as additional controls. Estimations are performed using ordinary least squares (OLS), with standard errors clustered at the municipal level. *, **, ***, significance at the 10%, 5%, and 1% levels, respectively.

Table 9. Effects of deregulation and price boom on fiscal budgets in municipalities exposed to illegal gold mining (2000–2021) – Opportunity cost mechanism (cont.)

	Public revenue per capita (in log)	Royalty revenue (in log)	Public expenditure per capita (in log)	Public expenditure on education per capita (in log)	Public expenditure on health per capita (in log)	Public expenditure on personnel per capita (in log)	Share of royalty revenue by public revenue (in log)	Share of royalty revenue by public expenditure
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel A. Market deregulation								
Illegal gold deposit x Post-2012	-0.004	-0.017	0.004	-0.002	0.003	0.004	-1.084	-1.919
	[0.028]	[0.127]	[0.022]	[0.016]	[0.010]	[0.018]	[0.585]*	[1.031]*
Gold deposit x Post-2012	0.017	0.205	0.006	0.008	0.000	0.001	0.647	0.776
	[0.014]	[0.083]**	[0.009]	[0.007]	[0.006]	[0.008]	[0.356]*	[0.553]
R-sq	0.655	0.848	0.640	0.563	0.631	0.664	0.529	0.511
Panel B. Price boom								
Illegal gold deposit x log(lagged gold price)	0.025	0.062	0.025	0.010	0.013	0.022	-0.094	-0.355
	[0.028]	[0.144]	[0.021]	[0.014]	[0.011]	[0.017]	[0.643]	[0.743]
Gold deposit x log(lagged gold price)	0.025	0.246	0.010	0.009	0.006	0.004	0.910	1.273
	[0.015]	[0.093]***	[0.010]	[0.006]	[0.006]	[0.008]	[0.353]**	[0.431]***
R-sq	0.655	0.848	0.640	0.563	0.631	0.664	0.528	0.510
Number of observations	12012	12012	12012	12012	12012	12012	12012	12012
Number of municipalities	546	546	546	546	546	546	546	546
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State x Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time trend x Basic controls (2000)	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Source: Elaborated by the author (2026).

Notes: The dependent variables are royalties and municipal budgets. Basic control variables include population density and the urbanization rate in 2000. Panel A adds gold prices interacted with dummy variables for illegal gold deposits and for any gold deposit as additional controls. Estimations are performed using ordinary least squares (OLS), with standard errors clustered at the municipal level. *, **, ***, significance at the 10%, 5%, and 1% levels, respectively.

Table 10. Effects of deregulation and price boom on health indicators and urban infrastructure in municipalities exposed to illegal gold mining (2000–2021) - Other conditions

	Crude birth rate (1000 inhabitants)	Low birth weight rate (1000 live births)	Fetal mortality rate (1000 live births)	Infant mortality rate (1000 live births)	Urban infrastructure area (in log)
	(1)	(2)	(3)	(4)	(5)
Panel A. Market deregulation					
Illegal gold deposit x Post-2012	1.891	3.159	-1.196	-0.489	-0.010
	[1.139]*	[1.991]	[0.907]	[1.096]	[0.023]
Gold deposit x Post-2012	0.226	-0.257	0.612	0.306	0.008
	[0.366]	[1.569]	[0.591]	[0.677]	[0.014]
R-sq	0.667	0.268	0.120	0.239	0.983
Panel B. Price boom					
Illegal gold deposit x log(lagged gold price)	1.826	0.672	-0.078	1.267	-0.006
	[1.261]	[1.930]	[0.777]	[1.298]	[0.056]
Gold deposit x log(lagged gold price)	0.429	-0.150	0.192	0.102	0.051
	[0.485]	[1.399]	[0.564]	[0.736]	[0.035]
R-sq	0.666	0.268	0.120	0.239	0.983
Number of observations	12012	12012	12012	12012	12012
Number of municipalities	546	546	546	546	546
Municipality FE	Yes	Yes	Yes	Yes	Yes
State x Year FE	Yes	Yes	Yes	Yes	Yes
Time trend x Basic controls (2000)	Yes	Yes	Yes	Yes	Yes

Source: Elaborated by the author (2026).

Notes: The dependent variables are health indicators and urban infrastructure area. Basic control variables include population density and the urbanization rate in 2000. Panel A adds gold prices interacted with dummy variables for illegal gold deposits and for any gold deposit as additional controls. Estimations are performed using ordinary least squares (OLS), with standard errors clustered at the municipal level. *, **, ***, significance at the 10%, 5%, and 1% levels, respectively.

Figure 10. Summary of the results of the mechanism analysis

Mechanisms	Rapacity (⇑)	Opportunity cost (⇓)	Alternative (⇑)	Result
Land use for gold mining	**Yes**	No	No	**Positive Effect (+)**
Illegal Markets and Social Disorganization	No	No	**Yes**	No Significant Effects
Aggregate income	No	**Yes**	No	No Significant Effect
Labor Market	No	**Yes**	No	**Negative Effect (-)**
Fiscal Budgets	No	**Yes**	No	**Negative Effect (-)**
Other Conditions (health and urbanization)	No	**Yes**	No	No Significant Effect

Local Economic Impact Effects of **illegal mining** on the local economy.

Source: Elaborated by the author (2026).

