

Gold Rush, Illegal Mining, Mercury Pollution, and Infant Health in the Amazon Rainforest*

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Abstract

Gold mining is a major source of mercury pollution, releasing substantial quantities into waterways annually. This study investigates the externalities of mercury contamination from gold mining on infant health in the Amazon Rainforest. We analyze a surge in small-scale mining during the mid-2000s gold boom in the Madre de Dios region, spanning Peru and Bolivia, which caused extensive mercury contamination, disproportionately affecting downstream Brazilian riverside populations. Our findings reveal that gestational exposure to mercury pollution is linked to lower birth weights and increases in both infant and fetal mortality. These findings underscore the urgent need for coordinated cross-border environmental regulations.

Keywords: Environmental pollution; Externalities; Gold mining; Mercury contamination; Infant health; Infant mortality; Amazon Rainforest; Cross-border regulations.

JEL Codes: I18, Q20, Q53, O13, P48.

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1 Introduction

Gold has long been one of the most sought-after and valuable metals, treasured by societies throughout the ages (Clay and Jones, 2008; Aragón and Rud, 2013; Berman et al., 2017; Benschaul-Tolonen, 2019). However, despite its enduring value, gold extraction regulations are inconsistently enforced, particularly in remote areas. In recent decades, rising gold prices and lax policies have fueled a surge in informal mining practices. These unregulated small-scale and artisanal mining activities are widely recognized for their environmental impact, contributing to deforestation, excessive water consumption, and mercury contamination.¹ These operations are responsible for releasing thousands of tons of mercury into waterways annually (Telmer and Veiga, 2009; Cordy et al., 2011; Swenson et al., 2011; Ashe, 2012; United Nations Environment Programme, 2013; Mudyazhezha and Kanhukamwe, 2014; Asner and Tupayachi, 2017; Spiegel et al., 2018; Torrance et al., 2021).²

The impact of gold mining can extend far beyond the extraction sites. Mercury from these activities seeps into rivers and lakes, contaminating aquatic life and affecting downstream communities that depend on these water sources. This contamination can lead to mercury poisoning, which poses life-threatening health risks. Despite these dangers, the full extent of these externalities remains poorly understood, hindering governmental efforts to implement effective interventions. In some cases, this lack of understanding can lead to overly stringent policies that, while intended to mitigate environmental damage, can raise costs and negatively impact local economies, even those not directly involved in gold mining.

Adding to this complexity, prior studies offer conflicting evidence on the health effects of gold mining, with some suggesting positive outcomes due to income shocks (Benschaul-Tolonen, 2019)

¹Unregulated small-scale and artisanal gold mining often poses greater environmental risks due to its reliance on mercury for gold extraction and the absence of stringent oversight. In contrast, larger-scale regulated mining operations typically employ advanced technologies designed to minimize mercury use and mitigate environmental impacts. However, it is essential to recognize that both unregulated and regulated mining require intensive water usage, which can lead to environmental degradation.

²Newspapers frequently spotlight the environmental devastation caused by intensive gold mining and deforestation, underscoring the significant health risks these activities pose to local populations. See [Times \(2020\)](#); [Guardian \(2020\)](#); [Times \(2023\)](#) for more information.

and others highlighting negative impacts (Romero and Saavedra, 2016; Akpalu and Normanyo, 2017). This discrepancy likely stems from the dual nature of mining’s economic impacts. On the one hand, increased income from gold mining can improve health outcomes by providing individuals with more financial resources (Benshaul-Tolonen, 2019). On the other hand, less obviously, the opportunity costs and economic shocks associated with mining can negatively impact community health (Harbaugh et al., 2002; Miller and Urdinola, 2010). For example, the income generated by gold mining can drive up the cost of living, making healthcare and other essentials less affordable, thereby exacerbating local health disparities (Akpalu and Normanyo, 2017). This complex interplay complicates the assessment of gold mining’s externalities, frequently resulting in ambiguous conclusions within the literature.

To clarify these conflicting findings in the literature, our study investigates the trade-offs between gold extraction and its health impacts on proximate populations, with a specific focus on infant health in riverside communities within the Amazon Rainforest. Our identification strategy leverages unique geographical features alongside comprehensive Brazilian datasets. We examine the aftermath of the Amazon Gold Rush, particularly focusing on the surge in small-scale gold mining that began in 2004 in the Madre de Dios region of Bolivia and Peru. This gold boom led to the annual release of an estimated 120 tons of mercury and the clearing of thousands of hectares of native forest (Swenson et al., 2011; Ashe, 2012), which subsequently contaminated the local food chain (Dórea and Barbosa, 2007; Oliveira et al., 2010; Soares et al., 2018). As this cross-border pollution infiltrates Brazil’s waterways, it has silently³ impacted downstream river communities, within the Madeira River Basin (*Rio Madeira* in Portuguese). To quantify these effects, we estimate the causal impact of gold mining on infant health by comparing affected regions along the Madeira River with similar, unaffected communities. Our econometric design incorporates the water flow direction from the Madeira Basin, allowing

³The term “silently” is used to describe the nature of the impact, as the Amazon Gold Rush occurred in a neighboring country, and the pollution traveled down the river, affecting the Brazilian riverside population without direct visual evidence of the mining operations. Additionally, consistent with this hypothesis, mercury poisoning initially occurs without immediate or visible symptoms, making the health impacts even more insidious and dangerous.

for precise estimation of the consequences of exposure to waterborne contamination and the consumption of mercury-tainted fish.

Building on this framework, our reduced-form analysis indicates that cross-border pollution from gold mining has significantly impacted infant health in Brazilian riverside communities. Our preferred econometric model estimates an increase of approximately 5.7 per thousand in infant mortality rates, representing a 34% rise relative to the baseline mean.⁴ In numerical terms, this increase corresponds to approximately 97 additional infant deaths per year attributable to gold mining pollution. Furthermore, our event study results reveal that these effects persist over time following the onset of the Amazon Gold Rush, with consistently elevated infant mortality rates observed in downstream river communities that continue to be exposed to pollution.

Expanding on these insights, our heterogeneous results provide compelling evidence that the primary causes of infant mortality linked to potential mercury exposure during pregnancy include infectious diseases, respiratory issues, and congenital conditions. These health complications typically manifest early in an infant’s life, particularly during delivery, consistent with the expected outcomes of gestational mercury poisoning. We also observe a significant increase in fetal mortality associated with potential mercury exposure. Furthermore, our findings reveal that infants born to mothers with lower levels of education are disproportionately affected, experiencing higher mortality rates. This vulnerable group also exhibits lower birth weights and slower fetal growth, both of which are attributable to gold mining pollution.

To ensure the robustness of our findings, we undertake a comprehensive set of additional exercises. First, we demonstrate that the impacts of cross-border pollution from gold mining diminish with increasing distance from the Madeira River to the Bolivian bordering. This is evidenced by Brazilian municipalities closer to the Bolivian border (i.e., the end of the Madre de Dios River) being more intensively impacted than those farther downstream. Second, we perform multiple placebo tests by examining parallel rivers in the same regions, which derive

⁴Although this estimated average treatment effect is relatively high, it is comparable to reductions observed in other water purification programs in developing countries, such as the 56% reduction reported by [Bhalotra et al. \(2021\)](#) and the 26% reduction found by [Galiani et al. \(2005\)](#) in the poorest areas, as well as a 34% reduction in the U.S. reported by [Alsan and Goldin \(2019\)](#).

from distinct sources and are not geographically connected to the Amazon Gold Rush event. Consistent with our expectations, these findings confirm that these rivers are unaffected. Third, we provide evidence that our results are not confounded by factors such as population migration, municipal policy responses, or changes in maternal composition related to the Amazon Gold Rush, further reinforcing the validity of our conclusions.

Delving deeper into the mechanisms at play, the literature identifies three primary pathways through which mercury contamination impacts human health: (i) inhalation during water boiling, (ii) direct ingestion of contaminated water, and (iii) consumption of contaminated fish and other food items (Ashe, 2012; Gibb and O’Leary, 2014; Esdaile and Chalker, 2018). Among these, the third pathway—consumption of contaminated food—is particularly relevant to our study. Mercury released by gold mining infiltrates freshwater ecosystems, contaminating fish that serve as critical dietary staples for riverside communities (Soares et al., 2018). These fish, acting as vectors of mercury transmitters, can travel up to 15 kilometers daily, dispersing toxins across extensive areas (Miranda-Chumacero et al., 2015). During the Amazon Gold Rush, mercury-laden fish from Madre de Dios likely reached Brazilian border communities within two weeks. Numerous studies corroborate this scenario, documenting a significant increase in mercury-contaminated fish in the Madeira River Basin during this period (Bastos et al., 2006; Dórea and Barbosa, 2007; Oliveira et al., 2010; Soares et al., 2018). Although mercury does not directly harm aquatic life, it bioaccumulates in fish, turning them into conduits for human mercury exposure, especially for pregnant women. Mercury transfers from mother to fetus through the bloodstream and subsequently through breastfeeding, amplifying its detrimental effects on infant health (Sagiv et al., 2012; Boucher et al., 2014).

Aligned with these pathways, our investigation into potential mechanisms provides three lines of evidence linking mercury contamination to adverse infant health outcomes in regions affected by the Amazon Gold Rush. First, using satellite data, we identify a substantial increase in airborne mercury across Brazilian border municipalities during the Amazon Gold Rush period. As airborne mercury contamination reliably proxies for river water pollution, this finding

underscores the far-reaching environmental impacts of cross-border gold mining, which substantially increase health risks for downstream Brazilian communities. Second, our findings further suggest that agriculture in downstream river regions reliant on mercury-contaminated river water suffers adverse effects, evidenced by reduced crop yields and diminished livestock productivity. This evidence highlights an indirect mechanism contributing to adverse infant health outcomes. Lastly, to examine the contaminated fish consumption hypothesis, we focus on seasonal increases in fish intake during a prominent Brazilian cultural celebration, analyzing gestational periods exposed to this dietary shift. Using this framework, we find suggestive evidence that fish consumption may serve as a significant transmission pathway for mercury’s impact on infant health. Specifically, our analysis indicates that seasonal spikes in fish consumption intensify mercury exposure during pregnancy, increasing health risks for newborns in riverside communities. This is reflected in amplified adverse outcomes, including higher infant mortality rates and compromised birth metrics, such as lower birth weights.

This paper contributes to the literature by presenting three novel findings. First, by rigorously examining the specific health impacts of gold mining pollution, we depart from previous studies that offer either correlation-based insights or generalized estimates that combine both externalities and income effects. Our approach is the first to establish a robust causal link between illegal mining activities and increased infant and fetal mortality in nearby populations. Second, we provide compelling evidence of negative health effects from cross-border pollution caused by illegal mining operations. By leveraging an external shock from neighboring countries that affect Brazilian municipalities located along downstream rivers, we highlight the complexities of managing environmental costs when pollution crosses national borders ([Lipscomb and Morarak, 2016](#)). These results offer critical insights for policymakers, advocating for coordinated international environmental regulations to mitigate the impacts of informal mining. Third, our unique empirical setting allows us to isolate and identify the health impacts resulting from gold mining externalities. This contribution helps address uncertainty about the health effects of gold mining, a topic often explored through the lens of the Environmental Kuznets Curve.

However, unlike the predictions of the curve, which suggests pollution declines after a certain income threshold is reached, our findings reveal that adverse health impacts from gold mining activities persist beyond the region of economic activity.⁵

This study intersects with three key areas of literature. First, it relates to the extensive empirical research examining the externalities of environmental degradation on infant health, with a particular focus on the adverse effects of air pollution, water contamination, and shortages on infant outcomes (Chay and Greenstone, 2003; Currie and Neidell, 2005; Galiani et al., 2005; Currie and Schmieder, 2009; Agarwal et al., 2010; Currie and Walker, 2011; Greenstone and Hanna, 2014; Brainerd and Menon, 2014; Knittel et al., 2016; Cesur et al., 2017; Berazneva and Byker, 2017; Alsan and Goldin, 2019; Rangel and Vogl, 2019; Bhalotra et al., 2021; Marcus, 2022; Dias et al., 2023; Clay et al., 2024; Berazneva and Byker, 2024). Second, our findings advance the understanding of the environmental impacts of natural resource exploration, specifically gold mining activities and their associated health risks (Romero and Saavedra, 2016; Akpalu and Normanyo, 2017; Benshaul-Tolonen, 2019; Von der Goltz and Barnwal, 2019; Rozo, 2020).⁶ Finally, our study contributes to the health literature by examining the specific pathways through which pollution—particularly mercury exposure—affects vulnerable populations, including children, pregnant women, and fetuses. We document the adverse effects of potential mercury exposure through gold mining pollution on infants, such as low birth weight, reduced abdominal and head circumference, shorter gestational periods, and neurodevelopmental disorders (Grandjean and Landrigan, 2006; Xue et al., 2007; Sagiv et al., 2012; Boucher et al., 2014; Murcia et al., 2016; Zinia et al., 2023).

Following this introduction, Sections 2.1 through 2.3 offer an overview of gold mining history in the Amazon Rainforest, detail the Amazon Gold Rush, and discuss the effects of mercury contamination on pregnant women. Sections 3 and 4 describe the data and empirical strategy

⁵The Environmental Kuznets Curve posits that pollution rises with economic growth before declining after a certain income threshold, forming an inverted U-shape (Harbaugh et al., 2002). Our study deviates from this traditional model, as it considers the wider externalities through cross-border pollution.

⁶Other studies have linked gold mining activities to increases in human capital accumulation, suicide rates, and population migration (Clay and Jones, 2008; Mejia, 2020; Kronenberg, 2021).

employed, respectively. The results, including robustness checks and an analysis of potential mechanisms, are presented in Section 5. In Section 6 we present a detailed mechanisms analysis. Section 7 offers evidence supporting the plausibility of the identification strategy. Finally, Section 8 presents the paper’s conclusions.

2 Amazon Gold Rush Background

2.1 The Gold Mining in the Amazon Rainforest and the Artisanal Mining Process

Gold mining in the Amazon Rainforest has deep historical roots, dating back to pre-colonial times. The Amazon’s rich deposits have long attracted mining activities, which persist into the present day (Mahar and Mundial, 1989). However, these operations, particularly illegal ones, have inflicted significant environmental damage, contributing to deforestation, biodiversity loss, increased carbon emissions, and adverse impacts on local communities (Assunção et al., 2015, 2022; Araujo et al., 2023; Fritz et al., 2023).

Artisanal gold mining, conducted by informal miners, commonly locally referred to as “Mineros del Oro” (Gold Miners), is a major driver of environmental degradation in the Amazon. These miners, working in small groups in remote areas with rudimentary tools, frequently use mercury, as well as other hazardous substances like arsenic, lead, and cyanide, to separate gold from other minerals (Swenson et al., 2011; Ashe, 2012; Fritz et al., 2023). Mercury is particularly favored by miners due to its simplicity and effectiveness in the gold extraction process.

Unlike large-scale or formal mining operations,⁷ artisanal mining involves a rudimentary process for crushing ore into smaller particles using basic tools. The crushed material is then

⁷There are examples of large-scale gold mining operations that do not use mercury, most of which are in developed countries. For instance, mines in Alaska, USA, employ advanced technologies such as gravity separation and flotation to extract gold without mercury. Similarly, large mining operations in Australia and Canada follow stringent environmental regulations that prohibit mercury use in gold extraction.

mixed with water to create a slurry, which is passed over a mercury-coated surface to form an amalgam that is then heated to evaporate the mercury, leaving behind pure gold. While effective in low-resource environments, this method releases substantial mercury-laden waste into the environment (Cordy et al., 2011). As a result, these activities are estimated to release 800 tons of mercury into water bodies each year, accounting for more than 60% of all mercury emissions from human activities (United Nations Environment Programme, 2013).

While artisanal mining predominantly occurs in remote areas, its environmental impacts often extend to urban regions. This process is highly water-intensive, with mining activities frequently concentrated near major waterways in these remote locations (Mudyazhezha and Kanhukamwe, 2014; Torrance et al., 2021). Rivers play a crucial role in these operations, washing away lighter materials and facilitating the collection of the heavier mercury-gold amalgam (Cordy et al., 2011). However, the proximity of mining operations to rivers, coupled with the natural flow of water, results in the release of toxic substances, including mercury, into aquatic ecosystems. Consequently, this contamination poses significant health risks to downstream communities that rely on these rivers for their livelihoods (Swenson et al., 2011; Kahhat et al., 2019; Fritz et al., 2023). Additionally, the constant use of machinery and diesel in ore extraction and transportation further degrades freshwater quality (Kahhat et al., 2019).

The consequences of these practices are considerable. Recent research by De Bakker et al. (2021) estimates that, on average, 2 kilograms of gold are produced annually per hectare in the Amazon Rainforest. To extract this amount, artisanal miners use about 5 kilograms of mercury, a significant portion of which is released into local rivers. This practice is estimated to affect up to forty-four thousand people, highlighting the environmental and health risks posed by small-scale mining in the region. These risks are further exacerbated by the lack of formal regulation and oversight, as miners often operate outside legal frameworks, evading law enforcement. Although mercury-free alternatives exist, their adoption remains limited in underdeveloped regions, likely due to technological barriers and a lack of governmental support.

2.2 The Amazon Madre de Dios Region Gold Rush Episode

In this subsection, we outline the Amazon Gold Rush episode in the Madre de Dios region, detailing its consequences and how it extended to the Brazilian community.

Gold Mining in Bolivia and Peru. Although gold mining in the Amazon Rainforest dates back to pre-colonial times, its magnitude has escalated substantially over the past few decades, largely driven by rising global gold prices and lax regulation. This surge in artisanal mining has led to significant environmental degradation. By the mid-2000s, remote regions of the Amazon witnessed a dramatic increase in small-scale mining operations, resulting in the deforestation of approximately 1,700 square kilometers across more than 1,600 sites ([Alvarez-Berríos and Aide, 2015](#)). The Madre de Dios rainforest—a region spanning southeastern Peru and parts of northern Bolivia—became the epicenter of this ecological crisis, where illegal mining activities resulted in the annual discharge of an estimated 120 tons of mercury into rivers ([Swenson et al., 2011](#); [Ashe, 2012](#)).

Mercury through Madre de Dios Mining. Between 2004 and 2011, the Madre de Dios region experienced a dramatic surge in mining activities, with illegal gold mining operations increasing by an estimated 1,650% ([Swenson et al., 2011](#)). During this period, data from Peru and Bolivia show a steady rise in mercury imports, primarily for use in these mining operations ([Swenson et al., 2011](#)). The widespread use of mercury at these sites led to elevated levels of this toxic metal in local populations, mainly through the consumption of contaminated fish ([Ashe, 2012](#)). Studies confirmed that, after 2003, mercury concentrations in river sediments, forest soils, and human samples in the Madre de Dios Basin rose significantly. This surge in mercury contamination particularly affected the Madre de Dios River, a major tributary of Brazil's Madeira River, and spread to other regions, including Bolivia's Beni River, impacting the broader fish food chain ([Molina et al., 2010](#); [Benefice et al., 2010](#); [Gibb and O'Leary, 2014](#)).⁸

This widespread environmental degradation and cross-border mercury pollution is what we refer

⁸The Madeira River in Brazil is supplied by two major tributaries: the Madre de Dios River in Peru and the Beni River in Bolivia.

to as the “Amazon Gold Rush” in the present paper.

Mercury in Brazilian Madeira River. The consequences of these gold mining externalities extend beyond the Madre de Dios region, directly impacting the Brazilian Madeira River and its surrounding communities. Mercury from the Madre de Dios mining sites is carried downstream, traveling approximately 200 kilometers through Peru and Bolivia before merging into the Brazilian side of the Madeira River. This distance is calculated from the epicenter of mining activities in the Madre de Dios region. This cross-border pollution affects the Brazilian riverside population along the Madeira River Basin, which serves as a crucial water source for 11 municipalities within the states of Rondônia (RO) and Amazonas (AM). Figures 2 and A.1 trace and contextualize the flow of these contaminated waters, highlighting the Brazilian riverside communities vulnerable to contamination.

Contamination in Fish on the Brazilian Side. As pollution flows downstream from the Madre de Dios River into Brazilian territory via the Madeira River, mercury infiltrates the aquatic ecosystem and accumulates within the food chain. Consequently, this contamination poses health risks to local riverside communities, where river fish serve as a dietary staple and the main source of protein. Larger predatory fish become the primary transmitters of this contamination as they consume smaller mercury-contaminated organisms, leading to elevated levels of mercury within their bodies (Chan et al., 2003; Stewart et al., 2008). This danger can extend further as migratory fish carry mercury downstream to more distant Brazilian communities. For context, if fish in Madre de Dios were contaminated during the peak of the Amazon Gold Rush, they could reach Brazilian communities within approximately two weeks.⁹ Once these fish enter broader food markets or are caught in rivers, they are consumed by a larger segment of the local Brazilian populace, many of whom may be unaware of the toxic burden.¹⁰

⁹This calculation is based on the average migration rate of Amazon fish from Miranda-Chumacero et al. (2015), suggesting that an Amazon freshwater fish can travel 15 kilometers per day, and the distance from Madre de Dios to the Brazilian Madeira River is 200 kilometers.