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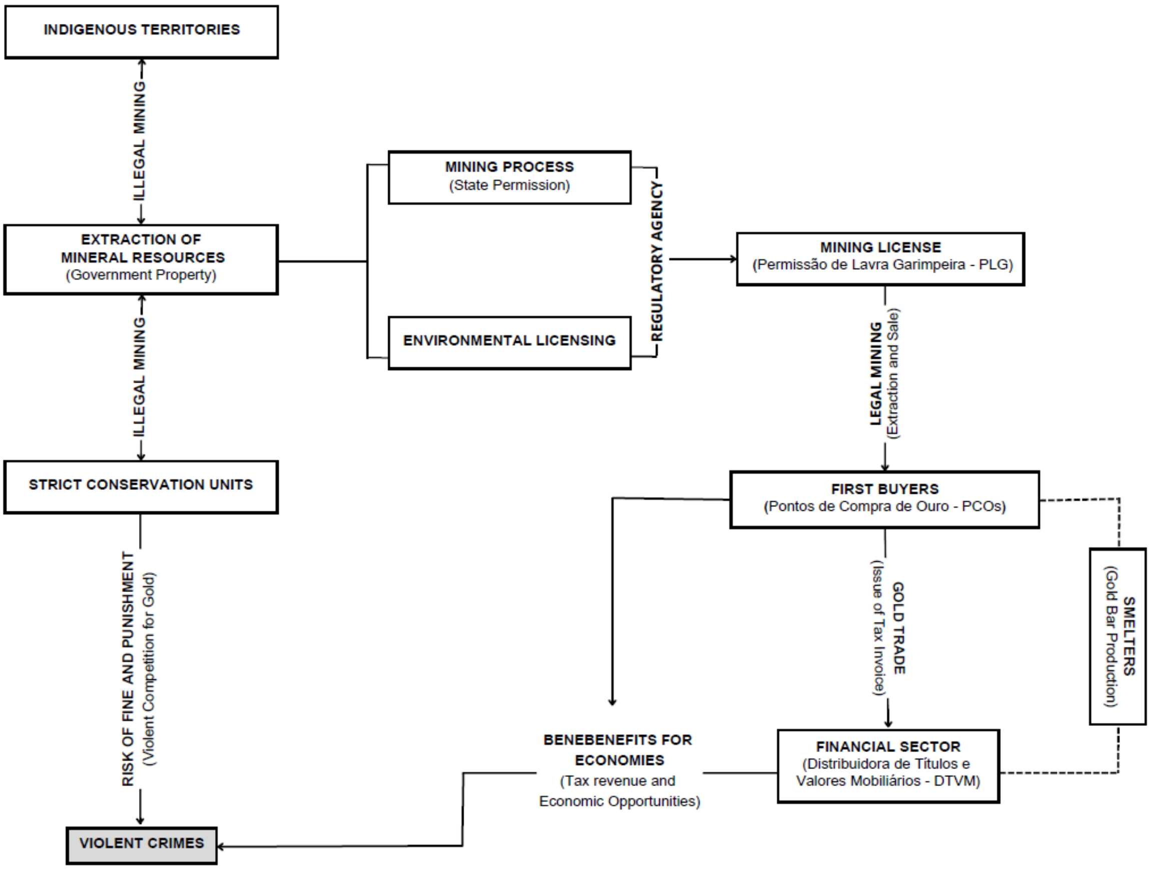
APPENDIX A

A.1 GOLD REGULATION CHAIN DIAGRAM

Figure A1. Gold regulation chain and violent crimes in the Brazilian Amazon



Source: Elaborated by the author (2026).

Figure A1 presents a schematic representation of the gold regulatory chain in the Brazilian Amazon, highlighting the coexistence of legal and illegal mining activities and their connection to violent crime. The diagram illustrates the institutional stages of licensing, mineral extraction, marketing, financial intermediation, gold refining, and tax collection.

APPENDIX B

B.1 ECONOMIC THEORY OF CRIME

Theoretical work highlights the importance of factor intensity in natural resource extraction for understanding its effects on crime (Dal Bó and Dal Bó, 2011). According to the Stolper–Samuelson theorem, shocks favoring capital-intensive activities tend to shift labor away from other sectors, increasing labor supply and putting downward pressure on wages. When legal earnings fall relative to rents from appropriable resources, incentives for crime may rise through a rapacity channel. Conversely, expansions in labor-intensive activities are expected to raise wages and increase the opportunity cost of engaging in illegal activities, thereby discouraging crime (Ferraz et al., 2022). Dube and Vargas (2013) provide empirical evidence supporting both mechanisms in the context of the Colombian conflict.

These predictions may be altered by general equilibrium and indirect labor-market effects. Resource-driven growth can generate indirect employment gains and wage increases (Aragón and Rud, 2013; Kotsadam and Tolonen, 2016; Cust and Poelhekke, 2015), raising the opportunity cost of crime in line with Becker (1968) and Ehrlich (1971). Growth may also strengthen state capacity by increasing fiscal revenues and enabling greater provision of public goods – such as security, education, and health – which can reduce crime through deterrence, incapacitation, and improved time allocation (Axbard et al., 2021).

While rapacity and opportunity-cost mechanisms can produce opposing effects in settings where legal and illegal activities coexist, this thesis focuses on illegal gold mining. In this context, legal earnings are minimal or nonexistent, so both mechanisms align in increasing incentives for Illegal extraction.

B.2 MATHEMATICAL PROOFS OF THE MODEL

Proof of prediction 1 (Market Deregulation). To investigate how the deregulation of the gold market affected the equilibrium of the number of illegal miners ($N_{n,I}^*$) and the level of local violent crimes (υ_n^*), we begin by analyzing the partial derivatives for the monitoring parameter of illegal gold trade (θ). Although this initial exercise is analogous to that performed by Pereira and Pucci (2026), in our version of the model, we incorporate the risk of imprisonment and fines for illegal miners and utilize a CES demand function, which is more appropriate for our context.

Considering the profit (3.18) and violence (3.20) equilibrium equation in addition to the fact that $c'^{-1}(.) = \mu(.)\ \{MC = p_I^*\}$, we calculate the following partial derivative:

$$\frac{\partial \upsilon_n^*}{\partial \theta} = \frac{1}{{N^*}_{n,I}^2}\frac{\partial N_{n,I}^*}{\partial \theta}\left[p_I^*\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right) - c\left(\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\right)\right] + \left(\frac{N_{n,I}^*-1}{N_{n,I}^*}\right)\left[p_I^*\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right) - c\left(\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\right)\right]\frac{\partial p_I^*}{\partial \theta}$$

Solving the second part $[.]\frac{\partial p_I^*}{\partial \theta}$ and considering that to maximize profit, the marginal cost (MC) must equal the equilibrium price of illegal gold (p_I^*), we have:

$$\left(\frac{N_{n,I}^* - 1}{N_{n,I}^*}\right)\left[\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right) - c'\left(\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\right)\mu'\left(p_I^* - \frac{\varphi}{1-\varphi}m\right) + p_I^*\mu'\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\right]\frac{\partial p_I^*}{\partial \theta}$$

$$\left(\frac{N_{n,I}^* - 1}{N_{n,I}^*}\right)\left[\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right) - p_I^*\mu'\left(p_I^* - \frac{\varphi}{1-\varphi}m\right) + p_I^*\mu'\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\right]\frac{\partial p_I^*}{\partial \theta}$$

$$\frac{\partial \upsilon_n^*}{\partial \theta} = \frac{1}{{N^*}_{n,I}^2}\frac{\partial N_{n,I}^*}{\partial \theta}\left[p_I^*\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right) - c\left(\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\right)\right] + \left(\frac{N_{n,I}^*-1}{N_{n,I}^*}\right)\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\frac{\partial p_I^*}{\partial \theta} \tag{3.24}$$

Next, we need to determine the signs of the partial derivatives on the right-hand side of equation (3.24). For this, we start by taking equation (3.22) and calculating the derivative $\left(\frac{\partial N_{n,I}^*}{\partial \theta}\right)$.

$$\frac{\partial N_{n,I}^*}{\partial \theta} = \frac{1}{2{N^*}_{n,I}}\frac{\frac{\partial p_I^*}{\partial \theta}}{(1-\phi)}\frac{\left[p_I^*\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right) - c\left(\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\right)\right]}{\left(\mu(1-\tau) - c\left(\mu(1-\tau)\right) - \tau\mu(1-\tau)\right)} = \frac{1}{2{N^*}_{n,I}}\frac{\frac{\partial p_I^*}{\partial \theta}\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)}{(1-\phi)\left(\mu(1-\tau) - c\left(\mu(1-\tau)\right) - \tau\mu(1-\tau)\right)}$$

$$\frac{\partial N_{n,I}^*}{\partial \theta} = \frac{\frac{\partial p_I^*}{\partial \theta}\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)}{2N_{n,I}^*(1-\phi)\lambda}, \text{ where } \lambda = \left(\mu(1-\tau) - c\left(\mu(1-\tau)\right) - \tau\mu(1-\tau)\right) \tag{3.25}$$

Introducing equation (3.25) into (3.24) and rearranging, we have:

$$\frac{\partial v_n^*}{\partial \theta} = \frac{1}{2N_{n,I}^* N^{*2}_{n,I}} \frac{\frac{\partial p_I^*}{\partial \theta} \mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\left[p_I^* \mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right) - c\left(\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\right)\right]}{(1-\phi)\lambda} + \left(\frac{N_{n,I}^* - 1}{N_{n,I}^*}\right)\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\frac{\partial p_I^*}{\partial \theta}$$

$$\frac{\partial v_n^*}{\partial \theta} = \mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\frac{\partial p_I^*}{\partial \theta}\left[\frac{1}{2N^*_{n,I}} + \frac{N_{n,I}^* - 1}{N_{n,I}^*}\right] = \mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\frac{\partial p_I^*}{\partial \theta}\left[\frac{2N_{n,I}^* - 1}{2N_{n,I}^*}\right] \tag{3.26}$$

where $1/N^{*2}_{n,I}$ is simplified.

Given that $\left[\frac{2N_{n,I}^* - 1}{2N_{n,I}^*}\right] > 0$ is greater than zero for a positive number of illegal miners $\left(N_{n,I}^*\right)$ and $\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right) \geq 0$, the sign of $\frac{\partial v_n^*}{\partial \theta}$ now depends only on the derivative $\frac{\partial p_I^*}{\partial \theta}$. To ensure a similar solution to Pereira and Pucci (2026) and to reduce the complexity of the non-numeric problem, we proceed with the case of the *Cobb-Douglas* function to prove that $\frac{\partial p_I^*}{\partial \theta} < 0$. In particular, we assume that legal and illegal gold can be substituted for each other continuously and proportionally ($\sigma \Longrightarrow 1$). Note that this is just an assumption to make the modeling more tractable. Therefore, equation (3.21) becomes:

$$p_I^* = \frac{(1-\alpha)}{\alpha}\left[\frac{\left(N_n - N_{n,I}^*\right)}{N_{n,I}^*}\frac{\mu(1-\tau)}{\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)}\right] - \theta f.$$

Taking equation (3.21) with $\sigma = 1$ and calculating the derivative, we obtain:

$$\frac{\partial p_I^*}{\partial \theta} = \Theta\left[-\frac{\partial N_{n,I}^*}{\partial \theta}\mu(1-\tau)N_{n,I}^*\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\right] + \Theta\left[-\left(N_n - N_{n,I}^*\right)\mu(1-\tau)\left(\frac{\partial N_{n,I}^*}{\partial \theta}\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right) + N_{n,I}^*\mu'\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\frac{\partial p_I^*}{\partial \theta}\right)\right] - f \tag{3.27}$$

where $\Theta = \frac{(1-\alpha)}{\alpha\left(N_{n,I}^*\right)^2 \mu^2\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)}$.

Substituting equation (3.25) into (3.27) and rearranging, we have:

$$\frac{\partial p_I^*}{\partial \theta} = -\frac{\partial p_I^*}{\partial \theta}\Theta\left[\frac{\mu^2\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\mu(1-\tau)N_{n,I}^*}{2N_{n,I}^*(1-\phi)\lambda}\right] + \frac{\partial p_I^*}{\partial \theta}\Theta\left[-\left(N_n - N_{n,I}^*\right)\mu(1-\tau)\left(\frac{\mu^2\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)}{2N_{n,I}^*(1-\phi)\lambda} + N_{n,I}^*\mu'\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\right)\right] - f$$

$$\frac{\partial p_I^*}{\partial \theta} = -\frac{\partial p_I^*}{\partial \theta}\Theta\left[\frac{\mu^2\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\mu(1-\tau)N_{n,I}^*}{2N_{n,I}^*(1-\phi)\lambda}\right] + \frac{\partial p_I^*}{\partial \theta}\Theta\left[-\frac{\mu^2\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\left(N_n - N_{n,I}^*\right)\mu(1-\tau)}{2N_{n,I}^*(1-\phi)\lambda} - N_{n,I}^*\left(N_n - N_{n,I}^*\right)\mu'\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\mu(1-\tau)\right] - f$$