¹⁰The contamination progresses silently, as mercury in fish cannot be detected without clinical testing, and the mining sites are relatively far away.

Shedding light on this issue, numerous studies have highlighted the contamination of fish in the Madeira River during this period. For instance, [Soares et al. \(2018\)](#) measured total mercury levels in commonly consumed fish species from the Madeira River during the Amazon Gold Rush period, as shown in [Figure A.3](#). Their findings reveal that all collected fish exhibited high levels of heavy metal contamination, with mercury concentrations exceeding legal limits and safe consumption thresholds, directly affecting infants and pregnant women in riverside communities. These results align with those of other studies, such as [Dórea and Barbosa \(2007\)](#) and [Oliveira et al. \(2010\)](#), which indicate that the Amazon Gold Rush led to widespread mercury contamination in fish across Brazilian rivers. Notably, mercury does not directly kill aquatic life but instead contaminates it, allowing the fish to act as vectors, transmitting mercury to humans, particularly pregnant women, through consumption.

The ongoing impact of this contamination is evident in recent reports from Brazilian Madeira River riverside populations. Health and environmental monitoring indicate that communities in the affected regions of the Madeira River continue to show elevated mercury levels due to ongoing illegal mining activities, which persist into the 2020s. This continued contamination has led to long-lasting health risks, even years after the initial contamination event:

“Samples of hair retrieved from federal agencies have detected that residents of the Madeira River region in the Amazon have mercury contamination up to three times higher than the maximum limit considered “acceptable” by the World Health Organization (WHO). ([Globo, 2021](#)) (translated from Portuguese).”

Overview. In summary, the literature reviewed in this section suggests that a series of factors triggered the Amazon Gold Rush event in the Madre de Dios region, sparking a gold rush that resulted in the uncontrolled dumping of mercury into the river. Consequently, this led to cross-border pollution that impacted the downstream Brazilian population from 2004 onwards—[Figures 2](#) and [A.2](#) visually represent these concepts.

2.3 The Mechanism and Expected Consequences of Mercury Contamination on Pregnant Women

In this subsection, we provide insights into how mercury exposure can lead to poisoning in pregnant women and negatively affect fetal development.

Mercury in Pregnant Women. Mercury is classified among the top chemicals of significant public health concern by the World Health Organization ([World Health Organization, 2017](#)). It is well-documented that mercury poisoning in humans can occur through three main pathways: inhalation, water consumption, and the food chain. In this context, the latter is the primary exposure route due to the heavy reliance on fish as a local dietary protein source ([Molina et al., 2010](#); [Benefice et al., 2010](#); [Gibb and O’Leary, 2014](#); [Esdaile and Chalker, 2018](#)). Methylmercury,¹¹ a highly toxic form of mercury found in contaminated fish,¹² poses risks to pregnant women and their developing fetuses. When expectant mothers consume fish contaminated with methylmercury, the toxin is absorbed into the bloodstream and can cross the placental barrier, directly affecting the fetus. Prenatal exposure to mercury is linked to cognitive and neurological impairments, including developmental delays and motor function difficulties ([Zahir et al., 2005](#); [Sagiv et al., 2012](#); [Boucher et al., 2014](#)). Additionally, high levels of mercury can damage the kidneys and, in severe cases, lead to respiratory failure ([Ozuah, 2000](#)).

Research also suggests that mercury contamination may affect the cardiovascular system, potentially leading to high blood pressure and other heart-related issues in pregnant women ([Sagiv et al., 2012](#); [Boucher et al., 2014](#)). Furthermore, mercury exposure can continue into infancy through breastfeeding, as mercury is transmitted via breast milk if the mother has been exposed. The implications of mercury exposure during pregnancy are far-reaching. Neurodevelopmental disorders, cognitive impairments, and memory problems are potential outcomes for

¹¹In aquatic environments, mercury is transformed by microorganisms into methylmercury, a more toxic form that bioaccumulates in aquatic organisms. For this analysis, mercury and methylmercury are treated as equivalent due to their similar toxic effects on pregnant women.

¹²Indeed, in some cases, fish are not recommended for consumption by pregnant women. However, river fish remain a dietary staple for many Amazonian communities, particularly those living near rivers.

children born to mothers exposed to mercury. Additionally, there is an increased risk of miscarriage, preterm birth, and low birth weight, which can have long-term health consequences for the child (Zahir et al., 2005).

Clinical Evidence of Mercury Exposure in Animals. While the potential impact of mercury exposure on pregnant women is well recognized, establishing a direct link to mortality in the existing literature has proven challenging, complicating efforts to quantify the magnitude of such exposure. However, valuable insights can be gleaned from clinical trials that examine the effects of mercury consumption in animal models. For example, the study by Gandhi et al. (2013) highlights the dangers of methylmercury contamination in fish through experiments conducted on pregnant rats. The findings indicate that exposure to relatively high doses of mercury during pregnancy resulted in a substantial reduction of approximately 25% in maternal weight gain. Moreover, exposure to the highest tested dose of mercury led to a 100% increase in the incidence of litter resorption, significantly reducing the number of viable offspring and demonstrating the reproductive toxicity associated with high-level mercury exposure.

Further evidence comes from the study by Sakamoto et al. (2002), which investigated the effects of prenatal and early postnatal exposure to methylmercury on rat offspring. In this study, exposure occurred in utero via the placenta and continued after birth through contaminated milk. The results revealed that mercury levels in the brains of newborns were significantly higher than those in their mothers at birth. Additionally, behavioral assessments conducted at around five weeks showed significant deficits in motor coordination and learning abilities among the mercury-exposed rats compared to the control group.

3 Data

Mortality and Health Data. To estimate the causal impacts of gold mining pollution exposure on infant health in Brazilian municipalities downstream of the Madeira River, we gather comprehensive information from several publicly available sources. Our primary sources of

health data include the Integrated Mortality System (Datusus-SIM) and the Information System on Live Births (Datusus-SINASC). Datusus-SIM provides detailed mortality records across Brazil, including the timing and causes of infant deaths, linked directly to the mother’s municipality of residence. Similarly, Datusus-SINASC provides extensive data on childbirth, covering maternal and child health indicators for all hospital and non-hospital deliveries across both public and private healthcare systems in Brazil. These rich datasets allow us to examine infant mortality with a granular perspective, enabling our analysis of the impacts of pollution exposure on various categories of infant mortality.

Other Data Sources. In addition to the health data, we collect information from IPEAdata, a supplementary data repository in Brazil. IPEAdata¹³ offers extensive information on the economic, demographic, and geographic aspects of the Brazilian population. Specifically, we gather data on each municipality’s education and health expenditures, as well as the coverage of two significant nationwide public policies: the Brazilian conditional cash transfer program (*Bolsa Família Program*) and the *Programa Saúde da Família*, a community-based healthcare program focusing on primary care. Additionally, we collect data on vaccine coverage, GDP, agricultural GDP, and population size, which are used to calculate per capita values.

Furthermore, to investigate potential responses from Brazilian cities affected by the Amazon Gold Rush shock, such as population migration, we use data from the Brazilian Demographic Censuses conducted in 2000 and 2010. These census rounds provide a ten-year snapshot of demographic changes and are published by the Brazilian Institute of Geography and Statistics (IBGE). Additionally, we collect environmental fines data from the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA)¹⁴, provides detailed information on fines issued to municipalities in the Brazilian territory. These data serve to investigate specific con-

¹³IPEAdata organizes and provides access to data from various sources, including the Brazilian demographic census, education data from INEP, and health data from the Datusus system, among others.

¹⁴IBAMA, the Brazilian Institute of Environment and Renewable Natural Resources, is a federal agency responsible for enforcing environmental regulations, managing conservation units, and monitoring environmental compliance across Brazil. The agency plays an essential role in the oversight of activities that impact the environment, such as deforestation, illegal mining, and pollution.

cerns in our empirical design. The combined information from IPEAdata, IBGE, and IBAMA is used as control variables in our econometric models and additional placebo exercises, explained in the next section. We then merge all the information to create an annual municipality panel dataset, spanning from 1997¹⁵ to 2015¹⁶.

To investigate both direct and indirect mechanisms associated with the Amazon Gold Rush, we gather additional data. First, we obtain mercury emissions data from the EDGAR (Emission Database for Global Atmospheric Research) database, specifically targeting emissions from artisanal and small-scale gold mining activities. The EDGAR database provides detailed information on global anthropogenic emissions, including pollutants such as mercury, based on estimates derived from satellite imagery and other sources.¹⁷ Second, we incorporate agricultural production data sourced from the Brazilian Institute of Geography and Statistics (IBGE). By analyzing these datasets together, we aim to explore how the environmental impacts of gold mining may extend beyond immediate contamination, potentially affecting local agricultural productivity and economic activities in the affected regions. This combined approach offers a comprehensive view of mercury contamination’s ripple effects on the environment and local economies. Appendix Table A.13 contains all variable definitions.¹⁸

Infant Mortality Outcomes. We calculate the infant mortality rate for each municipality, used as an outcome in the main regressions, as follows:

¹⁵Due to limited data availability and the potential presence of several measurement errors, we exclude data from 1994 to 1996. Since the Amazon Gold Rush occurred outside this period, we believe this does not compromise our empirical strategy.

¹⁶We opted to end the panel data in 2015, as from 2016 onwards the region experienced significant income shocks due to the construction of hydroelectric plants.

¹⁷The EDGAR (Emission Database for Global Atmospheric Research) database captures mercury emissions data through a combination of satellite imagery, ground-based observations, and emission modeling. Satellites detect atmospheric concentrations of mercury and other pollutants by measuring the intensity of light reflected from the Earth’s surface and atmosphere. This process identifies spectral signatures associated with specific pollutants, including mercury in the atmosphere. This data has been widely used in studies assessing other types of air pollutants, such as sulfur dioxide and nitrogen oxides, to understand their economic, environmental, and health impacts (e.g., see Charris et al., 2024).

¹⁸Our sample reflects a diverse representation of the Amazonian community; however, due to data limitations and the absence of information on individuals’ race, we are unable to isolate the specific impacts of pollution exposure within Indigenous communities.

$$IMR_{mt} = \frac{\text{Infants deaths up to 1 year old}_{mt}}{\text{Live births}_{mt}} \times 1,000$$

where the numerator represents the number of infant deaths up to 1 year old for municipality m in year t , while the denominator represents the number of live births in the municipality for the same period. The Datasus-SIM data enable us to examine mortality rates with a more granular perspective by exploring specific ICD-10 causes of death and the timing of mortality occurrences. This data enables us to analyze the effects of gold mining pollution on different categories of infant mortality, ranging from fetal deaths to those occurring up to one year old. With this level of detail, we explore crucial heterogeneities in the impacts of pollution on infants' health.

Treatment Status Definition. To evaluate the causal impact of externalities from gold mining activities, we define treatment status based on the proximity of municipalities to the Madeira River watercourse. While we lack direct data on mercury contamination within the river's food chain, extensive research has documented a marked increase in mercury levels in the Madeira River post-2003 (Bastos et al., 2006; Dórea and Barbosa, 2007; Oliveira et al., 2010; Swenson et al., 2011; Ashe, 2012; Soares et al., 2018), attributed to the Amazon Gold Rush.

Building on this foundation, we classify municipalities in the Brazilian states of Amazonas (AM) and Rondônia (RO), through which the Madeira River flows, as treated. These municipalities, dependent on the Madeira River as a primary water source, are directly impacted by gold mining pollution resulting from cross-border contamination during the Amazon Gold Rush. Conversely, municipalities in these same states that are unaffected by the pollution serve as the control group.¹⁹ In total, the treatment group consists of 11 municipalities that directly benefit from the river's water supply, and these are designated as treated. The control group for the main analysis consists of 105 municipalities. Figure 2 illustrates our treatment definition,

¹⁹In some supplementary exercises, we modify the control group to conduct robustness checks.

with red indicating treated municipalities and green indicating control municipalities. Gray municipalities are excluded from the analysis.

To further validate our treatment classification, we use satellite data on airborne mercury levels to examine whether the Amazon Gold Rush led to increased atmospheric mercury in the affected regions. This analysis enhances our estimation of the event’s impact, providing additional evidence that municipalities reliant on the Madeira River’s water supply experienced significant mercury contamination, thereby supporting our treatment classification.

Descriptive Analysis. In Table 1, we present summary statistics for all the variables used in our empirical exercises. In this table, Panel (A) presents summary statistics for the dependent variables and main model regressor at the municipality level. We can observe that in our panel data around municipalities, 10% of the observations are assigned as treated. Panel (B) exhibits the additional dependent variables at the individual level, which we use to investigate infant mortality channels. Panel (C) presents summary statistics for the main control variables and for additional variables used in supplementary robustness check exercises.²⁰

4 Empirical Strategy

4.1 Econometric model

Background. In our econometric setup, we observe Brazilian municipalities annually between 1997 and 2015. For our initial econometric specification, we identify treatment status based on each municipality’s proximity to the Madeira River. As mentioned earlier, we use geographical context to assign treatment status: municipalities through which the Madeira River flows are classified as treated, while all remaining municipalities in the Amazon Basin are classified as controls, as illustrated in Figure 2 in the previous section.

²⁰Particularly, we choose to use the logarithmic form of the municipality GDP, municipality agricultural GDP, and Airborne Mercury Particles variables to mitigate potential concerns related to outliers.

Aggregated Model. Our first econometric benchmark specification is as follows:

$$Y_{mt} = \alpha + \tau Treated_{mt} + \phi X_{mt} + \theta_m + \omega_{st} + \epsilon_{mt} \quad (1)$$

where Y_{mt} represents the outcome variable observed for municipality m in year t . The treatment status is indicated by the dummy variable $Treated_{mt}$, which equals 1 if the Madeira River crosses the municipality’s border and 0 otherwise, starting from 2004 onwards. The term “Treated” refers to municipalities affected by externalities resulting from gold mining activities.²¹ The parameters θ_m and ω_{st} represent municipality-specific and year-state fixed effects, respectively. The state-year fixed effect, ω_{st} , controls for any unobserved factors or shocks that vary by state and year, such as state-level policies, economic conditions, or environmental factors influencing all municipalities within a state during a given year.

The vector of coefficients ϕ corresponds to the control variables X_{mt} , which account for time-varying factors that could influence the outcome beyond the treatment. Specifically, X_{mt} includes six key characteristics: (i) the population covered by the government cash-transfer program *Bolsa Família*, (ii) the population covered by the primary healthcare program *Programa Saúde da Família*, (iii) municipal spending on education and culture, (iv) vaccination coverage, (v) the number of municipal environmental fines, and (vi) municipal GDP and agricultural GDP, all measured on a per capita basis.

The parameter of interest, τ , represents the causal effect of being exposed to the Amazon Gold Rush. The term ϵ_{mt} represents the random error term. The coefficient α represents the intercept, capturing the baseline level of the outcome variable when all other variables are held constant. To estimate the average treatment effect accurately and address variance concerns, we weight all regressions by baseline population size, mitigating potential correlation issues between treatment status and the outcome variable.

²¹In this context, terms such as potential mercury exposure, gold mining pollution, Amazon Gold Rush, small-scale illegal mining, and cross-border pollution describe the Brazilian areas impacted by the Madre de Dios Gold Rush, where gold mining pollution spread across national boundaries.

Heterogeneous Model. In addition to equation (1), we also investigate the possibility that the effects of the Amazon Gold Rush on infant mortality rates vary over time using an event-study estimator. To do this, we estimate equation (2), which accounts for heterogeneous effects based on the exposure time.

$$Y_{mt} = \alpha + \sum_{\substack{j=-7 \\ j \neq -1}}^{12} \beta_j Treated_{mt,j} + \phi X_{mt} + \theta_m + \omega_{st} + u_{mt} \quad (2)$$

where β_j represents a vector of parameters that capture the temporal effects of gold mining pollution exposure at varying intervals. The index j takes values in the set $\{-7, \dots, 12\}$, except for $j = -1$, which in this specification represents our baseline. Each estimate of β_j measures the average causal impact on the affected municipalities j years after exposure to the Amazon Gold Rush event, compared to the period just before the shock ($j = -1$). The remaining terms in the model remain unchanged from equation 1, and u_{mt} represents the new random error term.²²

Inference. Regarding inference, we use the conventional Cluster-Robust Standard Errors (CRVE) at the municipality level in both equations (1)-(2), following the recommendations of Abadie et al. (2023). This addresses the serial correlation and potential heteroscedasticity concerns. However, a concern may arise about our inference given that our econometric setup includes only 11 treated municipalities. This limitation raises genuine concerns regarding the robustness of our statistical inference. Consequently, some assumptions required for the consistency of the cluster-robust variance estimator may not hold (Conley and Taber, 2011; Ferman and Pinto, 2019). We believe that this limitation is primarily relevant in supplementary analyses where the treatment group is further divided into smaller subsamples, which may weaken the

²²Although Figure A.2 shows a substantial increase in Peru’s mercury imports, which might suggest the use of a Difference-in-Differences (DiD) model with heterogeneous treatment intensity, our binary model is more appropriate as it focuses specifically on mercury usage in gold mining rather than import fluctuations alone. Ideally, we would use the expansion of Madre de Dios mining areas as a direct indicator of mercury use, as it closely reflects actual gold mining mercury use. However, due to data limitations, this prevents us from capturing treatment intensity heterogeneity directly. Our binary model instead captures the spatial and temporal spread of mercury pollution across mining-affected regions, estimating the overall impact of the Amazon Gold Rush.

consistency of standard error estimates.

To address these concerns, we also conduct additional inference exercises using the estimator developed by [Ferman and Pinto \(2019\)](#). Their variance estimator is particularly suited for cases with a limited number of treated units, providing consistent standard errors that improve the robustness of statical inference. By applying this adjustment in our primary empirical exercises, especially where sample sizes are smaller, we obtain more reliable standard errors that mitigate potential bias. These adjusted estimates add an extra layer of rigor to validate our findings across varying treatment specifications, ensuring the robustness and reliability of our inference.²³

4.2 Identification assumptions and potential concerns

Identification. In this econometric setup for models (1)-(2), our identification strategy relies on two main assumptions to support the consistency of the estimators for causal inference interpretation.

Assumption 1 - Non-anticipation of Treatment Effect. We assume that individuals do not anticipate the treatment before its implementation. This assumption is essential for identifying causal effects in our analysis. This implies that expectations about the treatment’s implementation do not influence individuals’ behavior in either the treatment or control groups.

Assumption 2 - Parallel Trends in Outcomes. This assumption posits that, in the absence of the treatment shock, the outcomes for both the treatment and control groups would have followed parallel paths over time. This is widely known as the parallel trends assumption, which is fundamental for the validity of the Difference-in-Differences (DiD) estimator. It enables the attribution of deviations from these parallel paths solely to the intervention, rather than to pre-existing differential trends in the outcome variable between the target and comparison groups.

Plausibility of The Identification. We assess the plausibility of these assumptions by exam-

²³In the tables we refer to this adjustment as “FP p-value”, which provides the p-value with the adjustment for the inference in differences-in-differences with the presence of few treated groups and heteroskedasticity ([Ferman and Pinto, 2019](#)).

ining pre-intervention estimated coefficients, denoted as β_j for $j < 0$. These coefficients indicate whether any significant effects existed before the treatment period or not. To further reinforce the robustness of our identification strategy, we conduct multiple additional tests. First, we employ placebo testing by excluding the actual treatment observations from the sample and reclassifying nearby municipalities along parallel rivers—unaffected by the Amazon Gold Rush—as treated units, as shown in Figure A.1. Second, we explore the heterogeneous effects of a municipality’s proximity to the Brazilian River relative to the Bolivian border (i.e., the end of the Madre de Dios River) by modifying equation 2 to include treatment dummy variables that capture varying distances from the river’s origin. The underlying hypothesis is that if water contamination originates from the Bolivian border, the effects of the gold mining pollution should be more pronounced in Brazilian municipalities closer to the border. Finally, we address the potential concern that the Amazon Gold Rush could be associated with income improvements for local families by including GDP per capita as an outcome variable. However, it is important to note that the treatment shock (i.e., gold mining excavations) occurred outside of Brazilian territory and affected the Brazilian municipalities only indirectly through the river flow.