$$\frac{\partial p_I^*}{\partial \theta} = -\frac{\partial p_I^*}{\partial \theta}\Theta\left[\frac{\mu^2\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\mu(1-\tau)N_{n,I}^*}{2N_{n,I}^*(1-\phi)\lambda}\right] + \frac{\partial p_I^*}{\partial \theta}\Theta\left[\frac{\mu^2\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\mu(1-\tau)N_{n,I}^*}{2N_{n,I}^*(1-\phi)\lambda}\right] - \frac{\partial p_I^*}{\partial \theta}\Theta\left[\frac{\mu^2\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\mu(1-\tau)N_n}{2N_{n,I}^*(1-\phi)\lambda} + N_{n,I}^*\mu'\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\left(N_n - N_{n,I}^*\right)\mu(1-\tau)\right] - f$$

$$\frac{\partial p_I^*}{\partial \theta} = -f(\Theta A)^{-1} < 0 \tag{3.28}$$

where $A = \frac{\mu^2\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\mu(1-\tau)N_n}{2N_{n,I}^*(1-\phi)\lambda} + N_{n,I}^*\mu'\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\left(N_n - N_{n,I}^*\right)\mu(1-\tau)$.

Therefore, we have to: $\frac{\partial p_I^*}{\partial \theta} < 0, \frac{\partial v_n^*}{\partial \theta} < 0$ and $\frac{\partial N_{n,I}^*}{\partial \theta} < 0$.

This result indicates that an increase in the risk of being caught by authorities in the illicit gold trade negatively affects the price of illegal gold, the number of illegal miners, and local violent crimes. Specifically, the greater the monitoring capacity of the authorities, the less incentive downstream market firms (first buyers, or PCOs) will have to buy illegal gold. Consequently, this will reduce the incentive for illegal gold mining and associated violent crimes. Therefore, in a scenario of deregulation of the gold market, we should expect opposite effects (Pereira and Pucci, 2026).

Proof of prediction 2 (Price Change). We now analyze how changes in gold prices affect local violent crime. Reconsidering the equation below and deriving with respect to illegal gold prices, we have:

$$\frac{\partial v_n^*}{\partial p_I^*} = \frac{1}{N^{*2}_{n,I}}\frac{\partial N_{n,I}^*}{\partial p_I^*}\left[p_I^*\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right) - c\left(\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\right)\right] + \left(\frac{N_{n,I}^*-1}{N_{n,I}^*}\right)\left[p_I^*\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right) - c\left(\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\right)\right]$$

$$\frac{\partial v_n^*}{\partial p_I^*} = \frac{1}{N^{*2}_{n,I}}\frac{\partial N_{n,I}^*}{\partial p_I^*}\left[p_I^*\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right) - c\left(\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\right)\right] + \left(\frac{N_{n,I}^*-1}{N_{n,I}^*}\right)\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right) \quad (3.29)$$

Deriving equation (3.22) with respect to the price of illegal gold and reorganizing as before, we find:

$$\frac{\partial N_{n,I}^*}{\partial p_I^*} = \frac{\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)}{2N^*_{n,I}(1-\phi)\lambda} \quad (3.30)$$

Substituting (3.30) into (3.29) and simplifying as before, we have:

$$\frac{\partial v_n^*}{\partial p_I^*} = \frac{1}{2N_{n,I}^*N^{*2}_{n,I}}\frac{\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\left[p_I^*\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right) - c\left(\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\right)\right]}{(1-\phi)\lambda} + \left(\frac{N_{n,I}^*-1}{N_{n,I}^*}\right)\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)$$

$$\frac{\partial v_n^*}{\partial p_I^*} = \mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right)\left[\frac{2N_{n,I}^* - 1}{2N_{n,I}^*}\right] \quad (3.31)$$

Given that $\left[\frac{2N_{n,I}^* - 1}{2N_{n,I}^*}\right] > 0$ is greater than zero for a positive number of illegal miners $\left(N_{n,I}^*\right)$ and $\mu\left(p_I^* - \frac{\varphi}{1-\varphi}m\right) \geq 0$, then we have $\frac{\partial N_{n,I}^*}{\partial p_I^*} > 0$ and $\frac{\partial v_n^*}{\partial p_I^*} > 0$. Therefore, a positive shock in gold prices increases the number of illegal miners and violent crimes.