Potential Threats to Identification. However, there are some potential limitations in our econometric approach that we should draw attention to. One of these is the possibility of omitted variables that correlate with both our treatment status and outcome variables. To mitigate this, we incorporate year-fixed effects to capture any time-aggregated shocks affecting the entire Brazilian Amazon region and state-by-year fixed effects to account for varying policies or shocks at the state level. Additionally, we include a vector of control variables to account for municipal differences or responses.²⁴

Moreover, another genuine concern is that the control units near the treated municipalities might be indirectly affected by the Amazon Gold Rush, leading to issues of treatment contami-

²⁴In the early 2020s, there were several innovations in the two-way fixed effects regression literature, focusing on accurately retrieving causal parameters in cases where treatment adoption is staggered. However, in our econometric setup, this concern is alleviated since all treated units were exposed to the shock simultaneously. Therefore, in this context, two-way fixed effects can appropriately recover the causal treatment effects (Goodman-Bacon, 2021).

nation or spillover effects. In Appendix 11, we test this hypothesis and demonstrate that it does not undermine our econometric design. To address potential spillovers, we redefine the control group by progressively excluding municipalities that are geographically closest to the treated areas. This approach allows us to ensure that any indirect effects stemming from proximity do not bias the results. Specifically, we conduct robustness checks by excluding first-order and second-order neighboring municipalities from the control group. The results, shown in Figure A.10 and A.11, indicate that the estimated impacts of mercury pollution remain consistent across these modified control groups. This consistency reinforces the validity of our findings and indicates that spillover effects are either minimal or well-contained within the directly treated municipalities.

Additionally, there is the possibility of other coinciding events, such as forest fires, policy implementations, or external factors, which could directly influence our main outcomes. To address this concern thoroughly, we incorporate relevant control variables and conduct additional estimations to assess the robustness of our findings. We also account for public policies introduced during the 1990s and 2000s, such as universal health coverage (FHS) and Bolsa Família (PBF), by including controls for these programs in all regression analyses and considering municipal healthcare and educational expenditures.

A common concern in evaluations similar to ours is the difficulty in distinguishing between income effects on the local population and the impacts of environmental disasters. Given that the treatment shock occurred in another country and silently affected Brazilian municipalities, this mitigates concerns about income effects confounding our results. Additionally, another related potential caveat is the sample composition effect. The Amazon Gold Rush shock could lead to local population migration and changes in the characteristics of expectant mothers over time due to gold mining pollution exposure. To investigate these concerns, we analyze municipal migration rates as an outcome variable in supplementary analyses and examine whether differences exist in observable characteristics of expectant mothers.

5 Results

5.1 Amazon Gold Rush impacts on infant mortality

In this section, we present the central results of our causal evaluation—the impacts of the Amazon Rainforest Gold Rush on Brazilian infant mortality rates. In the following subsections, we outline the potential pathways through which this increase in infant mortality may occur and conduct various robustness checks. Specifically, we analyze delivery outcomes related to infant mortality, focusing on cases likely affected by the ingestion of mercury-contaminated food by pregnant women.

Main Results - Aggregated Form. We begin our results analysis using the model specification in equation (1). Table 2 presents the effects of gold mining pollution on infant mortality rates in Brazilian municipalities located along the Madeira River, in the heart of the Amazon Rainforest. Across most table columns, our results indicate that the effects of the Amazon Gold Rush on infant mortality are positive and statistically significant at the 5% level. In column (1), municipalities exposed to river pollution experienced an increase of approximately 3.88 per thousand in the infant mortality rate due to the Amazon Gold Rush. Notably, the inclusion of sample weights in the models more than doubles this effect to 8.29, as shown by the comparison between columns (1) and (2) in Table 2.

In column (3), after including control variables, the point estimate declines to 6.60. In columns (4) and (5), where state-year fixed effects and social program controls are included respectively. This demonstrates the stability of the results, underscoring the robustness of our findings. Our preferred model, as specified in column (5), indicates that the Amazon Gold Rush increased infant mortality rates by 5.74 per thousand in Brazilian municipalities relying on the Madeira River as their primary water source. This represents an increase of around 34 percent in the infant mortality rate relative to the control mean for these municipalities.²⁵ In numerical terms, this increase corresponds to approximately 97 additional infant deaths per

²⁵The calculation of the mean effect involves dividing the estimated effect by the mean of the control group.

year attributable to mercury river pollution.

Our initial results suggest that the surge in informal mining practices in the Madre de Dios region has adversely impacted Brazilian infant health through downstream water pollution. These findings are consistent with existing literature, which links mercury poisoning from fish consumption to negative infant health outcomes ([Grandjean and Landrigan, 2006](#); [Xue et al., 2007](#); [Sagiv et al., 2012](#); [Boucher et al., 2014](#); [Murcia et al., 2016](#); [Zinia et al., 2023](#)). For comparison, in a different context, [Benshaul-Tolonen \(2019\)](#) investigated the expansion of large-scale gold mining in Africa and found that local infant mortality rates decreased by more than 50%, coinciding with rapid economic growth. This results can be attributed to income effects outweighing the detrimental externalities. The increased income generated from mining activities likely improved access to healthcare, nutrition, and overall living conditions, exerting a more substantial beneficial influence on reducing infant mortality rates than the negative impacts of pollution.

Our study also aligns with other studies that emphasize the adverse health impacts of economic activities in diverse environmental contexts. For instance, [Dias et al. \(2023\)](#) found that water contamination from pesticide use led to an approximate 5% increase in infant mortality rates across multiple regions in Brazil. While their research encompasses a broad geographic area with another kind of pollution, our study focuses specifically on the effects of pollution within a single river system. This targeted approach may account for the greater magnitude of our findings, as the concentrated pollution in the Madeira River likely resulted in higher exposure levels and, consequently, a more severe impact on infant mortality. Additionally, the disparity in the number of infant deaths between our study and others can be attributed to differences in the scale and scope of the populations examined. For example, [Dias et al. \(2023\)](#) reported an increase of 0.93 per 1,000 births, leading to an estimated 503 infant deaths per year across a large sample of municipalities. In contrast, our study, which examines a smaller population with 1,406 births over 11 years, results in fewer overall deaths despite a higher per-thousand increase in infant mortality.

Furthermore, when only considering the scale of impact in terms of the control group mean, our findings are more similar to those of [Bhalotra et al. \(2021\)](#), who evaluated a water purification program in Mexico and identified an approximate 56% reduction in infant mortality rates attributable to diarrhea. Similarly, [Galiani et al. \(2005\)](#) assessed the effects of water service privatization in Argentina and reported a 26% decline in infant mortality within impoverished areas. These comparisons highlight the differential health impacts of economic activities, contingent upon the nature of the externalities and the specific contexts in which they manifest. However, it is noteworthy that while both studies evaluate water purification and found reductions in infant mortality, our research reveals a contrasting positive effect—increased infant mortality—due to the adverse externalities of gold mining pollution.

Main Results - Event-Study Form. We now examine the heterogeneous effects of gold mining pollution on infant mortality rates over time, employing a time-varying treatment status as outlined in equation (2). The results, illustrated in Figure 3, reveal a pronounced, positive, and persistent impact of the Amazon Gold Rush on infant mortality rates, with statistically significant effects observed even eleven years after the onset of the mining boom along Brazil’s Amazonian border. This enduring impact can be attributed to several factors. First, the sustained gold mining activities since 2004 have led to continuous pollution of downstream Brazilian rivers, as documented by [Swenson et al. \(2011\)](#) and [Ashe \(2012\)](#). Consequently, mercury-contaminated fish remains a dietary staple for communities along these polluted rivers ([Dórea and Barbosa, 2007](#); [Oliveira et al., 2010](#); [Soares et al., 2018](#)). Second, as a heavy metal, mercury persists in river ecosystems for prolonged periods, requiring considerable time to dissipate ([Hilson, 2006](#)) and potentially creating cumulative impacts on local communities. Similar persistence effects have been documented in other environmental studies involving river-borne pollutants, such as the stable impact of pesticide contamination reported by [Dias et al. \(2023\)](#).

To assess the reliability of our time-varying results, we perform a robustness check by re-estimating the results presented in the previous figures using different models and displaying

them side-by-side to compare the point estimates. This exercise is shown in Figure A.4. First, regarding the pre-intervention coefficients, the figure indicates that none of them is statistically significant, and they hover around zero. During the post-treatment period, the coefficients displayed on the right side of the figure demonstrate a clear and consistent pattern of positive and statistically significant effects of gold mining pollution on infant mortality across all econometric models. Notably, not only are the point estimates stable across different models, but so are their standard errors, providing additional robust support for our results.

Effects by Distance to the River’s Source. We also examine the heterogeneous effects of gold mining pollution on infant mortality rates based on the distance from the source of the Madeira River to the Bolivian bordering.²⁶ The rationale behind this analysis is that Brazilian municipalities closer to the Bolivian border were likely more affected by the event compared to those farther along the Madeira River. To test this hypothesis, we divided our treatment municipalities into four groups, creating binary variables that capture the treatment status at distances of 200, 400, 600, and 800 kilometers (km). These distance-based dummy variables were then incorporated into equation (2) by modifying the sum in equation (2) to reflect the timing of $Treated_{mt,j}$. We hypothesize that pollution effects are more pronounced in areas closer to the Bolivian border (the source of the Madeira River). The results of this analysis are presented in Figure 4, where various econometric model results are shown side by side to facilitate comparison.

As illustrated in Figure 4, there is a clear negative relationship between distance and infant mortality. The estimated coefficients reveal that the impact of the Amazon Gold Rush on infant mortality diminishes with increasing distance from the Bolivian border. The magnitude of these results is consistent across different econometric models. Moreover, even at relatively great distances, specifically at 600 km, the effect remains statistically significant in some models at the 5% level. However, by 800 km or more, the effect, while still positive, loses statistical

²⁶The Madeira waterway has a navigable extension of 1,060 km. Of these, approximately 180 km are within the boundaries of Rondônia (RO), and 876 km are in the state of Amazonas (AM).

significance across all models. This phenomenon could be attributed to the dilution of mercury within the food chain dynamics, given that river fish typically do not migrate over long distances. These findings suggest that the impact of the Amazon Gold Rush on Brazilian infant mortality decreases with increasing distance from the border, indicating that the adverse effects of pollution on infant health are disproportionately concentrated in municipalities closer to the border.

Heterogeneous Effects Across Brazilian States. In Figure A.5, we analyze the heterogeneous effects of the Amazon Gold Rush disaggregating the treatment status variable by the two Brazilian states, Amazonas (AM) and Rondônia (RO). The figure results confirm that the effects of river pollution on infant mortality in Brazilian municipalities are primarily driven by Rondônia (RO), the state where the *Rio Madeira* originates and which is closest to the Madre de Dios region at the Bolivian border. This finding is consistent with the results presented earlier in Figure 4, further indicating that the state of Rondônia (RO) has been the most affected by the Amazon Gold Rush.²⁷

However, one aspect requires careful consideration, particularly in the context of the last two empirical exercises. In these analyses, we divided the treatment observations into smaller groups using multiple binary variables to capture varying distance effects. This approach could potentially introduce issues with statistical inference, mainly by increasing the risk of overestimation due to imprecise variance in the estimator (Conley and Taber, 2011; Ferman and Pinto, 2019). Nevertheless, even with this consideration, the estimated coefficients remain plausible, indicating a negative relationship between increased distance and infant mortality rates. To address these concerns, we applied the p-value adjustment recommended by Ferman and Pinto (2019) to account the presence of few treated groups. As a result, our interpretation of the findings remains unchanged, further reinforcing the robustness of the results.

²⁷It is important to note that this empirical exercise focusing on Brazilian states differs from the distance-based analysis. Here, the sample is divided into municipalities within two states (AM and RO), meaning that both the treatment and control groups vary according to this division. In contrast, the distance-based analysis divides only the treatment group.

Heterogeneous Effects by Timing and Cause of Death. Next, in Table 3, we investigate the heterogeneous effects of the Amazon Gold Rush on infant mortality rates, focusing on both the cause and timing of infant death. Panel (A) shows the effects by cause of death, while Panel (B) details the effects by timing of death. Starting with Panel (A), the coefficients for infant mortality rates due to respiratory, congenital, and infectious diseases are positive and statistically significant at the 5% level. An important finding is a 32% increase in congenital infant mortality rates compared to the control group, potentially attributable to gold mining pollution. This indicates that mercury from gold mining may be a contributing factor. Medical literature suggests that the consumption of fish and water contaminated with mercury can result in prenatal poisoning, leading to congenital issues in infants (Schober et al., 2003; Xue et al., 2007; Ekino et al., 2007). Moreover, respiratory and infectious causes are frequently linked to congenital factors that influence fetal development.

Additionally, the results at the bottom of the table in Panel (B) show a significant positive effect on fetal mortality. The magnitude of this coefficient indicates a substantial increase in fetal mortality by approximately 116% relative to the control group, with an impact of 0.125 deaths per thousand newborns. This provides strong evidence of contamination during the gestational period for those exposed to pollution. Furthermore, Panel (B) also reveals an increase of around 8% and 27% in perinatal and neonatal infant mortality, respectively. This reinforces our earlier findings, indicating that the effects of pollution on infant mortality extend beyond childbirth. A more detailed examination of Panel (B) reveals a positive and significant impact on infant mortality for almost all analyzed periods, with the highest magnitude near delivery. We find a significant positive effect on mortality in the first 24 hours, the first week, and the first month of life. These results highlight the vulnerability of infants during this period and align with the literature on the effects of mercury ingestion during pregnancy or in newborns (Landrigan et al., 2004; Choi et al., 2006).

Moreover, certain results in the table, although not statistically significant, provide suggestive evidence through their precise null estimates that gold mining pollution may be the primary

driver of infant mortality rates. For instance, our analysis shows that the impact of the Amazon Gold Rush on infant deaths from external causes is not statistically significant at the 5% level. This outcome is consistent with expectations, given the absence of a direct correlation between river mercury pollution and these specific types of mortality. Overall, the findings in Table 3 align with the literature, which has established a link between infant health outcomes and exposure to heavy metals such as mercury in utero (Landrigan et al., 2004; Choi et al., 2006).

Exploring Different Control Groups. Lastly, in Appendix C, Section 11, we conduct additional exercises to explore the effects of the Amazon Gold Rush using different control groups, as illustrated in Figure A.9. The results of these analyses are presented in Figure A.10. The figure results show the heterogeneous timing effects of gold mining pollution on infant mortality rates across the various control groups. In this exercise, we use three distinct control groups: first, all municipalities in the sample, where all unaffected municipalities are considered control units, as in previous exercises; second, the exclusion of the nearest-neighbor municipalities; and third, the exclusion of the second-nearest-neighbor municipalities.

Overall, the results in these figures indicate that, regardless of the control group selection, the Amazon Gold Rush had a statistically significant positive effect on infant mortality. For control groups excluding the nearest and second-nearest-neighbor municipalities (represented in red and green), we observe that as we subsample the observations, the standard errors of the estimates increase. However, this does not impact the point estimates, which consistently remain robust and stable. We also conduct the same analysis using the treatment in its aggregated form with a single dummy variable, as shown in Table A.14. It's important to highlight that this exercise also provides evidence of no spillover effects affecting the control group, which could otherwise bias our estimates.

5.2 Additional Infant mortality channels

Identifying Delivery Mechanisms. To deepen our investigation into the causal effects of cross-border pollution from gold mining on infant outcomes, we examine the potential mecha-

nisms underlying its impact on infant mortality. Specifically, we assess the effects on childbirth-related outcomes using individual-level data on delivery status. Figure 5 presents the effects of gold mining pollution on five different delivery outcomes, divided into two panels. Panel (A) displays the results for mothers with lower education levels, and Panel (B) displays the results for mothers with higher education levels. Each point estimate in the figure represents the result of a separate regression based on the variable analyzed. All outcome variables are standardized.

Close examination of the panels in Figure 5 reveals that the effects are notably more pronounced among infants from mothers with lower levels of education. Focusing on children of mothers with less education, the first estimated coefficient at the top of Panel (A) in Figure 5 shows a decrease of 0.1 standard deviation (82.3 grams) in birth weight due to the Amazon Gold Rush, significant at the 5% level. This represents a reduction of approximately 3% relative to the control mean. A possible explanation is that during gestation, women are exposed to pollution through water, primarily via contaminated food, directly impacting the fetus. Additionally, to explore heterogeneity in newborn birth weight, we further divided it into two categories: low birth weight and very low birth weight. Both estimated coefficients are positive and statistically significant at the 10% level, indicating an increase of approximately 7% for low birth weight, and 10% for very low birth weight.

This result suggests that gold mining pollution is causing the birth of very low-weight babies. Although the estimated coefficient for preterm births (those with a low gestational period) is positive, it is not statistically significant at the 5% level. The final estimated coefficient shows a negative, statistically significant effect on the fetal growth rate²⁸, representing a 1.3% decrease compared to the control group. The magnitudes of all these results can be found in the tables in the Appendix. Lastly, it is important to acknowledge that the results derived from this analysis of the infant mortality channels could be underestimated, considering we have already identified a positive impact on fetal mortality rates in previous tables.

²⁸The fetal growth rate is calculated by dividing the infant's birth weight (in grams) by the total number of completed gestational weeks. This measure provides an estimate of the average weight gain per week during gestation, offering a standardized approach to assess fetal development across varying lengths of pregnancy.

In the Appendix, we provide additional exercises exploring the heterogeneity of the effects on infant health across different maternal education levels, as shown in Tables A.6. This table also indicates that the impacts of the Amazon Gold Rush on birth weight are stronger in magnitude for less educated women. In Figure A.6, we conduct a supplementary empirical exercise that displays the heterogeneous results of gold mining pollution on infant mortality rates across various levels of maternal education and race. Notably, the impact on infant mortality was more pronounced among less educated women and non-white mothers during the Amazon Gold Rush period. This finding supports our primary hypothesis that families from lower social classes living near the river were more affected by the Amazon Gold Rush.

Finally, we stratify the sample by the gender of the infant to investigate whether gold mining pollution has differential effects on male and female infants. This analysis is motivated by existing literature suggesting that male infants are generally more vulnerable to environmental stressors, often referred to as the “fragile male hypothesis” (Almond et al., 2011; Carrillo and Feres, 2019; Dias et al., 2023). The results, presented in Table A.10 in the Appendix, show that the point estimated coefficient for male infants is higher, indicating that the effects of gold mining pollution exposure are more pronounced for boys. This finding underscores the heightened vulnerability of male infants to environmental pollutants.

Overall, the results in this subsection suggest that pregnant women exposed to river pollution from the Madeira River experience detrimental effects on infant health. These results align with the existing literature, which has established a link between infant health outcomes and exposure to heavy metals such as mercury in utero (Schober et al., 2003; Landrigan et al., 2004; Choi et al., 2006; Xue et al., 2007; Murcia et al., 2016). In the next section, we explore the mechanisms driving these impacts on infant mortality.

6 Mechanisms Analysis

Background of the Potential Mechanisms Analysis. A central limitation of our study is the absence of direct data on mercury levels in the Madeira River’s water. This restricts our ability to directly assess the pathways of river pollution from the Amazon Gold Rush and its effects on the local food chain, specifically mercury contamination in fish. To address these data gaps, we present three complementary lines of evidence, alongside with the infant health delivery mechanisms discussed in the previous section.

First, we use satellite data to investigate whether airborne mercury particles, particularly near the Brazilian border, increased due to the Amazon Gold Rush.²⁹ Since airborne mercury contamination serves as a reliable proxy for river water pollution, this approach enables us to evaluate the environmental impact of mercury contamination resulting from cross-border gold mining pollution. Second, we leverage a culturally significant period of increased fish consumption to examine gestational exposure to potentially mercury-contaminated fish. In this, we compare gestational outcomes during periods potentially exposed to contaminated fish with those during periods theoretically less affected by the event. This analysis provides suggestive evidence of the health risks associated with consuming contaminated fish and its impact on infant outcomes. Finally, we assess whether downstream water contamination has affected the local agricultural sector, which may act as an indirect mechanism influencing riverside infant health.

6.1 Airborne Mercury Exposure in Affected Regions

Airborne Mercury Exposure in Brazil. In our study, the central hypothesis is that mercury contamination in the Madeira River flows downstream and adversely affects infant health through fish consumption as a primary exposure pathway. Since direct data on waterborne mercury is unavailable, we assess whether mercury emissions from the Madre de Dios Gold Rush led

²⁹In Appendix Table A.1, we further explore this link through correlation analyses between atmospheric mercury levels and infant mortality rates on the Brazilian side, demonstrating a strong association between airborne mercury from artisanal gold mining and infant mortality in Brazil.

to elevated airborne mercury levels in nearby Brazilian regions due to artisanal and small-scale mining activities.

Mercury detected in the air may also indicate water contamination, as atmospheric mercury can disperse over large distances. We hypothesize that airborne mercury exposure during the Amazon Gold Rush serves as an indicator of river contamination and its impact on infant mortality and other health outcomes. Additionally, mercury released from polluted water bodies also becomes detectable through satellite imagery under high temperatures. This approach enables us to evaluate mercury exposure across regions affected by river pollution, providing a clearer understanding of its environmental contamination.

Results of Airborne Mercury Particles in Brazilian Border Regions. Table 4 presents the estimated impact of the Amazon Gold Rush on airborne mercury particles in Brazilian municipalities, using the model from equation 1. Notably, across all models, the coefficients are positive, indicating a consistent rise in airborne mercury levels in Brazilian river border communities. In our preferred model (in the last column), we estimate that airborne mercury particles increase by approximately 36.4% per kilometer. Relative to the control mean, this implies that the Amazon Gold Rush is associated with a rise exceeding two thousand percent in municipalities along the Madeira River. These findings strongly indicate a significant association between the Amazon Gold Rush and elevated mercury contamination in Brazilian communities.

To further investigate the origin of the mercury pollution, Figure 6 presents the heterogeneous effects of mercury particles based on distance of Madeira river to the Bolivian bordering. The results indicate that air contamination is most pronounced in municipalities closest to the border, supporting our hypothesis that cross-border gold mining activities significantly contribute to downstream mercury pollution in Brazil. Notably, the distance regressions detected mercury presence primarily near the Brazilian border, whereas our earlier infant mortality analyses indicated that the effects extended further downstream (see results of Figure 4).³⁰ This

³⁰It is important to highlight that this distance analysis mirrors the approach previously used in the study of infant health outcomes. This approach focuses on the use the starting point of Brazilian river distances to

discrepancy may be attributed to mercury contamination traveling downstream via water flow and bioaccumulating in fish, both of which serve as transmission pathways. To further investigate this possible pathway, the next subsection explores fish consumption as a potential mechanism for mercury exposure in downstream populations.

6.2 Fish Consumption as a Key Mechanism

Potential Contaminated Fish Consumption. As previously mentioned, the primary limitation of this study is the lack of direct data on mercury levels in the Madeira River’s water. To address this, we use Holy Week (*Semana Santa*)—a culturally significant period in Catholic countries like Brazil—when fish consumption increases significantly as people abstain from meat.³¹ In riverside communities that rely heavily on fish, Holy Week serves as an exogenous variation period of intensified fish intake. Approximately 60% of the population consumes fish instead of meat during this time (Romero and Saavedra, 2016).³² This increase in fish consumption offers an opportunity to indirectly evaluate mercury exposure and its potential effects on infant health, particularly in regions affected by the Amazon Gold Rush, where river fish are likely to contain high mercury levels (Garcez et al., 2023).

We hypothesize that the heightened fish consumption during Holy Week may increase mercury exposure for pregnant women, impacting fetal development and infant health. So, we use Holy Week as a natural experiment to test whether gestational exposure in affected regions results in more intense adverse health infant outcomes by (i) comparing infant health outcomes in gold-mining-polluted versus unaffected regions (as the previews exercises) and (ii) examining differences in outcomes between gestational periods that overlap with Holy Week and those that do not in the affected regions.³³

Bolivian border regions, emphasizing cross-border pollution originating from the Madre de Dios crisis and its impact on fish contamination.

³¹Holy Week is a major religious holiday in Catholic regions such as Brazil, Peru, and Colombia, significantly impacting dietary habits and food markets across South America.

³²This period also leads to an increased availability of fish in restaurants, markets, street fairs, and other informal sales channels, further driving population consumption (Garcez et al., 2023).

³³Graphical results display exposure differences as green (Amazon Gold Rush only) and red (Holy Week and

Definition of Holy Week Exposure Indicator. Intending to explore this period, we create the *Holy Week Exposure Indicator*, a binary variable that identifies whether Holy Week—a period typically lasting seven days annually—overlaps with any part of the 270-day gestational period for infants in mercury-polluted regions (1 if it does, 0 otherwise).³⁴ Holy Week generally occurs in March or April, with its exact timing varying each year based on the first Sunday following the Paschal full moon after the spring equinox. Table A.15, in the Appendix section, outline the specific dates of Holy Week across the panel data period.

Holy Week Mechanism Results. Based on this framework, our findings reveal that gestational exposure to increased fish consumption during Holy Week in mercury-contaminated regions is strongly associated with elevated infant mortality rates and adverse delivery outcomes. This is illustrated in Figure 8, with additional analyses presented in Appendix D (Figures A.12 to A.15), which reinforce these results. These findings indicate that infants exposed to Holy Week during gestation in Gold Rush-affected areas face a higher mortality risk³⁵ compared to those not exposed, as evidenced by the divergence between red and green estimated coefficients.

These elevated risks are likely driven by a the dietary mechanism: increased consumption of mercury-contaminated fish during Holy Week. Mercury’s neurotoxic effects are particularly harmful during fetal development, which may account for the higher incidence of low birth weight observed among infants exposed during this period (Sagiv et al., 2012; Boucher et al., 2014). This pattern is notably more pronounced among mothers with lower education levels, as illustrated in Figure A.14. Through the Holy Week period, we identified a potential association between heightened fish consumption and more pronounced adverse effects on infant health. This finding suggests the role of mercury-contaminated fish as a potential mechanism driving these effects.

Amazon Gold Rush) coefficients.

³⁴Using this variable, we identify deliverers exposed to the gestational period during Holy Week. These analyses encompass both delivery infant health outcomes as well as municipality-level mortality rates, generating distinct outcome variables for periods with and without gestational exposure to Holy Week.

³⁵This pattern is consistently observed across supplemental analyses in Figures A.12, A.13, and A.15.

6.3 Local Agricultural Indirect Mechanism

Local Agricultural Production as an Indirect Mechanism. To complement our analysis of potential mechanisms, we now examine how river pollution affects downstream local agricultural activities. We hypothesize that reduced agricultural output in contaminated areas may reflect broader pollution effects, indirectly contributing to higher infant mortality.

The results of this additional exercise are displayed in Panel (B) of Table 7. Most of the estimated coefficients are negative, with some being statistically significant, suggesting that the Amazon Gold Rush adversely impacted downstream agricultural production in Brazilian regions along the river. Specifically, river mercury pollution appears to reduce soybean and milk output, with the latter one observed in both per capita cow counts and total milk production. This decline may be linked to water contamination, which potentially affects soil quality. Consequently, agricultural productivity in riverside communities is affected by the Amazon Gold Rush, underscoring the broader impact of mercury pollution.

These findings align with existing literature on soil mercury contamination, which highlights that mercury from polluted water and feed accumulates in livestock and staple crops such as soy and other beans (Basri et al., 2017; Li et al., 2017). This bioaccumulation degrades agricultural productivity and compromises food quality. As a result, gold mining pollution may indirectly affect riverine populations by deteriorating agricultural resources and potentially impacting infant health. Finally, although we observed negative agricultural effects, our previous findings suggest that these effects do not significantly impact the GDP of local agricultural sectors, as shown in Panel (A) of Table 7. This suggests that the agricultural impacts, while present, may be relatively modest in scale, reinforcing the hypothesis of a silent yet pervasive effect of downstream pollution.

Mechanisms Overview. This section synthesizes the key potential mechanisms underlying our main findings. Our analysis highlights the link between mercury contamination in rivers and adverse health outcomes. We identify three primary channels during Amazon Gold Rush

event: (i) an increase in local airborne mercury particles, (ii) potentially contaminated fish consumption in affected areas, and (iii) indirect impacts on local agricultural production. These mechanisms underscore river contamination and dietary exposure as primary pathways through which the Amazon Gold Rush impacts infant health.

7 Testing the Plausibility of the Identification

Testing the Identification. We now assess the plausibility of our identification strategy through multiple empirical tests. First, we analyze pre-intervention estimated coefficients from the main event study regressions, capturing the effects before the treatment’s implementation. Second, we conduct robustness checks via placebo exercises, examining similar rivers that were theoretically unaffected by the Amazon Gold Rush shock. Third, we perform supplementary analyses to investigate potential migration, maternal composition, and municipal responses that could compromise the interpretation of our results.

7.1 Plausibility of the identification checks

Pre-intervention Treatment Tests. As previously mentioned, we use the pre-intervention estimated coefficients from the main event study regressions, denoted as β_j where j takes negative values, to assess the plausibility of the identification assumptions. These placebo pre-intervention treatment tests, as displayed on the left side in Figures 3 and A.4, show that none are statistically significant at the 5% level. Moreover, it is noteworthy that the average of the pre-intervention point estimates is approximately zero. Consequently, the jointly estimated coefficients produce a flat curve during the pre-trends test, suggesting no differential impact on the outcome variable before the event. This finding provides robust evidence supporting the plausibility of our identification strategy.

7.2 Placebo exercises using similar and closer rivers as treatment

Rivers Placebo Tests. To further validate our empirical approach, we conducted additional placebo tests. For these tests, we excluded municipalities directly dependent on the Madeira River—specifically, those through which the river flows—and reassigned the treatment status to similar, nearby riverside municipalities that were not affected by the Amazon Gold Rush. Specifically, we use municipalities along the Tapajós and Juruá rivers, which run parallel to the Madeira River but originate from different sources and were theoretically not impacted by the pollution. The geographical context of this approach is illustrated in Figure A.1 in the appendix, showing the distribution of rivers in the Amazon Rainforest. The results of these exercises are presented in Tables 6 and A.4.

We began by conducting the placebo tests using each river separately, as shown in Table 6. In these exercises, presented in columns (1) to (3), we altered the treatment status by designating unaffected rivers as treated counterparts. In column (1) - Placebo 1, we designated the Juruá River as the intervention group, including 7 municipalities. In column (2) - Placebo 2, the treated group consists of 8 municipalities along the Tapajós River. Finally, in column (3) - Placebo 3, both the Juruá and Tapajós Rivers are classified as treated, encompassing 15 municipalities.³⁶

Furthermore, in Table A.4, we classify both the Juruá and Tapajós Rivers as treated (encompassing 15 municipalities), with each column representing a different econometric model, incorporating fixed effects and control variables in a staggered manner. Following our preferred specification, the results show no statistically significant differences from the null hypothesis at the 5% level. This exercise reinforces our main empirical hypothesis, strongly indicating that the Gold Rush event’s impact was confined to the Madeira River region.

³⁶For a clearer understanding of the geographical context and the placebo exercises, please refer again to Figure A.1. In these placebo exercises, we hypothesize that the rivers, which run parallel to the Madeira River, remained unaffected by the Amazon Gold Rush.

7.3 Migration, composition effects, agricultural production, and potential municipalities reaction

Overview of the Identification Concerns. We now examine the potential compositional effects on our sample resulting from migration within the affected riverside population due to the Amazon Gold Rush shock. For example, women who remained in the municipalities may differ in characteristics from those who left during the event period. Moreover, municipalities that were more severely affected by the shock may have implemented policies to mitigate the effects of the pollution. To investigate these concerns, we conduct the following additional analyses.

Population Migration. We start by testing the potential effects of the Amazon Gold Rush on population migration using data from the Brazilian demographic census. The results, presented in Table 5, estimate the impacts of the Amazon Gold Rush on migration patterns for the years 2000 and 2010. The econometric models reveal a slight negative effect in columns (1) and (2). However, the statistical significance diminishes once state-time fixed effects are included, as seen from column (3) onward. In our preferred model, shown in column (5), the results indicate no statistically significant difference in population migration due to river pollution exposure. This suggests that there is no evidence of migration related to the event that could bias our primary findings.³⁷

Women’s Fertility. Another factor that may influence the interpretation of our results is the potential impact of the Amazon Gold Rush on women’s fertility over time. One might assume that women would choose to have fewer children due to pollution concerns, which could artificially decrease or increase infant mortality rates, thus altering the interpretation of our results. To investigate this potential issue, we examine if pollution from the Amazon Gold Rush affected women’s fertility decisions over time. The results, presented in Table A.3, show

³⁷For this analysis, we used data from the 2000 and 2010 Brazilian Demographic Census, which includes detailed information on residents’ length of stay within their municipalities. This data allowed us to assess migration patterns by examining changes in the proportion of individuals remaining in the same municipality over time.

that although most of the estimated coefficients are positive, none are statistically significant at the 5% level. Consequently, these precise null estimates lead us to conclude that pollution exposure does not significantly influence trends in women’s fertility over time. In other words, the pollution caused by Gold Rush exposure does not appear to influence women to have more or fewer children.

Sample Composition Concerns. Continuing our analysis of potential issues, we further investigate whether the Amazon Gold Rush led to any compositional changes in the observable characteristics of expectant mothers. This investigation aims to assess whether the characteristics of the riverside population shifted over time due to the event. The results, presented in Figure 7, display each entry corresponding to a different regression output. To facilitate a more detailed evaluation, we grouped variables into specific categories. For example, prenatal care was segmented into categories of no prenatal care, low prenatal care (1–3 visits), moderate prenatal care (4–6 visits), and high prenatal care (7+ visits). This approach enhances our ability to analyze potential compositional shifts, enabling us to examine, with greater specificity, whether particular observable characteristics of expectant women changed in response to gold mining pollution exposure.

Notably, all estimated coefficients are centered around zero and are not statistically significant at the 5% level. This pattern holds across all observable characteristics tested, including marital status, maternal age, years of education, number of antenatal visits, and location of birth. In particular, the final estimated coefficient, representing the ‘Same Location’ variable, shows no significant change in birth location.³⁸ The results from this analysis indicate no patterns of migration, changes in delivery location, or shifts in the tested observable characteristics among expectant mothers, consistent with the findings in Table 5.

Potential Municipality Reactions. Next, one might expect Brazilian municipalities to respond to the Amazon Gold Rush. To explore this possibility, Panel (A) of Table 7 presents our

³⁸The “Same Location” variable is defined as cases where the municipality of birth is the same as the mother’s municipality of residence.

analysis of potential municipal reactions to pollution exposure. The hypothesis tested is that affected municipalities may have implemented measures to mitigate the impact of the Amazon Gold Rush pollution. The table is organized as follows: columns (1) and (2) evaluate differences in municipal spending, specifically on health and education; column (3) examines potential differences in vaccination coverage; columns (4) and (5) assess variations in the coverage of social programs, including the Bolsa Família Program (a nationwide cash-transfer program) and the Family Health Program (a nationwide healthcare program); and columns (6) and (7) estimate the relationship between the gold mining pollution and municipal GDP. In summary, the results consistently indicate no significant responses from the affected municipalities. The lack of statistical significance suggests that municipalities did not exhibit any measurable response to the Gold Rush during the period analyzed.

It is important to highlight that our previous tests focusing on identification issues align with one of our central hypotheses: mercury contamination in the Madeira River likely affected the Brazilian population silently, without triggering public alarm or directly drawing local media attention. This can be attributed to two key factors: (i) the primary surge in gold mining activity took place outside Brazil’s territory, leading to an absence of direct visual evidence or local awareness of the mining operations, and (ii) mercury contamination tends to occur downstream, crossing into Brazilian territories and contaminating the food chain via fish. Notably, mercury does not directly kill aquatic life but instead contaminates it, allowing the fish to serve as vectors of mercury transmission to humans, particularly pregnant women. Mercury poisoning manifests without immediate or visible symptoms, rendering the health impacts even more insidious and challenging to detect.

Brazilian Environmental Fines. Lastly, we conducted an additional placebo exercise to investigate whether the environmental shock from gold mining originated within Brazilian municipalities. This analysis utilized data on environmental fines imposed by Brazil’s federal environmental agency, IBAMA,³⁹ specifically for areas along the Madeira River in Brazil. Since

³⁹IBAMA (*Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis*) is responsible for

mercury pollution originates from gold mining activity in the Madre de Dios region of Peru and Bolivia, it is carried downstream across the border through the river. We, therefore, hypothesize that there should be no association between environmental fines in Madeira River municipalities and pollution from this cross-border activity. The results of this analysis are shown in Figure A.7. Notably, all estimated points are centered around zero, with post-estimation coefficients indicating no substantial evidence of Brazilian environmental fines. Almost all coefficients are not statistically significant at the 5% level, except for two coefficients in the pre-treatment period.

These findings suggest no link between the Amazon Gold Rush and internal Brazilian environmental fines, further supporting that the environmental impact originated outside Brazil. It is worth noting that previous analyses using satellite images have shown an increase in airborne mercury due to artisanal mining excavations in cross-border regions, as illustrated in Figure 6 and Table 4. Together, these results—rising mercury levels without corresponding changes in Brazilian environmental fines—strongly reinforce our identification strategy, suggesting that the environmental impacts indeed originated outside Brazilian borders.

8 Conclusion

This paper provides novel evidence on the negative externalities generated by the small-scale gold mining in neighboring Amazonian countries on Brazilian populations. Our results reveal that the pollution introduced in rivers are associated with a increase in infant mortality rates in affected areas, particularly among newborns, due to potential mercury contamination from the Amazon Gold Rush in the Madre de Dios region of Peru and Bolivia. In contrast, studies on large-scale, regulated mining in Africa report a 50% reduction in infant mortality due to economic growth, despite potential pollution risks (Benshaul-Tolonen, 2019). This stark discrepancy underscores the importance of distinguishing between the regulated, economically beneficial impacts of large-scale mining and the severe health risks posed by unregulated practices.

enforcing environmental laws and imposing fines within Brazilian territory. These fines do not apply to areas outside Brazil, such as Peru and Bolivia, where mercury pollution from gold mining in the Madre de Dios region originates.

Our findings highlight the need for stringent cross-border environmental regulations to mitigate health risks associated with gold mining activities. Immediate interventions, such as regular water testing and health monitoring for pregnant women and infants, are essential to understanding contamination mechanisms and reducing their impacts. Robust environmental policies are critical to safeguarding the health of populations living near mining regions. Additionally, as current monitoring efforts primarily address the immediate impacts of contamination, future research should investigate the medium-term effects of river pollution exposure on Amazonian communities to deepen our understanding of these long-term environmental and health consequences.

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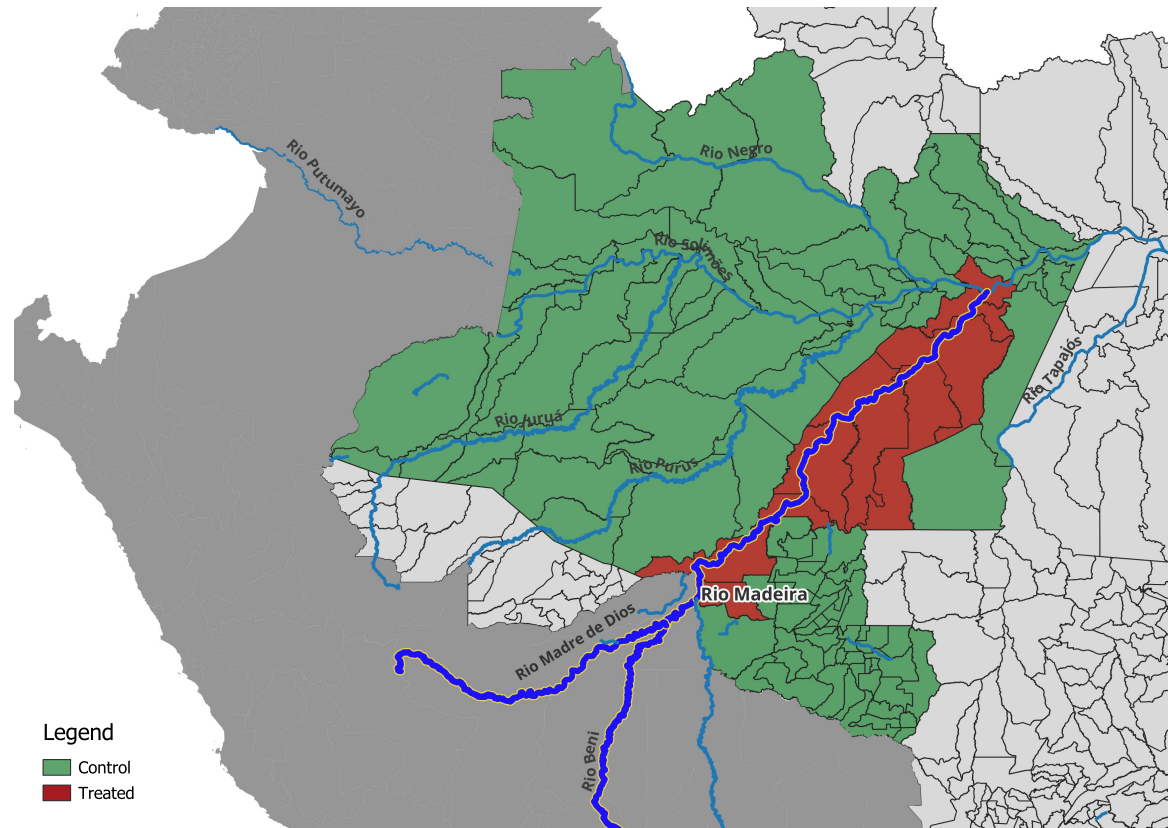
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Figure 1: Illustration of the environmental impacts resulting from artisanal and small-scale gold mining on riverside flora in the Madre de Dios region of the Amazon Rainforest between 2003 and 2011



Note: This figure is a satellite image comparing the Madre de Dios region in the remote Amazon areas of Peru and Bolivia before and after the Amazon Gold Rush, during the years 2003 and 2011. The Inambari River (also known as the Madre de Dios River) is a tributary of the Madeira River (the Brazilian-affected river). The area shown on the right side, highlighted as an area of artisanal mining, depicts the impact of the sudden increase in illegal gold mining in the Amazon Rainforest. Source: Figure retrieved from the paper by [Swenson et al. \(2011\)](#).