APPENDIX C

C.1 VARIABLES AND DATA SOURCES

Table C1. Variables and data sources

Variable	Description	Source	Period
Homicide rate	Homicide rate (100,000 inhabitants)	MS-DATASUS	2000-2021
Any Gold deposit	Any Gold deposit - Outside protected areas	SGB	-
Illegal gold deposit	Illegal gold deposit - Inside protected areas	SGB	-
Gold Price - World	Gold Price - World (US$ per troy ounce)	WORLD BANK	1995-2021
Gold Price - Brazil	Gold Price - Brazil (R$ per troy ounce)	WORLD BANK	1995-2021
PCOs	*Pontos de Compra de Ouro* (PCOs)	BCB	2021
Protection area	Integral protection area	FUNAI / MMA	-
Population density	Population density	CENSUS - IBGE	2000
Urbanization rate	Population share - urban	CENSUS - IBGE	2000
Population Share # man	Population share - man	CENSUS - IBGE	2000
Population Share # black	Population share - black	CENSUS - IBGE	2000
Population Share # young	Population share – Young (18-29 yrs)	CENSUS - IBGE	2000
Illiteracy rate	Illiteracy rate	CENSUS - IBGE	2000
Public security	Employment share - security	CENSUS - IBGE	2000
Income inequality	Income inequality - Theil index	CENSUS - IBGE	2000
Metropolitan	Metropolitan region	CENSUS - IBGE	2000
Mahogany area	Mahogany area	Lentini et al. (2003)	-
Rapacity			
Gold mining area - All	Gold mining area - All	MAPBIOMAS	2000-2021
Gold mining area - Garimpo	Gold mining area - Garimpo	MAPBIOMAS	2000-2021
Gold mining area - Industrial	Gold mining area - Industrial	MAPBIOMAS	2000-2021
Illegal Market and Social Disorganization			
Overdose deaths	Overdose death rate (100,000 inhabitants)	MS-DATASUS	2000-2021
Suicides by firearm	Share of suicides by firearm	MS-DATASUS	2000-2021
Traffic accident deaths	Traffic accident death rate (100,000 inhabitants)	MS-DATASUS	2000-2021
Opportunity cost (Aggregate income)			
GDP per capita	GDP per capita (BRL 1000)	SIDRA IBGE	2000-2021
GDP share - Agriculture	GDP share - Agriculture	SIDRA IBGE	2000-2021
GDP share - Manufacturing	GDP share - Manufacturing	SIDRA IBGE	2000-2021
GDP share - Services	GDP share - Services	SIDRA IBGE	2000-2021
Opportunity cost (Labor market)			
Employment	Employment	BD - RAIS	2000-2021
Extractive employment	Extractive employment	BD - RAIS	2000-2021
Non-extractive employment	Non-extractive employment	BD - RAIS	2000-2021
Employment - Unskilled	Employment - Unskilled	BD - RAIS	2000-2021
Employment - Skilled	Employment - Skilled	BD - RAIS	2000-2021
Wage earnings	Wage earnings	BD - RAIS	2000-2021
Wage Earnings - Unskilled	Wage earnings - Unskilled	BD - RAIS	2000-2021
Wage Earnings - Skilled	Wage earnings - Skilled	BD - RAIS	2000-2021
Opportunity cost (Fiscal budgets)			
Public revenue	Public revenue per capita (BRL 1000)	IPEA/STN	2000-2021
Royalty revenue	Royalty revenue (BRL 1000)	STN	2000-2021
Public expenditure	Public expenditure per capita (BRL 1000)	IPEA/STN	2000-2021
Public expenditure share - education	Public expenditure per capita - education (BRL 1000)	IPEA/STN	2000-2021
Public expenditure share - health	Public expenditure per capita - health (BRL 1000)	IPEA/STN	2000-2021
Public expenditure share - personal	Public expenditure per capita - personal (BRL 1000)	IPEA/STN	2000-2021
Share (Royalty rev. / Public rev.)	Share (royalty revenue / public revenue) (BRL 1000)	IPEA/STN	2000-2021
Share (Royalty rev. / Public exp.)	Share (royalty revenue / public expenditure) (BRL 1000)	IPEA/STN	2000-2021
Other conditions			
Crude birth rate	Crude birth rate (1000 inhabitants)	MS-DATASUS	2000-2021
Low birth weight rate	Low birth weight rate (1000 live births)	MS-DATASUS	2000-2021
Fetal mortality rate	Fetal mortality rate (1000 live births)	MS-DATASUS	2000-2021
Infant mortality rate	Infant mortality rate (1000 live births)	MS-DATASUS	
Urban infrastructure area	Urban infrastructure area	MAPBIOMAS	2000-2021

Source: Elaborated by the author (2026).

C.2 DESCRIPTIVE STATISTICS

Table C2. Descriptive statistics

	Protected area		*Non-protected area*		*Rest of the Amazon*	
	Illegal gold deposit (N=44)		Any Gold deposit (N=88)		No gold deposit (N=414)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Homicide rate	30.72	33.17	26.81	24.43	18.71	21.46
Homicide rate # Black & Indigenous	25.59	29.49	19.81	20.18	15.35	18.30
Homicide rate # Young (15-39 yrs.)	18.56	21.30	17.07	17.37	12.80	15.79
Homicide rate # Outside of home	23.56	28.00	20.62	20.21	14.78	18.25
Homicide rate # Public Street	8.58	11.69	10.04	12.36	7.30	10.86
Homicide rate # Man	27.13	29.17	24.32	22.76	17.05	20.04
Homicide rate # Young man	16.91	20.20	15.53	16.30	11.76	14.87
Homicide rate # Young man (Black & Indigenous)	14.30	17.58	12.10	13.94	10.02	13.36
Homicide rate # Young man (Single)	11.76	13.95	11.10	12.74	8.54	11.68
Homicide rate # Young man (Outside home)	14.29	18.61	12.98	14.14	9.97	13.31
Homicide rate # Young man (Public Street)	5.63	8.29	6.63	9.24	5.24	8.47
Homicide rate # Young man (Firearm and Knives)	14.77	18.70	14.03	15.54	10.63	13.90
Homicide rate # Physical aggression	0.89	2.75	0.52	1.74	0.45	1.93
Homicide rate # Fire and chemicals	0.07	1.15	0.05	0.70	0.05	0.78
Homicide rate # Firearms and Knives	24.23	27.63	23.26	22.44	16.31	19.61
Homicide rate # Unspecified	2.90	11.20	0.91	3.06	0.61	2.83
Homicide rate # Police interventions	0.20	1.58	0.09	0.81	0.07	1.08

Source: Elaborated by the author (2026).

Table C3. Descriptive statistics

	Protected area		*Non-protected area*		*Rest of the Amazon*	
	Illegal gold deposit (N = 44)		Any Gold deposit (N=88)		No gold deposit (N = 414)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Rapacity						
Log: Deforestation - Gold mining area	3.00	3.27	2.22	3.04	0.08	0.60
Log: Deforestation - Gold mining area (garimpo)	2.86	3.21	2.03	2.98	0.08	0.60
Log: Deforestation - Gold mining area (industrial)	0.37	1.41	0.35	1.34	0.00	0.00
Opportunity cost						
Log: GDP per capita	1.67	0.67	1.81	0.61	1.49	0.69
GDP share - Agriculture	18.21	11.73	18.21	10.48	21.32	10.14
GDP share - Manufacturing	9.14	8.39	8.70	7.70	6.35	5.81
GDP share - Services	20.25	8.85	20.56	7.72	20.35	7.94
Log: Employment	6.93	1.73	7.19	1.44	6.65	1.70
Log: Mineral extraction employment	1.60	2.41	1.41	1.86	0.54	1.31
Log: Non-mineral extraction employment	6.90	1.71	7.16	1.46	6.64	1.70
Log: Unskilled employment	6.78	1.71	7.05	1.43	6.46	1.69
Log: Skilled employment	4.70	1.95	4.84	1.82	4.49	2.01
Log: Real wages	6.05	0.49	6.03	0.31	5.94	0.49
Log: Real wages unskilled	5.91	0.47	5.91	0.28	5.80	0.48
Log: Real wages skilled	6.43	1.54	6.54	1.10	6.25	1.41
Illegal Market and Social Disorganization						
Overdose death rate (100,000 inhabitants)	1.30	3.57	1.86	3.91	1.56	4.60
Share of firearm suicides	8.38	23.22	9.51	25.62	5.96	21.06
Traffic accident death rate (100,000 inhabitants)	18.06	17.20	21.36	23.19	15.62	20.45
Fiscal budgets						
Log: Public revenue per capita	0.44	0.24	0.45	0.20	0.42	0.22
Log: Royalty revenue	4.10	1.78	4.08	1.46	3.83	1.14
Log: Public expenditure per capita	0.30	0.17	0.30	0.13	0.29	0.15
Log: Public expenditure on education per capita	0.17	0.12	0.17	0.08	0.18	0.10
Log: Public expenditure on health per capita	0.12	0.08	0.12	0.07	0.11	0.08
Log: Public expenditure on personnel per capita	0.23	0.14	0.24	0.12	0.22	0.13
Share of royalty revenue by public revenue	1.62	5.11	1.45	5.11	0.83	3.08
Share of royalty revenue by public expenditure	2.61	8.84	2.18	6.93	1.31	4.68
Other conditions						
Crude birth rate (1000 inhabitants)	20.75	9.95	17.25	5.00	17.71	5.42
Low birth weight rate (1000 live births)	68.35	25.27	63.43	21.43	65.91	23.64
Fetal mortality rate (1000 live births)	11.28	7.69	10.52	8.36	11.86	9.40
Infant mortality rate (1000 live births)	22.15	13.63	16.06	10.12	17.26	12.59
Log: Urban infrastructure area	5.92	1.08	5.93	1.21	5.49	1.15

Source: Elaborated by the author (2026).

APPENDIX D

D.1 ANALYSIS OF AVOIDABLE HOMICIDES

Table D1. Analysis of avoidable homicides (2000-2021)

	Market deregulation	Price boom
	(2013-2021)	(2004-2021)
Coefficient (β)	8.3	6.4
Mean population	37043	34270
Homicides per year	3.07	2.19
Shock	Post-2012 (=1)	Δlog(3)
Homicides per year x Shock	3.07	2.41
Munic. with illegal gold deposits	44	44
Number of years (post-shock)	9	18
Avoidable homicides (Total)	1218	1908

Source: Elaborated by the author (2026).
Notes: Based on the results of Table 2.

D.2 SENSITIVITY ANALYSIS

Table D2. Effects of deregulation and price boom on violence in municipalities exposed to illegal gold mining (2000–2021)

	Homicide rate									
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel A. Market deregulation										
Illegal gold deposit x Post-2012	8.311	8.235	8.317	8.323	8.219	8.492	8.454	8.531	8.492	8.990
	[3.300]**	[3.321]**	[3.316]**	[3.300]**	[3.311]**	[3.333]**	[3.288]**	[3.290]***	[3.321]**	[3.347]***
Any Gold deposit x Post-2012	0.268	0.205	0.727	0.225	0.344	0.292	0.295	0.727	0.814	1.434
	[1.849]	[1.843]	[1.870]	[1.849]	[1.867]	[1.848]	[1.836]	[1.843]	[1.852]	[1.864]
R-sq	0.504	0.504	0.506	0.505	0.504	0.504	0.505	0.505	0.505	0.514
Panel B. Price boom										
Illegal gold deposit x log(lagged gold price)	6.443	6.444	6.451	6.456	6.307	6.519	6.535	6.543	6.425	6.630
	[2.994]**	[3.000]**	[2.997]**	[2.996]**	[3.006]**	[3.022]**	[2.995]**	[3.002]**	[2.999]**	[3.048]**
Any Gold deposit x log(lagged gold price)	-0.933	-0.932	-0.345	-0.979	-0.822	-0.923	-0.916	-0.726	-0.988	-0.220
	[1.787]	[1.788]	[1.793]	[1.783]	[1.822]	[1.792]	[1.785]	[1.792]	[1.796]	[1.867]
R-sq	0.502	0.503	0.505	0.503	0.503	0.503	0.504	0.504	0.504	0.512
Dep. variable mean	20.983	20.983	20.983	20.983	20.983	20.983	20.983	20.983	20.983	20.983
Number of observations	12012	12012	12012	12012	12012	12012	12012	12012	12012	12012
Number of municipalities	546	546	546	546	546	546	546	546	546	546
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State x Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time trend x Munic. Charc in 2000:										
Illiteracy rate		Yes								Yes
Male population share			Yes							Yes
Black population share				Yes						Yes
Young population share (18-29 yrs)					Yes					Yes
Share of workers in public safety jobs						Yes				Yes
Income inequality (Theil Index)							Yes			Yes
Dummy for metropolitan region								Yes		Yes
Dummy for mahogany areas									Yes	Yes
Basic controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Source: Elaborated by the author (2026).

Notes: The dependent variable is the homicide rate per 100,000 inhabitants. Basic control variables include population density and the urbanization rate in 2000. Panel A adds gold prices interacted with dummy variables for illegal gold deposits and for any gold deposit as additional controls. Estimations are performed using ordinary least squares (OLS), with standard errors clustered at the municipal level. *, **, ***, significance at the 10%, 5%, and 1% levels, respectively.