Figure 2: Amazon Gold Rush Geographical Context - Distribution of Brazilian Municipalities, their Principal Rivers Within the Amazon Rainforest, and the Treatment and Control Status



Note: This map was created by the authors. This figure depicts the geographical context of the Amazon River drainage basin in South America, including parts of Brazil, Bolivia, Colombia, Ecuador, and Peru. The main rivers highlighted are the Brazilian Madeira River, the Beni River, and the Madre de Dios Basin. The treatment status is displayed with red municipalities representing those defined as "treated" observations (11 municipalities) that were affected by the Madre de Dios Gold Rush, while green municipalities serve as "control" observations (105 municipalities) that were not affected by the event. Gray municipalities are those for which we do not use data.

Table 1: Descriptive Statistics from Datasets for Municipality and Individual Level Data

Panel (A) - Dependent variables and main regressor at municipality level					
	Mean	SD	Min	Max	Data Source
Infant mortality rate	15.641	12.094	0.000	156.250	Datasus - SIM/Sinasc
Infant mortality fetal rate	0.085	0.621	0.000	12.195	Datasus - SIM/Sinasc
Infant mortality 24h rate	3.778	5.024	0.000	66.098	Datasus - SIM/Sinasc
Infant mortality week rate	4.468	5.132	0.000	68.965	Datasus - SIM/Sinasc
Infant mortality month rate	1.763	3.625	0.000	71.428	Datasus - SIM/Sinasc
Infant mortality year rate	5.632	7.806	0.000	142.855	Datasus - SIM/Sinasc
Infant mortality neonatal rate	10.097	8.151	0.000	93.750	Datasus - SIM/Sinasc
Infant mortality infect. rate	1.355	3.127	0.000	47.619	Datasus - SIM/Sinasc
Infant mortality diarrhea rate	0.779	2.299	0.000	38.461	Datasus - SIM/Sinasc
Infant mortality renal rate	0.011	0.170	0.000	3.745	Datasus - SIM/Sinasc
Infant mortality perinatal rate	8.214	7.287	0.000	73.770	Datasus - SIM/Sinasc
Infant mortality digestive rate	0.111	0.831	0.000	19.230	Datasus - SIM/Sinasc
Infant mortality circulatory rate	0.063	0.498	0.000	12.500	Datasus - SIM/Sinasc
Infant mortality nutritional rate	0.578	2.415	0.000	58.823	Datasus - SIM/Sinasc
Infant mortality resp rate	1.161	2.813	0.000	40.000	Datasus - SIM/Sinasc
Infant mortality external rate	0.292	2.118	0.000	63.965	Datasus - SIM/Sinasc
Infant mortality congenital rate	1.916	3.049	0.000	27.270	Datasus - SIM/Sinasc
Infant mortality others rate	10.339	8.828	0.000	73.770	Datasus - SIM/Sinasc
Treatment variable	0.096	0.295	0.000	1.000	Administrative Data

Panel (B) - Additional dependent variables at individual level					
	Mean	SD	Min	Max	Data Source
Child birth weight	3232.2	540.30	110	6930	Datasus - Sinasc
Preterm	0.069	0.254	0.000	1.000	Datasus - Sinasc
Low birth weight	0.076	0.266	0.000	1.000	Datasus - Sinasc
Very low birth weight	0.009	0.094	0.000	1.000	Datasus - Sinasc
Fetal growth rate	83.61	13.81	0.000	454.5	Datasus - Sinasc
Mother's age	23.931	6.167	9.000	64.000	Datasus - Sinasc
Married	0.415	0.492	0.000	1.000	Datasus - Sinasc
Mother's schooling age	3.636	1.255	0.000	8.000	Datasus - Sinasc
Birth at residence mun. (same location)	0.924	0.264	0.000	1.000	Datasus - Sinasc
Antenatal care visits	0.928	0.258	0.000	1.000	Datasus - Sinasc
Marital status - married	0.415	0.492	0.000	1.000	Datasus - Sinasc

Panel (C) - Control and additional variables at municipality level					
	Mean	SD	Min	Max	Data Source
Education expenditure	15.480	1.327	0.000	20.835	Ipeadata
Health expenditure	15.024	1.404	0.000	20.497	Ipeadata
Cov. by families in <i>Bolsa Família</i> Program	0.768	2.278	0.000	11.838	Ipeadata
Cov. by <i>Programa Saúde da Família</i>	1.166	2.864	0.000	12.306	Ipeadata
Pop. vaccine coverage	7.729	1.931	0.000	13.592	Ipeadata
GDP per capita	8.838	2.728	2.815	21.242	IBGE
Agro. GDP	6.720	1.298	0.6373	10.124	IBGE
Environmental fines	0.0007	0.0012	0.000	0.0147	IBAMA
Population migration	9.875	0.917	7.747	14.404	Demographic Census
Total Harvested Area	0.4406	0.9317	0.001	18.0815	Ipeadata
Total Rice	0.1228	0.3753	0.000	5.4327	Ipeadata
Total Corn	0.0997	0.2910	0.000	7.0092	Ipeadata
Harvested Soybeans	0.0768	0.5355	0.000	10.5125	Ipeadata
Temporary Crops	0.3261	0.9010	0.001	18.0640	Ipeadata
Total Cattle	6.3891	9.4840	0.000	62.462	Ipeadata
Milk (cows per capita)	0.4518	0.7394	0.000	4.728	Ipeadata
Milk Production	371.0	647.3884	0.000	3936	Ipeadata

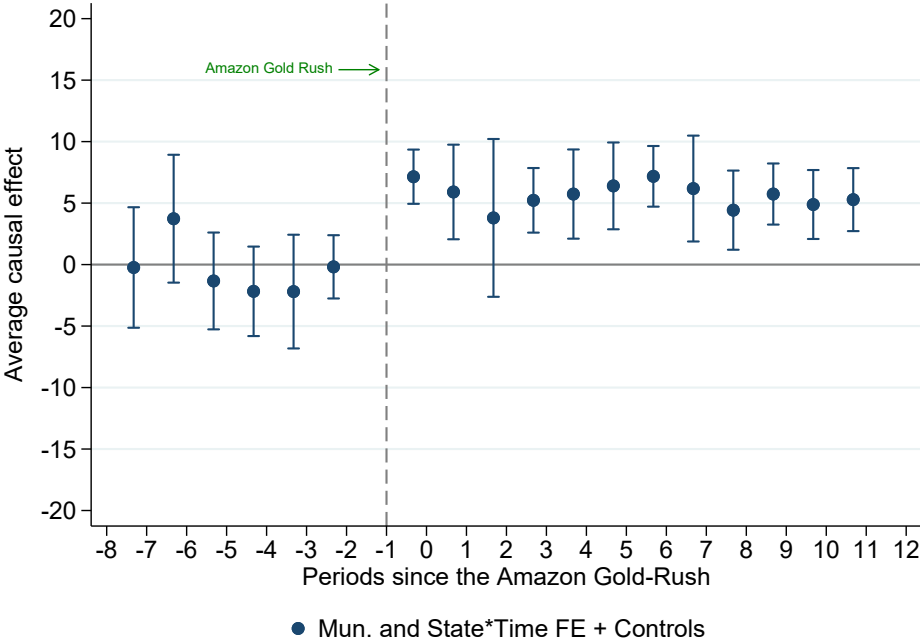
Note: This table contains the summary statistics for datasets at the municipality level from 1997 to 2015. Panel (A) provides information on the dependent variables related to infant mortality rates and the treatment indicator. Panel (B) provides additional dependent variables at the individual level, primarily related to birth and maternal characteristics. Panel (C) includes control and other supplementary variables used in robustness check exercises. The abbreviation “Cov.” stands for “coverage”, and “Pop.” stands for “population”. Specifically, the population migration variable is available for the years 1990, 2000, and 2010. The data for these variables are drawn from five different Brazilian data sources: (i) Datasus-SIM, (ii) Datasus-SINASC, (iii) Ipeadata, (iv) Demographic Census, and (v) IBAMA (for detailed information on these sources and their abbreviations, see the main text). The municipality-level data includes 1,860 observations for Panels (A) and (C), while the individual-level data in Panel (B) comprises 1,876,246 observations, although the number varies by variable. All infant mortality rates, government program coverage, and population migration figures are expressed per thousand individuals. GDP, agricultural GDP, and health expenditures are presented in millions of BRL (R\$). Childbirth weights are expressed in grams. Population migration is measured per ten thousand individuals, while airborne mercury particles are expressed in kilograms per square kilometer (kg/km^2). Note that Panel (C) have some variables are not used as control variables but are included as outcome variables in supplementary empirical analyses to provide additional insights.

Table 2: Effects of Amazon Gold Rush on Brazilian Infant Mortality Rates

	(1)	(2)	(3)	(4)	(5)
Treated	3.881* (2.192)	8.298*** (2.812)	6.604** (1.486)	5.948*** (1.190)	5.743*** (1.243)
FP p-value	0.001	0.001	0.001	0.001	0.001
R-squared	0.329	0.493	0.522	0.555	0.557
Control mean	[16.621]	[16.621]	[16.621]	[16.621]	[16.621]
Observations	1,623	1,623	1,623	1,623	1,623
Mun. FE	✓	✓	✓	✓	✓
Year. FE	✓	✓	✓	✓	✓
Sample weights		✓	✓	✓	✓
State × Year. FE			✓	✓	✓
Basic Controls				✓	✓
Social Program Controls					✓

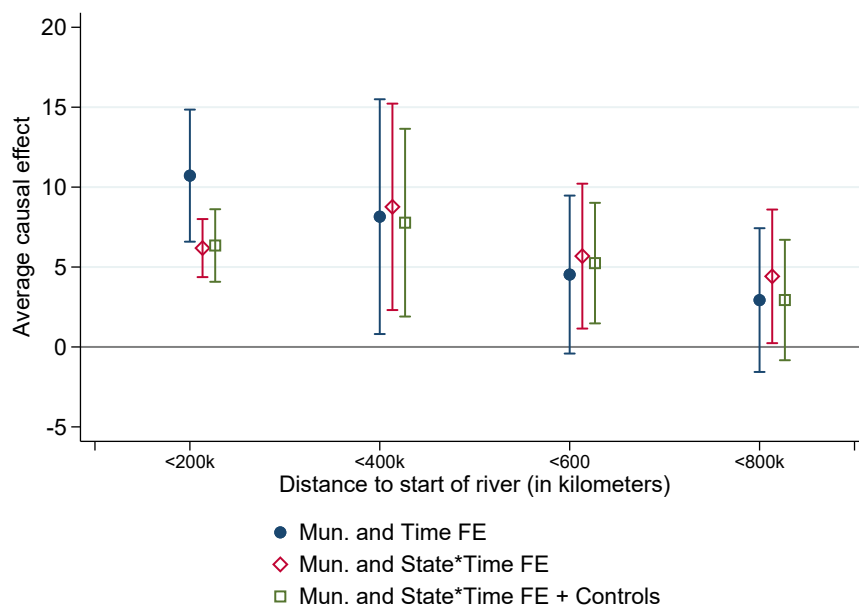
Note: This table contains the estimation of the effect of the Amazon Gold Rush (gold mining pollution exposure) event from 1997 to 2015 on infant mortality rates in the Brazilian Amazon rainforest at the municipality level. “Treated” is the interaction between the post-period and the treatment dummy, which identifies the Brazilian municipalities affected. Values in parentheses are the municipality cluster-robust standard errors. Control variables were omitted for space considerations. “FP p-value” is the p-value with adjustment for a small sample size. The estimates in column (5) are obtained using equation 1. “Control mean” values, in brackets, indicate the mean value of the outcome variable for the control group. “Basic Controls” include population vaccination coverage, the local number of municipal environmental fines, and municipal per capita health and educational spending, as well as GDP and agricultural GDP, both in logarithmic per capita form. “Social Program Controls” include Bolsa Família and Programa Saúde da Família, both in per capita form. The symbols *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively.

Figure 3: Timing Heterogeneous Effects of Amazon Gold Rush on Brazilian Infant Mortality Rates



Note: This figure plots the results for the heterogeneous effects of the Amazon Gold Rush (gold mining pollution exposure) event on infant mortality rates in Brazilian municipalities with gold mining pollution exposure. All estimated coefficients come from the same regression, using equation 2, which includes year-by-state interactions, municipality fixed effects, control variables, and sample weights. The confidence intervals are at the 95% level and are calculated in pointwise form using cluster-robust standard errors at the municipality level. The omitted category is the -1 period. The time interval for this analysis spans from 1997 to 2015 at the municipality level. “Mun.” is an abbreviation for the municipality. “Controls” refers to control variables, which include local population vaccination coverage, the number of Brazilian municipal environmental fines, municipal per capita health and educational spending, as well as Bolsa Família and Programa Saúde da Família allocations, both in per capita form.

Figure 4: Heterogenous effects of Amazon Gold Rush on infant mortality rates by distance to starting point of the Madeira River (to the Bolivian border)



Note: This figure displays the results of heterogeneous effects of the Amazon Gold Rush (gold mining pollution exposure) on infant mortality rates by the distance to the start of the Madeira River. Each color represents a different econometric model, where all estimated coefficients within the same color come from the same regression. The estimates of the green model are obtained using equation 2, with a slight modification of the treated dummy variables. All regressions include the relevant population sample weights. The confidence intervals are at the 95% level and are calculated in pointwise form using cluster-robust standard errors at the municipality level. The time interval for this analysis spans from 1997 to 2015 at the municipality level. “Mun.” is an abbreviation for the municipality, and “Controls” refers to the set of control variables, which include local population vaccination coverage, the number of Brazilian municipal environmental fines, municipal per capita health and educational spending, as well as Bolsa Família and Programa Saúde da Família allocations, both in per capita form. Additionally, GDP and agricultural GDP per capita are both expressed in logarithmic form.

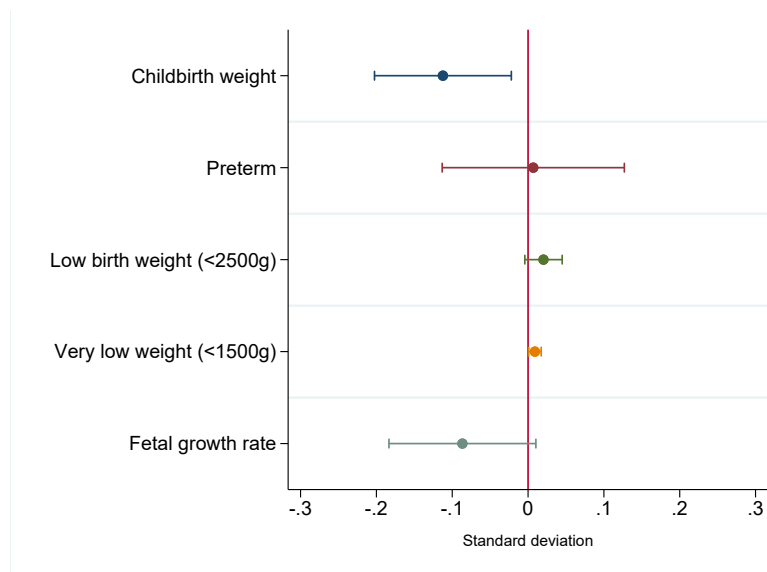
Table 3: Heterogeneous Effects of Amazon Gold Rush on Brazilian Infant Mortality Rates by Cause and Timing of the Death

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel (A) - Infant Mortality by Causes								
Infant Mortality Rates	Infect.	Congenital	Respiratory	Malnutrition	Circulatory	External	Others Causes	Non-classified
Treated	1.682*** (0.450)	1.102*** (0.255)	1.622*** (0.407)	0.271 (0.167)	0.040 (0.032)	-0.019 (0.094)	0.283 (0.635)	1.004*** (0.321)
Control mean	[4.416]	[3.478]	[3.077]	[1.474]	[0.063]	[0.322]	[2.758]	[1.749]
R-squared	0.316	0.371	0.359	0.273	0.117	0.166	0.289	0.412
Observations	1,623	1,623	1,623	1,623	1,623	1,623	1,623	1,623
Panel (B) - Infant Mortality by Timing								
Infant Mortality Rates	Fetal	Day (in 24h)	Week (1day-7days)	Month (8days-29days)	Year (30days-1year)	Neonatal Mort.	Perinatal Mort.	
Treated	0.125** (0.060)	1.408*** (0.353)	2.422*** (0.603)	1.115*** (0.187)	0.813 (0.712)	3.963*** (0.791)	2.560*** (0.625)	
Control mean	[0.1128]	[3.955]	[4.752]	[1.907]	[5.895]	[8.880]	[4.855]	
R-squared	0.213	0.281	0.454	0.262	0.490	0.452	0.450	
Observations	1,623	1,623	1,623	1,623	1,623	1,623	1,623	

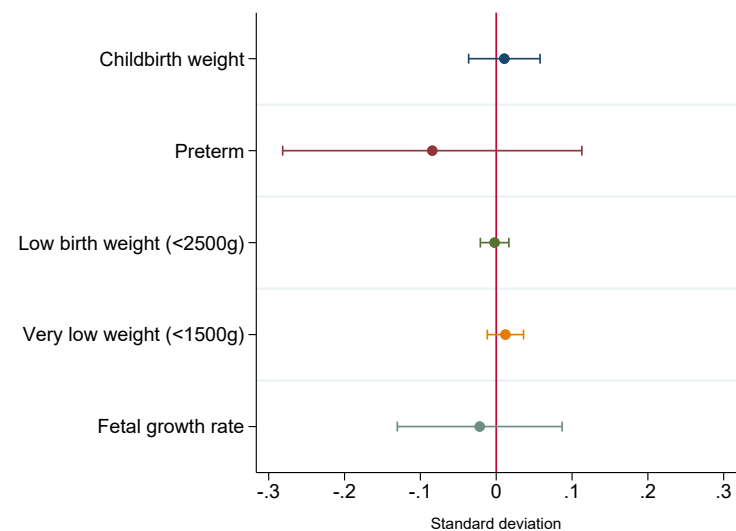
*Note: This table contains the estimation of the heterogeneous effect of the Amazon Gold Rush (gold mining pollution exposure) from 1997 to 2015 on infant mortality rates in the Brazilian Amazon by cause (Panel (A)) and timing of death (Panel (B)). "Treated" is the interaction between the post-period and the treatment dummy, which identifies the Brazilian municipalities affected. Values in parentheses are the municipality cluster-robust standard errors. All regressions are weighted by the relevant population size. The estimates in this table are obtained using equation 1. All regressions include year-by-state interactions, municipality-fixed effects, control variables, and sample weights. Control variables were omitted for space considerations. Control variables encompass population vaccination coverage, the number of Brazilian municipal environmental fines, per capita municipal spending on health and education, GDP, and agricultural GDP per capita, both in logarithmic form. Additionally, per capita allocations for Bolsa Família and Programa Saúde da Família are included as control variables. "Control mean" values, in brackets, indicate the mean value of the outcome variable for the control group. The symbols *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively.*

Figure 5: Potential Delivery Mechanisms - Effects of the Amazon Gold Rush by Maternal Education Level

Panel (A): Mothers with Lower Education Level



Panel (B): Mothers with Higher Education Level



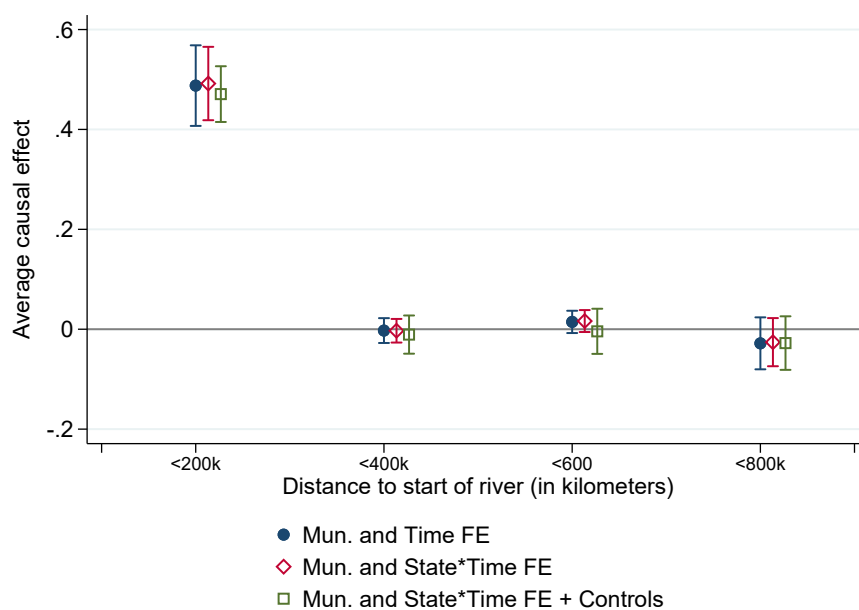
Note: This figure displays the potential mechanisms of the effects of the Amazon Gold Rush (gold mining pollution exposure) on individual-level outcomes, based on a sample of 1,897,442 births from 1997 to 2015. Panel (A) displays the coefficients for children from women with lower education levels, and Panel (B) provides the results for children from women with higher education levels. All outcomes are standardized, with each color representing a different outcome variable. All regressions include control variables from model 1, such as population vaccination coverage, the number of municipal environmental fines, and per capita municipal spending on health and education. Additional controls include the mother's age, years of education, marital status, municipality, and year-by-state fixed effects, GDP and agricultural GDP per capita (in logarithmic form), and per capita allocations for Bolsa Família and Programa Saúde da Família. The confidence intervals are at the 95% level and are calculated using cluster-robust standard errors at the municipality level.

Table 4: Potential Mechanisms Analysis - Effects of Amazon Gold Rush on the Log of Brazilian Airborne Mercury Particles

	(1)	(2)	(3)	(4)	(5)
Treated	0.407*** (0.050)	0.362*** (0.010)	0.362*** (0.012)	0.363*** (0.011)	0.364*** (0.012)
FP p-value	0.001	0.001	0.001	0.001	0.001
R-squared	0.857	0.885	0.891	0.896	0.902
Control mean	[0.0135]	[0.0135]	[0.0135]	[0.0135]	[0.0135]
Observations	1,623	1,623	1,623	1,623	1,623
Mun. FE	✓	✓	✓	✓	✓
Year. FE	✓	✓	✓	✓	✓
Sample weights		✓	✓	✓	✓
State × Year. FE			✓	✓	✓
Basic Controls				✓	✓
Social Program Controls					✓

*Note: This table contains the estimation of the effect of the Amazon Gold Rush (gold mining pollution exposure) event from 1997 to 2015 on the logarithm of Brazilian airborne mercury particles in the Brazilian Amazon rainforest at the municipality level. “Treated” is the interaction between the post-period and the treatment dummy, which identifies the Brazilian municipalities affected. Values in parentheses are the municipality cluster-robust standard errors. All regressions include population sample weights. Control variables were omitted for space considerations. The estimates in column (5) are obtained using equation 1. “Control mean” values, in brackets, indicate the mean value of the outcome variable for the control group. “Basic Controls” include population vaccination coverage, the local number of municipal environmental fines, and municipal per capita health and educational spending, as well as GDP and agricultural GDP, both in logarithmic per capita form. “Social Program Controls” include Bolsa Família and Programa Saúde da Família, both in per capita form. The symbols *, **, and *** represent statistical significance at the 10%, 5%, and 1% levels, respectively.*

Figure 6: Potential Mechanisms Analysis - Heterogenous effects of Amazon Gold Rush on Log of Brazilian Airborne Mercury Particles by Distance to Starting Point of the Madeira River (to the Bolivian border)



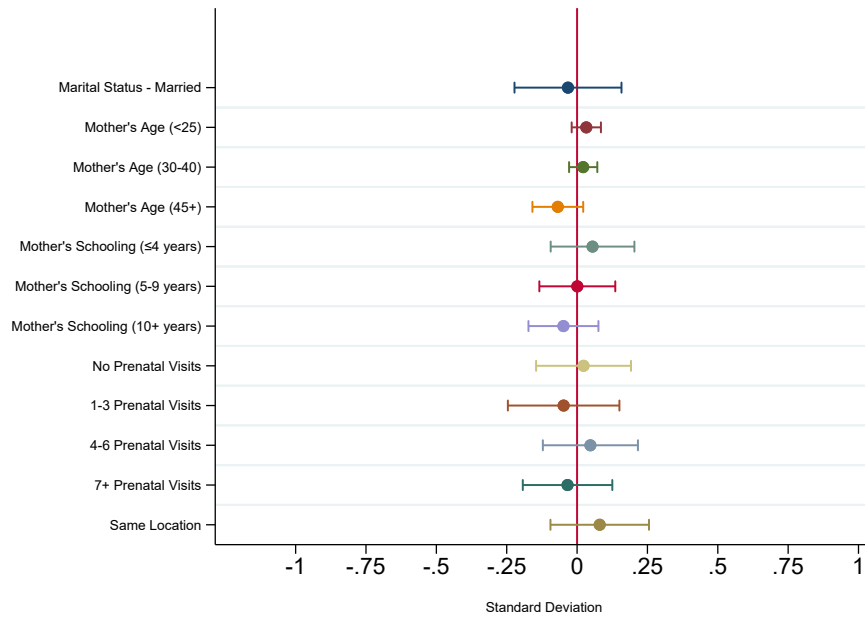
Note: This figure displays the results of the heterogeneous effects of the Amazon Gold Rush (gold mining pollution exposure) on the Brazilian logarithm of airborne mercury particles by the distance to the start of the Madeira River. Each color represents a different econometric model, where all estimated coefficients within the same color come from the same regression. The estimates of the green model are obtained using equation 2, with a slight modification of the treated dummy variables. All regressions include the relevant population sample weights. The confidence intervals are at the 95% level and are calculated in pointwise form using cluster-robust standard errors at the municipality level. The time interval for this analysis spans from 1997 to 2015 at the municipality level. “Mun.” is an abbreviation for the municipality, and “Controls” refers to the set of control variables, which include local population vaccination coverage, the number of Brazilian municipal environmental fines, municipal per capita health and educational spending, as well as Bolsa Família and Programa Saúde da Família allocations, both in per capita form. Additionally, GDP and agricultural GDP per capita are both expressed in logarithmic form.

Table 5: Effects of Amazon Gold Rush on Potential Population Migration

	(1)	(2)	(3)	(4)	(5)
Treated	-0.090** (0.040)	-0.075** (0.037)	-0.062 (0.043)	-0.041 (0.037)	-0.037 (0.042)
R-squared	0.557	0.663	0.676	0.707	0.737
Control mean	[1.045]	[1.045]	[1.045]	[1.045]	[1.045]
Observations	177	177	177	177	177
Mun. FE	✓	✓	✓	✓	✓
Year. FE	✓	✓	✓	✓	✓
Sample weights		✓	✓	✓	✓
State × Year. FE			✓	✓	✓
Basic Controls				✓	✓
Social Program Controls					✓

*Note: This table contains the estimation of the effect of the Amazon Gold Rush (gold mining pollution exposure) from 2000 to 2010 on population migration in Brazil. “Treated” is the interaction between the post-period and the treatment dummy, which identifies the Brazilian municipalities affected. Values in parentheses are the municipality cluster-robust standard errors. All regressions are weighted by the relevant population size. Control variables were omitted for space considerations. All regressions include control variables from model 1, which encompass population vaccination coverage, the number of Brazilian municipal environmental fines, and per capita municipal spending on health and education. Additionally, GDP and agricultural GDP per capita are both expressed in logarithmic form. Per capita allocations for Bolsa Família and Programa Saúde da Família are also included as control variables. “Control mean” values, in brackets, indicate the mean value of the outcome variable for the control group. The symbols *, **, and *** represent statistical significance at 10%, 5%, and 1% respectively.*

Figure 7: Potential sample composition effects - Effects of Amazon Gold Rush in Observable Mothers Characteristics



Note: This figure displays the results for potential composition effects of the Amazon Gold Rush (gold mining pollution exposure) on women's observable characteristics from 1997 to 2015. Each color represents a different econometric model, where all estimated coefficients within the same color come from the same regression. To provide more granularity in the analysis, some variables were segmented into categories. For example, prenatal care was classified into multiple groups based on the number of visits: no prenatal care, low prenatal care (1–3 visits), moderate prenatal care (4–6 visits), and high prenatal care (7+ visits). Similarly, maternal age and schooling were divided into specific ranges to assess targeted effects. The regression includes year-by-state interactions, municipality-fixed effects, and control variables. All regressions include control variables from model 1, which encompass population vaccination coverage, the number of Brazilian municipal environmental fines, and per capita municipal spending on health and education. Additionally, GDP and agricultural GDP per capita are both expressed in logarithmic form. Per capita allocations for Bolsa Família and Programa Saúde da Família are also included as control variables. The confidence intervals are at the 95% level and are calculated in pointwise form using cluster-robust standard errors at the municipality level.

Table 6: Placebo Exercise - Effects of Amazon Gold Rush on Infant Mortality Rates Using Similar Rivers in Proximity Unaffected by The Mercury Contamination

	(1)	(2)	(3)
	Placebo Test - 1	Placebo Test - 2	Placebo Test - 3
Treated	-4.090 (2.515)	-2.731 (2.523)	-1.987 (8.378)
R-squared	0.5378	0.5353	0.5335
Control mean	[15.843]	[16.164]	[16.203]
Observations	1,425	1,425	1,425

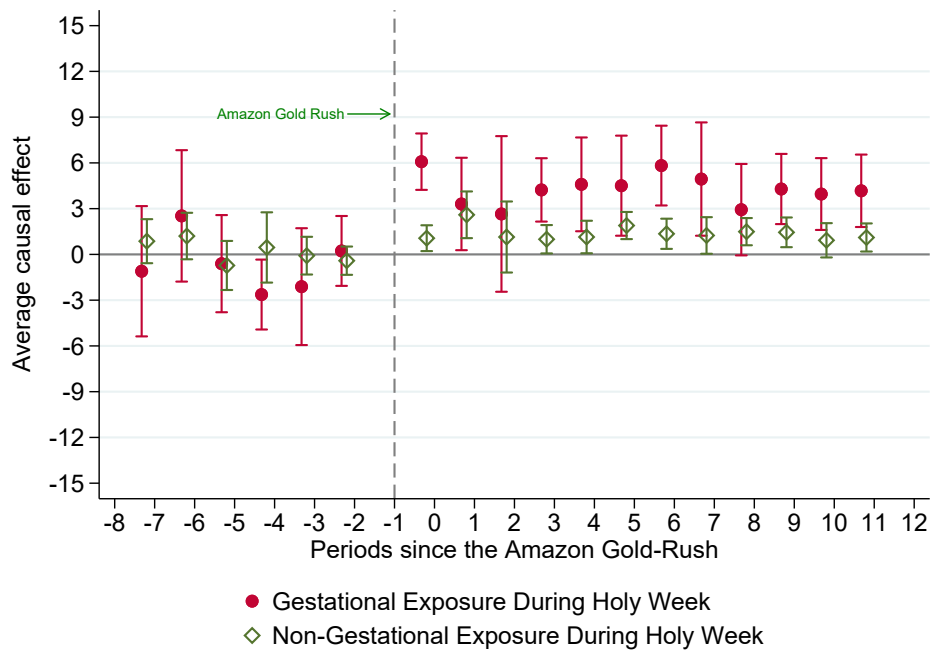
*Note: This table displays the placebo exercise results of the Amazon Gold Rush (gold mining pollution exposure) impacts on rivers in proximity that were unaffected by the event from 1997 to 2015. Each panel represents a different placebo exercise. For each placebo exercise, the treatment status is changed by using rivers unaffected by the Gold Rush event as treated counterparts. Values in parentheses are the municipality cluster-robust standard errors. In Placebo Test - 1, the Juruá River is defined as treated. In Placebo Test - 2, the Tapajós River is defined as treated. In Placebo Test - 3, both the Juruá and Tapajós Rivers are defined as treated. The regional distribution of these rivers can be viewed in Figure A.1. All regressions include year-by-state interactions, municipality fixed effects, and sample weights using the model from equation 1. Control variables are omitted for space considerations. These include population vaccination coverage, the number of municipal environmental fines, per capita municipal spending on health and education, GDP (log-transformed), and agricultural GDP per capita. Additionally, per capita allocations for Bolsa Família and Programa Saúde da Família are included. “Control mean” values, in brackets, indicate the mean value of the outcome variable for the control group. The symbols *, **, and *** represent statistical significance at 10%, 5%, and 1%, respectively.*

Table 7: Potential Municipalities Reactions and Indirect Mechanisms Analysis – Effects of Amazon Gold Rush in Municipalities Expenditures and Public Policy Coverage, Women Fertility and GDP's

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Panel (A): Potential Municipalities Reactions - Municipality Spending, Vaccination, and Social Program Coverage								
	Health Spending	Education and Culture Spending	Vaccination Cov.	Cov. of Bolsa Familia Program	Cov. of Family Health Program	Women Fertility	Mun. GDP	Mun. Agro. GDP
Treated	0.008 (0.010)	-17.331 (23.842)	-16.154 (20.366)	0.007 (0.013)	0.020 (0.021)	1.803 (1.342)	0.6658 (1.802)	-0.0524 (0.231)
R-squared	0.888	0.812	0.793	0.806	0.726	0.710	0.839	
Control Mean	[0.230]	[398.60]	[254.52]	[0.0712]	[0.165]	[19.009]	[8.852]	[6.758]
Observations	1,674	1,674	1,674	1,674	1,674	1,674	1,674	1,674
Panel (B): Potential Agricultural Indirect Effects								
	Total Harvested Area	Total Rice	Total Corn	Harvested Soybeans	Temporary Crops	Total Cattle	Milk (cows per capita)	Milk Production
Treated	-0.019 (0.038)	-0.045 (0.045)	0.001 (0.009)	-0.027** (0.014)	-0.036 (0.035)	-0.686 (0.623)	-0.103** (0.051)	-70.550* (39.858)
R-squared	0.839	0.580	0.758	0.726	0.785	0.922	0.892	0.888
Control Mean	[0.3127]	[0.0845]	[0.0648]	[0.0767]	[0.2125]	[4.4305]	[0.3772]	[314.026]
Observations	1,623	1,385	1,568	1,623	1,623	1,608	1,505	1,512

Note: This table displays the results for the potential municipality reactions to the Amazon Gold Rush (gold mining pollution exposure) in Panel (A), which includes outcomes related to Municipality Spending, Vaccination, and Social Program Coverage, and in Panel (B), which focuses on Potential Agricultural Indirect Effects. All dependent variables are in rate form, per population. Each column represents a regression using a different outcome variable. "Treated" is the interaction between the post-period and the treatment dummy, identifying Brazilian municipalities affected by the Gold Rush. Values in parentheses are municipality cluster-robust standard errors. In Panel (A), the spending and GDP variables are expressed in per capita terms, in thousands of Reais. In Panel (B), all variables are expressed in per capita terms. All regressions include year-by-state interactions, municipality fixed effects, and sample weights following the model from equation 1. Control variables were omitted for space considerations. "Control mean" values, in brackets, indicate the mean outcome value for the control group. The symbols *, **, and *** represent statistical significance at 10%, 5%, and 1% respectively.

Figure 8: Exploring the Potential Mechanisms of Holy Week as a Period of Increased Contaminated Fish Consumption on Infant Mortality Rates



Note: This figure presents the potential mechanisms of increased fish consumption during Holy Week in relation to infant mortality, particularly under conditions of gold mining pollution exposure. Each color represents a distinct econometric specification, with all estimated coefficients within the same color derived from a single regression model. Regressions include sample weights, with 95% confidence intervals calculated using cluster-robust standard errors at the municipality level. The omitted category is the -1 period. The analysis spans 1997 to 2015 at the municipality level. The control variables include the local vaccination coverage, municipal environmental fines, per capita municipal spending on health and education, and per capita allocations for Bolsa Família and Programa Saúde da Família. Additional controls include GDP and agricultural GDP per capita (both in logarithmic form). More about this exercise can be found in Appendix D, in Section 12.

Appendix - Online Appendix

The rest of this study is divided as follows. In Appendix A in Section 9, we present additional figures and tables referenced throughout the text, providing a detailed examination of the Amazon Gold Rush context and its impacts. Appendix B in Section 10 provides details about the definition of the variables used in the analysis. Appendix C in Section 11 presents robustness checks of the main results using different control groups, addressing concerns about potential spillover effects on the control group. Lastly, Appendix D in Section 12 offers further exploration of the Holy Week period as an exogenous increase in fish consumption, assessing its role as a key mechanism for mercury exposure during gestation.

- **Appendix A:** This section includes supplementary figures and tables that illustrate key contextual elements of the Amazon Gold Rush, such as the geographical spread of gold mining activities, event timing, and the mechanisms driving pollution exposure. Additionally, it presents robustness checks of the event study estimator and detailed heterogeneous analyses by region, maternal education, and race. These visual representations and tables provide deeper insights into the research findings and highlight the underlying dynamics of mercury contamination and its health impacts.
- **Appendix B:** This section offers a detailed definition of the variables used in the empirical exercises, ensuring that the reader fully understands the data sources and constructs employed in the analysis. These definitions help clarify how we operationalize key concepts such as infant mortality, pollution exposure, and control and the potential mechanism variables.
- **Appendix C:** Here, we present additional robustness checks using different control groups. These exercises serve to verify the consistency of the results by exploring how the treatment effects change under alternative control group compositions, providing a deeper understanding of the validity of our identification strategy.

- **Appendix D:** In this final appendix, we provide additional details on the analyses related to Holy Week (*Semana Santa*) as an exogenous period of increased fish consumption. This section explores the heightened mercury exposure risks that occur due to the cultural significance of Holy Week in Brazil, during which fish consumption rises substantially. We conduct exercises to measure the impact of Holy Week on infant health outcomes in mercury-contaminated areas, offering further evidence of fish consumption as a primary mechanism for mercury exposure during gestation.

Taken together, Appendices A, B, C, and D provide a comprehensive examination of our analysis, providing additional evidence of the Amazon Gold Rush's impact on infant health.

9 Appendix A - Additional Tables and Figures

This appendix provides supplementary figures and tables that enhance the understanding of the analyses presented in the main text. Each figure and table contributes to a deeper exploration of the Amazon Gold Rush’s impact on Brazilian municipalities, offering robustness checks and additional context to support our findings.

Figures

- **Figures A.1 and A.2:** These figures set the stage by depicting the geographical and temporal context of the Amazon Gold Rush. They provide a visual understanding of the affected regions and the timing of gold mining expansion. Particularly, Figure A.1 displays the affected region highlighted alongside other rivers in the Amazon Rainforest Basin. Figure A.2 displays the description of the characterization of the Amazon Gold Rush (gold price, mercury imports, and forest mining area) using Peru data and international gold prices from 2002 to 2010.
- **Figure A.3:** This figure illustrates the mercury contamination levels in four fish species commonly consumed by riverside populations along the Brazilian Madeira River. The data, sourced from river sample analyses conducted in 2015, provides a visual representation of mercury concentration in these species, highlighting potential health risks associated with fish consumption in mercury-polluted regions. The mercury levels in these fish species underscore the broader environmental impact of the Amazon Gold Rush on the Madeira River, where gold mining activities have introduced significant contaminants into the aquatic ecosystem. This figure serves to emphasize the heightened exposure risk for populations dependent on river fish for sustenance.
- **Figure A.4:** Offers a robustness check for the event study estimator by varying the econometric specifications of equation 2. Three different models are plotted side by side for direct comparison. The first model includes municipality and year-fixed effects, while

the second adds state-by-year fixed effects to the municipality-fixed effects. The third model, which follows our primary econometric approach, incorporates municipality, state-by-year fixed effects, and time-varying control variables. This comparison helps to assess the robustness of our main results across alternative specifications, ensuring their stability. In summary, they show the strong stability of our results independent of the econometric model.