D.3 ROBUSTNESS TO ALTERNATIVE INFERENCE PROCEDURES

Table D3. Effects of deregulation and price boom on violence in municipalities exposed to illegal gold mining (2000–2021)

	Homicide rate			
	SE Cluster at the local level (baseline)	SE Cluster at the local level (wild bootstrap p-value)	SE cluster at microregional level	SE cluster at mesoregion level
	(1)	(2)	(3)	(4)
Panel A. Market deregulation				
Illegal gold deposit x Post-2012	8.311	8.311	8.311	8.311
	[3.300]**	[<0.016]**	[3.805]**	[4.263]*
Any Gold deposit x Post-2012	0.268	0.268	0.268	0.268
	[1.849]	[<0.884]	[1.728]	[1.145]
R-sq	0.504	0.504	0.504	0.504
Panel B. Price boom				
Illegal gold deposit x log(lagged gold price)	6.443	6.443	6.443	6.443
	[2.994]**	[<0.033]**	[3.150]**	[3.393]*
Any Gold deposit x log(lagged gold price)	-0.933	-0.933	-0.933	-0.933
	[1.787]	[<0.623]	[1.807]	[1.334]
R-sq	0.502	0.502	0.502	0.502
Dep. variable mean	20.983	20.983	20.983	20.983
Number of observations	12012	12012	12012	12012
Number of municipalities	546	546	546	546
Municipality FE	Yes	Yes	Yes	Yes
State x Year FE	Yes	Yes	Yes	Yes
Time trend x Basic controls (2000)	Yes	Yes	Yes	Yes

Source: Elaborated by the author (2026).

Notes: The dependent variable is the homicide rate per 100,000 inhabitants. Basic control variables include population density and the urbanization rate in 2000. Panel A adds gold prices interacted with dummy variables for illegal gold deposits and for any gold deposit as additional controls. Estimations are performed using ordinary least squares (OLS), with standard errors clustered at the municipal level. *, **, ***, significance at the 10%, 5%, and 1% levels, respectively.

D.4 ROBUST FOR SUBSAMPLE TESTS

Table D4. Effects of deregulation and price boom on violence in municipalities exposed to illegal gold mining (2000–2021)

	Homicide rate				
	Baseline	Winsorizing zero values	Municipalities with changes in territorial boundaries	Excluding metropolitan area	Excluding populous municipalities
	(1)	(2)	(3)	(4)	(5)
Panel A. Market deregulation					
Illegal gold deposit x Post-2012	8.311	7.969	7.499	8.148	7.803
	[3.300]**	[3.662]**	[3.285]**	[3.395]**	[3.280]**
Any Gold deposit x Post-2012	0.268	0.783	0.494	1.783	1.031
	[1.849]	[2.034]	[1.828]	[1.867]	[1.826]
R-sq	0.504	0.498	0.493	0.479	0.483
Panel B. Price boom					
Illegal gold deposit x log(lagged gold price)	6.443	5.839	5.860	6.007	6.205
	[2.994]**	[3.270]*	[2.969]**	[3.058]*	[3.013]**
Any Gold deposit x log(lagged gold price)	-0.933	-0.156	-0.976	-0.047	-0.844
	[1.787]	[2.123]	[1.754]	[1.810]	[1.830]
R-sq	0.502	0.496	0.492	0.477	0.481
Number of observations	12012	8932	12298	10626	11770
Number of municipalities	546	406	559	483	535
Municipality FE	Yes	Yes	Yes	Yes	Yes
State x Year FE	Yes	Yes	Yes	Yes	Yes
Time trend x Basic controls (2000)	Yes	Yes	Yes	Yes	Yes

Source: Elaborated by the author (2026).

Notes: The dependent variable is the homicide rate per 100,000 inhabitants. Basic control variables include population density and the urbanization rate in 2000. Panel A adds gold prices interacted with dummy variables for illegal gold deposits and for any gold deposit as additional controls. Estimations are performed using ordinary least squares (OLS), with standard errors clustered at the municipal level. *, **, ***, significance at the 10%, 5%, and 1% levels, respectively.

D.5 CONSIDERING ONLY MUNICIPALITIES WITH GOLD DEPOSITS

Table D5. Effects of deregulation and price boom on violence in municipalities exposed to illegal gold mining (2000–2021)

	Homicide rate			
	Full Sample (Baseline)		Munic. with gold	
	(1)	(2)	(3)	(4)
Panel A. Market deregulation				
Illegal gold deposit x Post-2012	11.491	10.559	10.812	9.014
	[3.659]***	[3.563]***	[3.686]***	[3.266]***
Any Gold deposit x Post-2012	-2.484	0.087		
	[1.645]	[1.717]		
R-sq	0.459	0.484	0.423	0.479
Panel B. Price boom				
Illegal gold deposit x log(lagged gold price)	10.982	8.938	11.290	7.535
	[3.617]***	[3.464]**	[3.826]***	[3.386]**
Any Gold deposit x log(lagged gold price)	-5.843	-1.242		
	[1.843]***	[1.879]		
R-sq	0.457	0.483	0.420	0.477
Dep. variable mean	20.983	20.983	28.113	28.113
Number of observations	12012	12012	2882	2882
Number of municipalities	546	546	132	132
Municipality FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Time trend x Basic controls (2000)	Yes	Yes	Yes	Yes
Time trend x Munic. Charc in 2000	No	Yes	No	Yes

Source: Elaborated by the author (2026).

Notes: The dependent variable is the homicide rate per 100,000 inhabitants. Basic control variables include population density and the urbanization rate in 2000. Panel A adds gold prices interacted with dummy variables for illegal gold deposits and for any gold deposit as additional controls. Estimations are performed using ordinary least squares (OLS), with standard errors clustered at the municipal level. *, **, ***, significance at the 10%, 5%, and 1% levels, respectively.