- **Figure A.5:** Depicts the heterogeneous effects of gold mining pollution on infant mortality rates across different Brazilian states, highlighting regional disparities in health impacts. Specifically, this analysis focuses on the differential effects of the Amazon Gold Rush on two impacted states: Rondônia (RO) and Amazonas (AM). As expected, the state of Rondônia, being geographically closer to the event, is more affected by the impacts of the Amazon Gold Rush. Additionally, this exercise also presents the results using various econometric models, demonstrating the robustness and stability of our findings, regardless of the model specification. It indicate that the RO state, bordering with the Bolivian country is the state more affected by the Amazon Gold Rush.
- **Figure A.6:** Displays the heterogeneous effects of pollution exposure on infant mortality based on the mother's race and education level. It provide insight into how social factors interact with environmental exposure. First, following the results of Panel (A), the results show that non-white mothers are more affected by river pollution. Second, following Panel (B), as expected with our main hypothesis, this exercise provides evidence that the women who present less education level are more affected by river pollution. It corroborates the idea that riverside communities are the most affected by the Amazon Gold Rush.
- **Figure A.7:** Visualizes the relationship between the Amazon Gold Rush and environmental fines imposed in Brazilian municipalities, emphasizing local governmental responses to environmental violations. The data used in this analysis comes from IBAMA, which operates solely within Brazilian municipalities. The objective is to test whether the gold

mining boom originated outside the Brazilian regions. The results suggest that there is no significant relationship between the Amazon Gold Rush and the environmental fines imposed on Brazilian municipalities. It corroborates the idea that the Amazon Gold Rush shock did not originate within Brazil.

- **Figure A.8:** Conducts a robustness check by sequentially excluding one treated municipality at a time to assess the stability of the results on the impact of gold mining on infant mortality rates. Each point estimate is from a different regression. The results show that our main findings remain robust and are not sensitive to the exclusion of any single treated municipality. In other words, the impact is not driven by the outcomes of just one municipality.
- **Figure A.9:** This figure provides the geographical context of Brazilian municipalities impacted by the Amazon Gold Rush, highlighting key river systems within the Amazon Rainforest and the treatment status for the study. It uses different color-coded groups to distinguish treated areas affected by the Gold Rush, unaffected control regions, and municipalities that are neighboring the impacted regions. Green municipalities serve as “Control” observations (105 municipalities) and were unaffected by the event. Purple municipalities are those classified as first-order neighbors. Beige municipalities are those classified as second-order neighbors. Gray municipalities are those for which we do not use data.
- **Figure A.10:** This figure presents a robustness check for the timing of heterogeneous effects of gold mining pollution exposure on infant mortality rates across multiple control groups. Using, (i) All sample, (ii) Excluding first order neighbors, and (iii) Excluding second order neighbors. Each color represents a different control group, with all coefficients estimated from a single regression model, which includes fixed effects and various control variables to account for socioeconomic factors. The results in this figure indicate a strong stability of the results of temporal effects of the Amazon Gold Rush on infant mortality,

independently of the control group.

- **Figure A.11:** This figure displays robustness checks for the aggregated effects of gold mining pollution on infant mortality rates across multiple control groups. Using, (i) All sample, (ii) Excluding first order neighbors, and (iii) Excluding second order neighbors. Each color represents a different control group, with coefficients estimated from the same regression model but without additional control variables due to limited sample size. The model includes weighted regressions and accounts for fixed effects, illustrating the Amazon Gold Rush's impact on infant mortality across different control setups. The results in this figure indicate a strong stability of the results of the effects from the Amazon Gold Rush on infant mortality, independently of the control group.
- **Figure A.12:** This figure illustrates the impact of Amazon Gold Rush-related pollution on infant mortality rates across multiple infant mortality categories, considering Holy Week (HW) as a potential mechanism for the consumption of contaminated fish. Each color-coded control group in the figure represents a different cohort for comparison, helping to isolate the effects of HW exposure. The red coefficients represent HW exposure, while the green coefficients indicate no HW exposure. The results show a clear pattern: when gestational periods coincide with HW, the effects appear stronger, potentially indicating mercury contamination.
- **Figure A.13:** This figure illustrates the heterogeneous effects of Amazon Gold Rush-related pollution on infant mortality rates by varying distances from the source of the Madeira River. Using Holy Week as a mechanism to capture increased exposure, the figure shows different infant mortality categories, allowing for a comparison of pollution impacts across varying proximity to the contamination source.
- **Figure A.14:** This figure displays the heterogeneous effects of the Amazon Gold Rush on childbirth weight, leveraging Holy Week as a mechanism to capture gestational exposure among different maternal categories. We opt to use three distinct maternal categories: (i)

total, (ii) mothers with low schooling levels, and (iii) non-White mothers. The figure highlights differences in birth outcomes, with particular focus on mothers exposed to increased mercury levels during Holy Week. The results indicate a pattern of higher intensity of the Gold Rush effects on vulnerable populations, particularly among mothers with low education and non-White mothers. This finding corroborates the idea that riverside communities are the most affected by the Amazon Gold Rush, as these populations are more likely to rely on contaminated fish consumption, the primary vector for mercury exposure.

- **Figure A.15:** This figure presents the heterogeneous effects of Holy Week exposure during the Amazon Gold Rush on infant mortality rates, analyzed across three distinct gestational trimesters. Each trimester's impact is examined separately, illustrating how the timing of exposure during pregnancy may influence infant mortality outcomes. The results suggest that exposure during the third trimester shows a slightly stronger point estimate. However, the effects across trimesters are quite similar, indicating no systematic difference in the period of exposure to potentially mercury-contaminated fish consumption. Importantly, all results point to an increase in infant mortality associated with Holy Week exposure.

Tables

- **Table A.1:** This table displays correlation estimates of the association between mercury emissions from Brazilian artisanal gold mining and infant mortality rates in the Amazon region. Importantly, these results do not constitute an identification strategy but rather show a correlation observed within Brazilian municipalities. The estimates in column (5), which include all control variables, suggest a strong positive and statistically significant association between mercury emissions and infant mortality. It is important to highlight that this analysis focuses on mercury exposure and infant mortality within the Brazilian border, distinguishing it from the main shock analyzed in the paper, which examines the transboundary effects of mining activities on Brazilian infant mortality.

- **Table A.2:** Presents a robustness check on the effects of gold mining pollution exposure on infant mortality rates by incrementally adding control variables. In each column a distinct control variable are add to the model, until the last column which is our preferred model. All models include the fixed effects from equation 1. The results suggest that the main findings are not driven some of the control variables. As shown in the table, the inclusion of control variables slightly alters the main result, reducing the estimate from 6.605 to 5.781. We interpret this as evidence of the relative robustness of our findings.
- **Table A.3:** This analysis examines the effects of the Amazon Gold Rush on fertility rates among women in affected regions, shedding light on the broader demographic impacts of pollution exposure. A key concern related to our infant mortality findings is whether fertility rates remained stable before and after the Amazon Gold Rush. Specifically, if women chose to have fewer children due to pollution exposure, the observed increase in infant mortality might merely reflect an artificial effect caused by a decline in fertility. To address this issue, the results presented in the table provide reassurance: none of the regressions indicate statistically significant effects at the 5% level, yielding a precise null result. This finding suggests no systematic changes in fertility rates, thereby reinforcing our hypothesis that pollution exposure had a silent yet detrimental impact on the Brazilian population.
- **Table A.4:** This analysis examines the effects of the Amazon Gold Rush on infant mortality rates by using nearby rivers unaffected by the event as a placebo. In these placebo exercises, the Jurua and Tapajos Rivers are treated as if they were affected, which are being unaffected by the event. The results presented in this table show that none of the placebo regressions yield statistically significant effects at the 5% level, thereby strengthening the credibility of our analysis. These null results provide strong evidence that the negative health impacts on infant mortality rates are specifically associated with pollution exposure from the Amazon Gold Rush, rather than other unrelated environmental or

socio-economic factors in neighboring regions. This outcome further reinforces the validity of our identification strategy.

- **Table A.5:** This table provides additional robustness checks by testing the sensitivity of our results under various sample restrictions. In columns (1) and (2), we exclude the top 1% of mortality observations and remove capital cities from the sample to assess whether extreme values or urban-specific dynamics drive the results. In columns (3) and (4), we split the sample by state to evaluate whether the effects are consistent across different regions. In columns (5) and (6), we restrict the time frame of the panel data to examine the stability of the results over shorter periods. Across all models, the results consistently indicate a positive and statistically significant effect of the Amazon Gold Rush on the Brazilian infant mortality rates. This consistency suggests that the observed effects are robust and not driven by specific sample restrictions or outliers, reinforcing the reliability of our main findings.
- **Table A.6:** This table examines potential mechanisms by analyzing delivery data to understand how pollution exposure affects health outcomes. Columns (1) to (5) present results for various delivery outcome variables. The findings indicate that in regions impacted by the Amazon Gold Rush, children are born with approximately 2% lower birth weights and show reduced fetal growth rates. Additionally, there is a notable result for children born with lower fetal growth rates and classified as having low birth weight. However, it is important to consider that earlier tables reveal a significant increase in fetal mortality due to the Amazon Gold Rush. As a result, the findings in this table may be underestimated due to survival bias, as the most severely affected fetuses may not survive to birth, underestimating the present observed effects.
- **Table A.7:** This table explores the effects of pollution exposure on infant mortality rates by maternal education level. The results indicate that regions impacted by the Amazon Gold Rush are primarily affected through less-educated women. Our preferred model

shows that the effects within this group largely drive the aggregated results. This finding suggests that the observed impacts are likely concentrated among riverside populations, who tend to have lower levels of education. These results further reinforce the reliability of our main findings by highlighting the vulnerability of socioeconomically disadvantaged groups to pollution exposure.

- **Table A.8:** Examines the potential mechanisms through which Amazon Gold Rush exposure affects women of different education levels. Columns (1) to (5) present results for less-educated women, while columns (6) to (10) focus on more highly educated women. The findings indicate that the negative effects of gold mining pollution are more pronounced among less-educated women, as shown by the greater reductions in both birth weight and fetal growth rates in this group. This suggests that pollution exposure has a more severe impact on the health outcomes of children born to less-educated women. Again it should be mentioned that earlier tables reveal a significant increase in fetal mortality due to the Amazon Gold Rush. As a result, the findings in this table may be underestimated due to survival bias.
- **Table A.9:** Analyzes the heterogeneous effects of gold mining exposure across Brazilian states, offering regional insights into the impact of pollution on infant mortality. The left side of the table presents results for Rondônia (RO), while the right side displays findings for Amazonas (AM). As expected, Rondônia, the state more directly affected by the Amazon Gold Rush, displays stronger negative outcomes. This supports our hypothesis that pollution originated near the country's borders. It should be mentioned that in this particular exercise, the control group has changed for municipalities inside each state, because of the sample cut.
- **Table A.10:** In this table we investigate the hypothesis of fragile males. Analyzes the effects of gold mining pollution on infant mortality by sex, investigating whether male (right side) or female (left side) infants are disproportionately affected. The results are

quite robust along the fixed effects and control variable add to the model. Also, the results suggest that male infants are more severely impacted by gold mining pollution, evidenced by a higher estimated coefficient. This supports the literature hypothesis of gender disparity in health outcomes.

- **Table A.11:** This table delves into the potential mechanisms of pollution exposure across the two Brazilian states most affected by the Amazon Gold Rush: Rondônia (RO) and Amazonas (AM). The analysis reveals that consistent with previous findings, Rondônia experiences more pronounced negative health outcomes related to delivery. Specifically, children born in Rondônia exhibit significantly lower birth weights and face greater risks of adverse health conditions compared to those in Amazonas. These results highlight the disproportionate impact on Rondônia, likely due to its closer proximity to the gold mining activities, which may have intensified the levels of pollution exposure. This further corroborates our hypothesis that pollution originating near the country's borders is a primary driver of the observed health disparities between the states.
- **Table A.12:** This table presents the estimated effects of mercury exposure during Holy Week—a period of increased fish consumption associated with the Amazon Gold Rush—on infant mortality rates. The coefficients distinguish between non-gestational and gestational exposure, highlighting how potentially contaminated fish consumption influences mortality outcomes. The results are robust across different econometric models, consistently showing stronger effects for gestational exposure during Holy Week. As expected, gestational exposure carries a higher likelihood of mercury contamination from fish in the Madeira River, reinforcing the heightened vulnerability of infants exposed to the gold mining pollution.
- **Table A.13:** This table provides a complete description of the construction of the variables used in our empirical analysis. It includes the treatment, dependent, and control variables. Panel (A) defines the treatment variable, while Panel (B) details the various

infant mortality measures used as dependent variables. Panel (C) lists additional infant health indicators, and Panel (D) describes the control variables included in the models. It also provide the database source for all the variables. This comprehensive overview supports the study’s robustness by detailing the variables involved in assessing the impact of gold mining pollution on infant health.

- **Table A.14:** This table contains robustness checks for the effect of Amazon Gold Rush-related mercury exposure on infant mortality rates, using various control groups based on the first and second neighbors of the treatment group. Each column represents a different control group. Notably, there is no systematic difference between the estimated effects when the first or second neighbors are retrieved from the control group. Corroborating with the classification of the control group of our causal assessment.
- **Table A.15:** In Table this table, we present the annual dates for Holy Week, from 1996 to 2015. It outlines the beginning and end dates of Holy Week each year, which are based on the first full moon after the spring equinox, following the lunar calendar. This period is used in our mechanism analysis as it marks an exogenous increase in fish consumption in Brazil, allowing us to investigate the health impacts associated with dietary changes in mercury-contaminated regions.

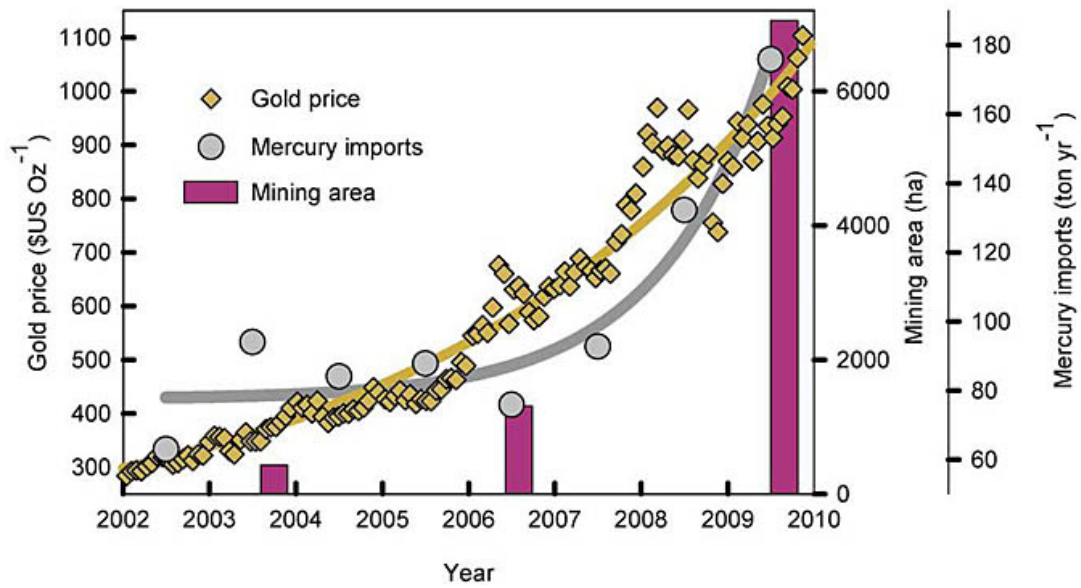
Each of these figures and tables plays a vital role in reinforcing the findings of the main manuscript, ensuring and showing that the analysis is robust, comprehensive, and transparent. The inclusion of robustness checks, heterogeneous effects, and alternative control group compositions strengthens the validity of the conclusions drawn from the study. Besides the present Appendix A, in the following Appendices B, C and D, we provide additional critical information to support our empirical analysis.

Figure A.1: Map of Key Rivers and the Madeira Basin in the Amazon Rainforest (highlighting the location of the Madeira River within the Amazon Basin)



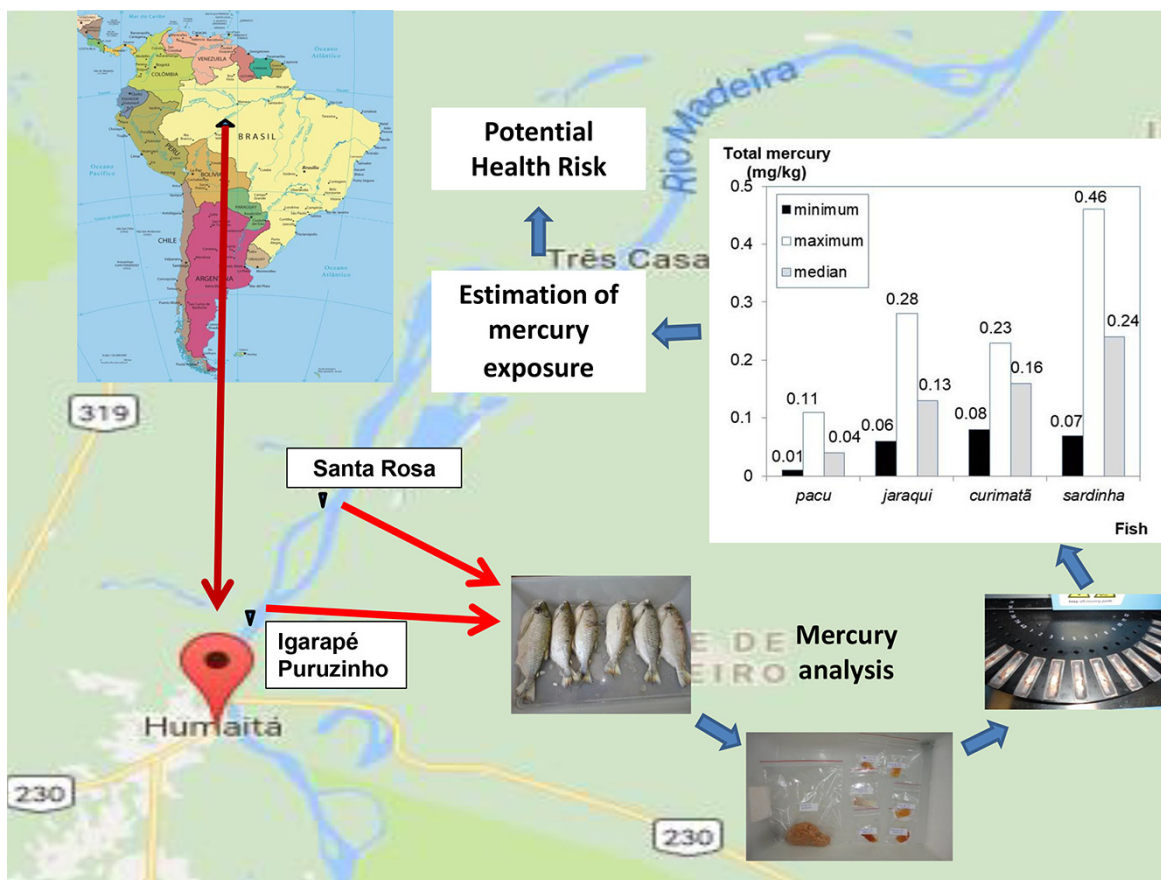
Note: This figure displays the map of the South American Amazon River drainage basin, spanning Brazil, Bolivia, Colombia, Ecuador, and Peru, with the Brazilian Madeira River Basin specifically highlighted. The Madeira River's tributaries, originating in Bolivia and Peru, were impacted by mercury pollution due to gold mining activities in these regions, contributing to cross-border environmental effects. (Source: Figure retrieved from Google Maps)

Figure A.2: Characterization of the Amazon Gold Rush - Analysis of Gold Prices, Mercury Imports, and Mining Expansion using Peruvian Data and International Gold Markets



Note: This figure illustrates the relationship between the price of gold, mercury imports, and the mining area in Peru. The yellow dots represent the international yearly gold price. The gray dots depict annual mercury import values, and the purple bars indicate the extent of Amazon gold mining by illegal mining. (Source: Figure retrieved from [Swenson et al. \(2011\)](#)).