D.6 ROBUST TO THE HORSE-RACE TEST

Table D6. Effects of deregulation and price boom on violence in municipalities exposed to illegal gold mining (2000–2021)

	Homicide rate				
	(1)	(2)	(3)	(4)	(5)
Illegal gold deposit x Post-2012	8.311	8.307			9.188
	[3.300]**	[3.471]**			[4.300]**
Any Gold deposit x Post-2012	0.268	0.461			0.337
	[1.849]	[1.898]			[2.108]
Illegal gold deposit x log(lagged gold price)		1.166	6.443	14.044	-4.854
		[2.369]	[2.994]**	[7.458]*	[10.085]
Any Gold deposit x log(lagged gold price)		-1.226	-0.933	0.312	-0.381
		[1.631]	[1.787]	[5.272]	[5.732]
Illegal gold deposit x log(gold price)	-1.156			-1.319	-0.812
	[1.560]			[5.038]	[5.534]
Any Gold deposit x log(gold price)	0.243			-9.371	4.971
	[1.797]			[5.605]*	[8.608]
R-sq	0.504	0.504	0.502	0.503	0.504
Dep. variable mean	20.983	20.983	20.983	20.983	20.983
Number of observations	12012	12012	12012	12012	12012
Number of municipalities	546	546	546	546	546
Municipality FE	Yes	Yes	Yes	Yes	Yes
State x Year FE	Yes	Yes	Yes	Yes	Yes
Time trend x Basic controls (2000)	Yes	Yes	Yes	Yes	Yes

Source: Elaborated by the author (2026).

Notes: The dependent variable is the homicide rate per 100,000 inhabitants. Basic control variables include population density and the urbanization rate in 2000. Panel A adds gold prices interacted with dummy variables for illegal gold deposits and for any gold deposit as additional controls. Estimations are performed using ordinary least squares (OLS), with standard errors clustered at the municipal level. *, **, ***, significance at the 10%, 5%, and 1% levels, respectively.

APPENDIX E

E.1 DECOMPOSITION OF HOMICIDES

Table E1. Effects of deregulation and price boom on male homicides in municipalities exposed to illegal gold mining (2000–2021)

	Male homicide rate						
	All ages	Young (ages 15-39)	Young (Black and Indigenous)	Young (Single)	Young (Outside home)	Young (Public street)	Young (Firearms and Knives)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A. Market deregulation							
Illegal gold deposit x Post-2012	7.566	3.364	2.344	0.801	3.436	1.203	2.233
	[3.037]**	[2.103]	[1.823]	[1.522]	[1.881]*	[1.090]	[1.883]
Any Gold deposit x Post-2012	-0.018	0.248	0.784	0.103	0.118	0.120	0.163
	[1.741]	[1.326]	[1.136]	[1.055]	[1.121]	[0.822]	[1.243]
R-sq	0.496	0.465	0.469	0.462	0.457	0.392	0.453
Panel B. Price boom							
Illegal gold deposit x log(lagged gold price)	5.144	2.664	2.411	0.932	2.504	0.377	1.818
	[2.703]*	[1.870]	[1.565]	[1.298]	[1.684]	[0.895]	[1.731]
Any Gold deposit x log(lagged gold price)	-0.849	-0.648	-0.609	0.013	-0.557	-0.376	-0.571
	[1.651]	[1.137]	[0.929]	[0.794]	[0.983]	[0.626]	[1.065]
R-sq	0.495	0.465	0.469	0.462	0.456	0.392	0.453
Dep. variable mean	19.03	12.78	10.70	9.21	10.80	5.49	11.51
Number of observations	12012	12012	12012	12012	12012	12012	12012
Number of municipalities	546	546	546	546	546	546	546
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
State x Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time trend x Basic Controls (2000)	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Source: Elaborated by the author (2026).

Notes: The dependent variable is the homicide rate per 100,000 inhabitants. Basic control variables include population density and the urbanization rate in 2000. Panel A adds gold prices interacted with dummy variables for illegal gold deposits and for any gold deposit as additional controls. Estimations are performed using ordinary least squares (OLS), with standard errors clustered at the municipal level. *, **, ***, significance at the 10%, 5%, and 1% levels, respectively.

APPENDIX F

F.1 DEFORESTATION IN THE BRAZILIAN AMAZON

Table F1. Effects of deregulation and price boom on deforestation in municipalities exposed to illegal gold mining (2000–2021)

	Deforestation in hectares (in log)	
	Full Sample	Munic. with protected area
	(1)	(3)
Panel A. Market deregulation		
Illegal gold deposit x Post-2012	0.012	0.008
	[0.018]	[0.018]
Any Gold deposit x Post-2012	0.012	0.014
	[0.010]	[0.011]
R-sq		
Panel B. Price boom	0.995	0.994
Illegal gold deposit x log(lagged gold price)	0.056	0.034
	[0.038]	[0.041]
Any Gold deposit x log(lagged gold price)	0.038	0.051
	[0.021]*	[0.027]*
R-sq	0.995	0.994
Number of observations	12012	7282
Number of municipalities	546	331
Municipality FE	Yes	Yes
State x Year FE	Yes	Yes
Time trend x Basic controls (2000)	Yes	Yes

Source: Elaborated by the author (2026).

Notes: The dependent variable is deforestation. Basic control variables include population density and the urbanization rate in 2000. Panel A adds gold prices interacted with dummy variables for illegal gold deposits and for any gold deposit as additional controls. Estimations are performed using ordinary least squares (OLS), with standard errors clustered at the municipal level. *, **, ***, significance at the 10%, 5%, and 1% levels, respectively.

APPENDIX G

G.1 DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

DECLARAÇÃO SOBRE O USO DE INTELIGÊNCIA ARTIFICIAL GENERATIVA

Em cumprimento à **Portaria CNPq nº 2.664/2026**, declaro, para os devidos fins, que, durante a preparação desta **Tese de Doutorado**, foram utilizadas as ferramentas **ChatGPT** e **Grammarly** para auxiliar na correção gramatical, tradução e revisão textual.

Essas ferramentas foram empregadas exclusivamente como suporte à escrita, não tendo sido utilizadas na concepção das ideias, delineamento metodológico, análise dos dados ou elaboração das conclusões.

Após a utilização dessas ferramentas, todo o conteúdo foi cuidadosamente revisado, validado e editado pelo autor, que assume total responsabilidade pela originalidade, precisão e integridade acadêmica do texto final.

Declaro, ainda, que o uso dessas tecnologias atendeu aos princípios de ética, transparência e integridade científica exigidos pelas normas aplicáveis, incluindo as diretrizes do CNPq e do PPGE-UFJF.

Juiz de Fora – MG, 20 de abril de 2026.

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