Figure A.3: Illustration of the Mercury Contamination in Fish of the Madeira River (Brazilian affected river)



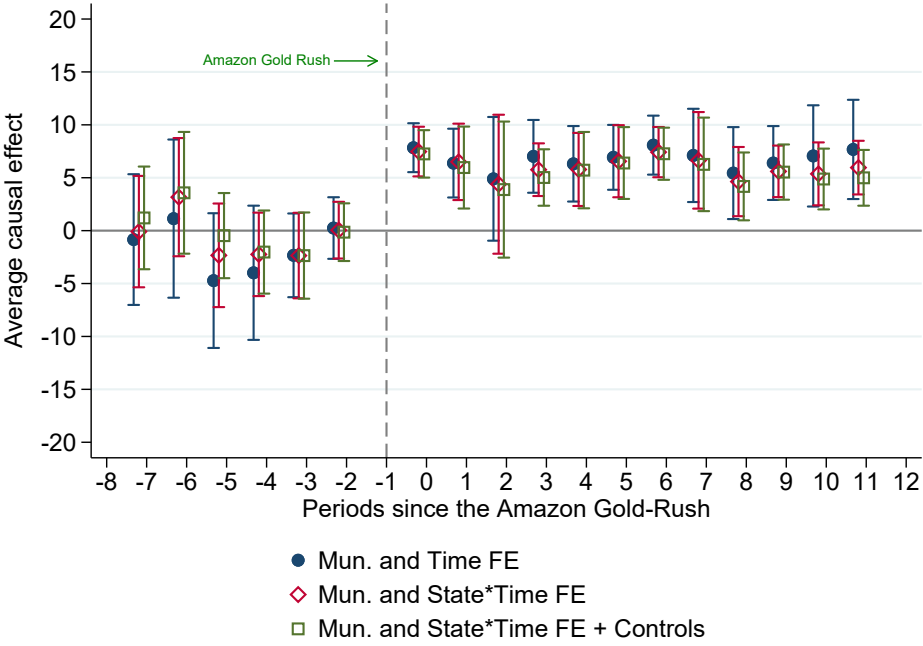
Note: This figure illustrates the mercury contamination levels in four commonly consumed fish species from the Brazilian Madeira River: “Pacu”, “Jaraqui”, “Curimatã”, and “Sardinha”. The data is based on river sample analyses conducted in 2015. (Source: Figure retrieved from Soares et al. (2018)).

Table A.1: Correlation between Brazilian Mercury Emissions from Artisanal Gold Mining and Infant Mortality Rates in the Amazon Region

	(1)	(2)	(3)	(4)	(5)
Mercury Emission	6.658* (3.961)	5.017*** (0.971)	2.719*** (0.685)	2.107*** (0.711)	2.359*** (0.752)
Control mean	[16.621]	[16.621]	[16.621]	[16.621]	[16.621]
R-squared	0.328	0.478	0.511	0.546	0.549
Observations	1,623	1,623	1,623	1,623	1,623
Mun. FE	✓	✓	✓	✓	✓
Year. FE	✓	✓	✓	✓	✓
Sample weights		✓	✓	✓	✓
State × Year. FE			✓	✓	✓
Basic Controls				✓	✓
Social Program Controls					✓

Note: This table presents correlation estimates of the effect of Brazilian mercury emissions from artisanal mining on infant mortality rates in the Brazilian Amazon rainforest at the municipality level, covering the period from 1997 to 2015. Values in parentheses are municipality cluster-robust standard errors. Control variables were omitted for space considerations. “Basic Controls” include population vaccination coverage, the local number of municipal environmental fines, and municipal per capita spending on health and education, along with GDP and agricultural GDP, both in logarithmic per capita terms. “Social Program Controls” include Bolsa Família and Programa Saúde da Família, both measured in per capita terms. The symbols *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively.

Figure A.4: Robustness Check - Timing Heterogeneity in the Effects of Gold Mining Pollution Exposure on Infant Mortality Rates



Note: This figure plots the results for the heterogeneous effects of the Amazon Gold Rush event (gold mining pollution exposure) on infant mortality rates. Each color represents a different econometric model, where all estimated coefficients within the same color come from the same regression. All regressions include sample weights. The confidence intervals are at the 95% level and are calculated in pointwise form using cluster-robust standard errors at the municipality level. The omitted category is the -1 period. The time interval for this analysis spans from 1997 to 2015 at the municipality level. “Mun.” is an abbreviation for the municipality. “Controls” refers to control variables, which include local population vaccination coverage, the number of Brazilian municipal environmental fines, municipal per capita health and educational spending, and Bolsa Família and Programa Saúde da Família allocations, both in per capita form. Additionally, GDP and agricultural GDP per capita are both expressed in logarithmic form.

Table A.2: Robustness Check - Impacts of Gold Mining Pollution Exposure on Infant Mortality Rates with Additional Control Variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Treated	6.605*** (1.487)	6.162*** (1.353)	6.159*** (1.350)	6.135*** (1.332)	5.911*** (1.273)	5.780*** (1.295)	5.764*** (1.261)	5.728*** (1.259)	5.743*** (1.243)
Brazilian Mun. Environmental Fines		486.307** (210.489)	487.376** (209.208)	484.794** (206.878)	498.970** (200.783)	452.470** (195.779)	387.650* (199.663)	354.464* (202.134)	376.804* (201.117)
Education Mun. Expenditure			-0.000 (0.002)	0.001 (0.002)	-0.001 (0.002)	-0.001 (0.002)	-0.001 (0.002)	-0.001 (0.002)	-0.001 (0.002)
Health Mun. Expenditure				-0.003 (0.004)	-0.002 (0.003)	-0.001 (0.003)	-0.001 (0.003)	-0.000 (0.003)	-0.001 (0.003)
PBF Mun. Cov.					28.450* (16.779)	23.478 (14.612)	23.126 (14.587)	15.970 (11.885)	22.807 (14.751)
PSF Mun. Cov.						9.302* (4.734)	8.403* (4.750)	6.400 (4.560)	8.412* (4.712)
Mun. Vaccines Cov.							10.172* (5.529)	10.761* (5.527)	10.282* (5.562)
Mun. GDP.								0.222 (0.170)	0.222 (0.170)
Mun. Agro. GDP.									0.240 (0.318)
Observations	1,674	1,623	1,623	1,623	1,623	1,623	1,623	1,623	1,623
R-squared	0.522	0.512	0.512	0.513	0.550	0.552	0.554	0.554	0.554

Note: This table contains the placebo estimation of the effect of the Amazon Gold Rush (gold mining pollution exposure) from 1997 to 2015 on the infant mortality rates in the Brazilian Amazon by adding the control variables in staggered form. "Treated" is the interaction between the post-period and the treatment dummy, which identifies the Brazilian municipalities affected. The last column follows the econometric model displayed in equation 1. Values in parentheses are the municipality cluster-robust standard errors. All regressions include sample weights as the fixed effects. The abbreviations of "cov." and "mun." are the acronyms for the terms "coverage" and "municipalities", respectively. The symbols *, ** and *** represent statistical significance at 10%, 5%, and 1% respectively.

Table A.3: Impacts of the Amazon Gold Rush on Women’s Fertility Rates

	(1)	(2)	(3)	(4)	(5)
Treated	-0.137 (1.414)	0.756 (1.605)	1.803 (1.342)	1.738 (1.109)	1.291 (1.112)
R-squared	0.428	0.503	0.539	0.602	0.631
Control mean	[19.276]	[19.276]	[19.276]	[19.276]	[19.276]
Observations	1,623	1,623	1,623	1,623	1,623
Mun. FE	✓	✓	✓	✓	✓
Year. FE	✓	✓	✓	✓	✓
Sample weights		✓	✓	✓	✓
State × Year. FE			✓	✓	✓
Basic Controls				✓	✓
Social Program Controls					✓

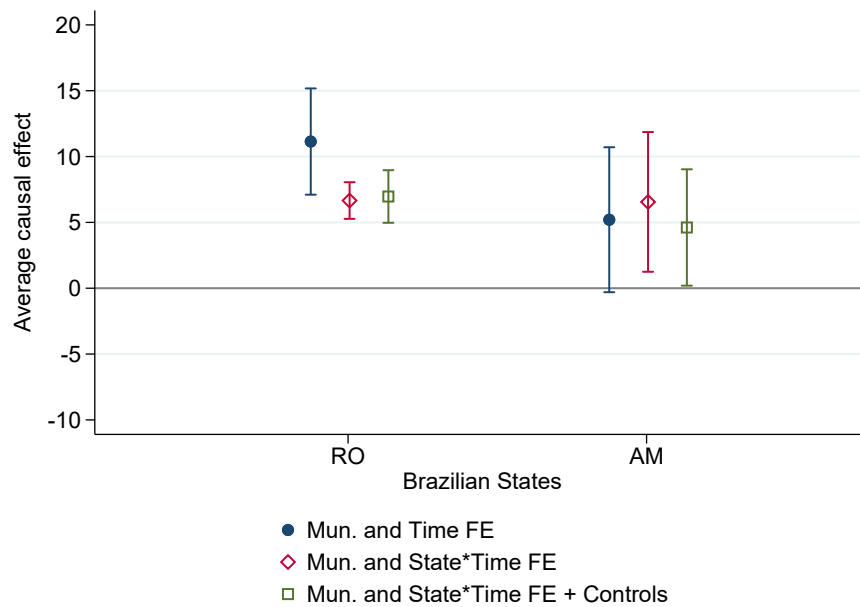
*Note: This table contains the estimation of the effect of the Amazon Gold Rush from 1997 to 2015 on women’s fertility. “Treated” is the interaction between the post-period and the treatment dummy, which identifies the Brazilian municipalities affected. Values in parentheses are the municipality cluster-robust standard errors. The econometric model follows equation 1. Control variables were omitted for space considerations. Control variables encompass population vaccination coverage, the number of municipal environmental fines, per capita municipal spending on health and education, GDP, and agrarian GDP per capita. Additionally, per capita allocations for Bolsa Familia and Programa Saúde da Familia are included as control variables. “Control mean”, values brackets, indicates the mean value of the outcome variable for the control group. The symbols *, **, and *** represent statistical significance at 10%, 5%, and 1% respectively.*

Table A.4: Placebo exercise - Effects of Amazon Gold Rush on infant mortality rates using similar rivers in proximity unaffected by the event

	(1)	(2)	(3)	(4)	(5)
Treated	-5.635 (8.282)	-2.203 (8.272)	-0.787 (8.284)	-0.752 (8.594)	-1.987 (8.378)
R-squared	0.329	0.469	0.498	0.528	0.533
Control mean	[16.203]	[16.203]	[16.203]	[16.203]	[16.203]
Observations	1,472	1,472	1,472	1,472	1,472
Mun. FE	✓	✓	✓	✓	✓
Year. FE	✓	✓	✓	✓	✓
Sample weights		✓	✓	✓	✓
State × Year. FE			✓	✓	✓
Basic Controls				✓	✓
Social Program Controls					✓

*Note: This table contains the placebo estimations of the effect of the Amazon Gold Rush (gold mining pollution exposure) from 1997 to 2015 on infant mortality rates in the Brazilian Amazon. Values in parentheses are the municipality cluster-robust standard errors. In placebo testing, both the Juruá and Tapajós Rivers are defined as treated (similar rivers in proximity unaffected by the event). The regional distribution of these rivers can be viewed in Figure A.1. Control variables were omitted for space considerations. Control variables encompass population vaccination coverage, the number of municipal environmental fines, and per capita municipal spending on health and education. Additionally, GDP and agricultural GDP per capita are both expressed in logarithmic form. Per capita allocations for Bolsa Família and Programa Saúde da Família are also included as control variables. “Control mean” values, in brackets, indicate the mean value of the outcome variable for the control group. The symbols *, **, and *** represent statistical significance at 10%, 5%, and 1% respectively.*

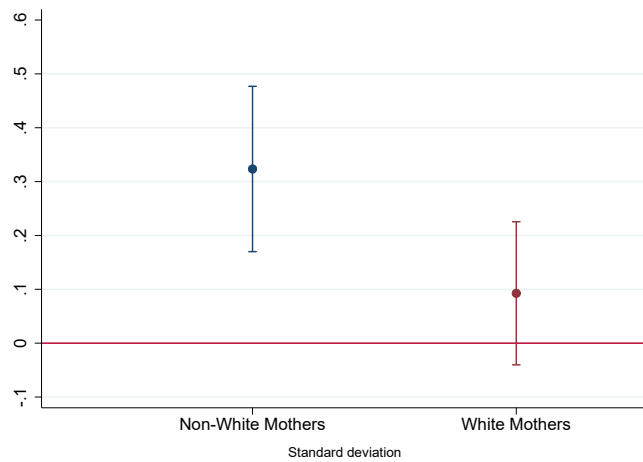
Figure A.5: Heterogeneous Effects of the Amazon Gold Rush on Infant Mortality Rates Across Brazilian States



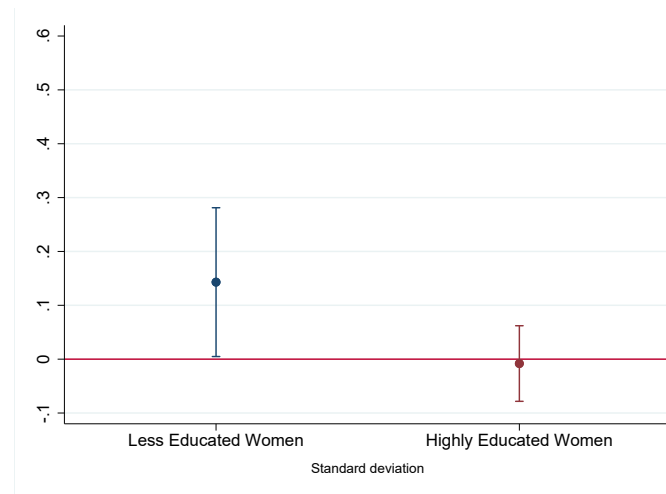
Note: This figure displays the results for the heterogeneous effects of the Amazon Gold Rush (gold mining pollution exposure) on infant mortality rates in different Brazilian states. Each color represents a different econometric model, where all estimated coefficients within the same color come from the same regression. The econometric model follows equation 1. All regressions include sample weights. Control variables encompass population vaccination coverage, the number of Brazilian municipal environmental fines, and per capita municipal spending on health and education. Additionally, GDP and agricultural GDP per capita are both expressed in logarithmic form. Per capita allocations for Bolsa Família and Programa Saúde da Família are also included as control variables. The confidence intervals are at the 95% level and are calculated in pointwise form using cluster-robust standard errors at the municipality level. The time interval for this analysis spans from 1997 to 2015 at the municipality level. “Mun.” is an abbreviation for municipality, and “Controls” refers to control variables.

Figure A.6: Heterogeneous Effects of the Amazon Gold Rush on Infant Mortality Rates by Mother's Educational Level and Race

Panel (A) - Pollution exposure by mother's race



Panel (B) - Pollution exposure by mother's education



Note: These two figures display the heterogeneous effects of the Amazon Gold Rush (gold mining pollution exposure) on infant mortality rates by different mothers' races in Panel (A) and by mothers' education in Panel (B). Each color represents a different econometric model within the figure. All regressions include sample weights. The confidence intervals are at the 95% level and calculated in pointwise form using cluster robust standard errors at the municipality level. The time interval for this analysis spans from 1997 to 2015 at the municipality level. All regressions include control variables from model 1, as well as the mother's age, mother's years of education, and municipality and year times state fixed effects.

Table A.5: Robustness Check - Additional Regressions for the Impact of Amazon Gold Rush (Gold Mining Pollution Exposure) on Infant Mortality Rates with Sample Restrictions

	(1)	(2)	(3)	(4)	(6)	(7)
	Excluding top 1% mort. observations	Excluding top 2 with highest population (Capitals)	Excluding AM states cities	Excluding RO states cities	Restrjing the sample for 1996 to 2010 (Symmetrical DID)	Restrjing the sample for 2003 to 2004 (2x2 DID)
Treated	5.758*** (1.462)	4.869** (2.442)	4.663** (1.765)	5.238*** (2.699)	5.695*** (2.133)	8.614*** (2.994)
R-squared	0.5944	0.3477	0.3857	0.3235	0.3932	0.7951
Control mean	[15.673]	[16.452]	[12.953]	[19.198]	[16.914]	[14.566]
Observations	1,657	1,822	896	1,135	1,449	182

*Note: This table contains the additional results for the Amazon Gold Rush (gold mining pollution exposure) on infant mortality rates using multiple sample restrictions. Values in parentheses are the municipality cluster-robust standard errors. The econometric model follows equation 1. “Treated” is the interaction between the post-period and the treatment dummy, which identifies the Brazilian municipalities affected. All regressions include year times states, municipality fixed effects, control variables, and sample weights. Control variables were omitted for space considerations. “Control mean”, values brackets, indicates the mean value of the outcome variable for the control group. Control variables encompass population vaccination coverage, the number of municipal environmental fines, per capita municipal spending on health and education, GDP, and agricultural GDP, both expressed per capita. Additionally, per capita allocations for Bolsa Familia and Programa Saúde da Familia are included as control variables. The symbols *, **, and *** represent statistical significance at 10%, 5%, and 1% respectively. The time interval for this analysis spans from 1997 to 2015 at the municipality level (depending on the column).*

Table A.6: Robustness Check - Effects of Amazon Gold Rush Exposure on Infant Mortality Rates by Maternal Education Level

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Less educated women					Higher educated women				
Treated	1.4447 (1.2621)	0.8467 (1.0676)	1.3541 (0.9723)	1.9520** (0.8557)	4.1590*** (1.310)	0.2046 (0.2280)	0.0901 (0.1454)	-0.1059 (0.145)	-0.1083 (0.119)	0.0713 (0.314)
Control mean	[11.085]	[11.085]	[11.085]	[11.085]	[11.085]	[0.6458]	[0.6458]	[0.6458]	[0.6458]	[0.6458]
Observations	1,860	1,674	1,478	1,478	1,478	1,860	1,674	1,478	1,478	1,478
Mun FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Year. FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sample weights		✓	✓	✓	✓		✓	✓	✓	✓
State × Year FE			✓	✓	✓			✓	✓	✓
Basic Controls				✓	✓				✓	✓
Social Program Controls					✓					✓

*Note: This table contains the estimation of the effect of the Amazon Gold Rush (gold mining pollution exposure) from 1997 to 2015 on infant mortality by different women's education levels in the Brazilian Amazon at the individual level. Columns (1) to (5) display the results for less educated women. Columns (6) to (10) display the results for women with a higher level of education. Specifically, for this exercise, the educational attainment of mothers was categorized into two groups. Higher Educated Women, denoting those with a college degree, and Less Educated Women, representing those without a college degree. Values in parentheses are the municipality cluster-robust standard errors. "Treated" is the interaction between the post-period and the treatment dummy, which identifies the Brazilian municipalities affected. The regression includes year times states, municipality fixed effects, and control variables. Control variables encompass population vaccination coverage, the number of municipal environmental fines, per capita municipal spending on health and education, GDP (expressed in logarithmic form), and agrarian GDP per capita. Additionally, per capita allocations for Bolsa Familia and Programa Saúde da Familia are included as control variables. "Control mean", values brackets, indicates the mean value of the outcome variable for the control group. The symbols *, **, and *** represent statistical significance at 10%, 5%, and 1% respectively.*

Table A.7: Potential Mechanisms of Amazon Gold Rush Exposure Effects on Health Outcomes

	(1)	(2)	(3)	(4)	(5)
	Child Birth Weight	Preterm	Low weight	Very low weight	Fetal growth rate
Treated	-58.789** (25.809)	0.0110 (0.011)	0.006* (0.003)	0.0011** (0.0003)	-1.198* (0.625)
Control mean	[3230.61]	[0.0682]	[0.0768]	[0.0089]	[83.585]
Observations	1,769,089	1,739,056	1,769,089	1,769,089	1,711,500

*Note: Note: This table contains the estimation of the effect of the Amazon Gold Rush (gold mining pollution exposure) from 1997 to 2015 on potential mechanisms in the Brazilian Amazon at the individual level. “Treated” is the interaction between the post-period and the treatment dummy, which identifies the Brazilian municipalities affected. Values in parentheses are the municipality cluster-robust standard errors. The econometric model follows equation 1. Control variables encompass population vaccination coverage, the number of municipal environmental fines, per capita municipal spending on health and education, GDP (expressed in logarithmic form), and agrarian GDP per capita. Additionally, per capita allocations for Bolsa Familia and Programa Saúde da Familia are included as control variables. “Control mean”, values brackets, indicates the mean value of the outcome variable for the control group. The symbols *, **, and *** represent statistical significance at 10%, 5%, and 1% respectively.*

Table A.8: Potential Mechanisms of Amazon Gold Rush Exposure Effects by Maternal Education Level

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Less educated Women					Higher educated Women				
	Child Birth Weight	Preterm	Low weight	Very low weight	Fetal growth rate	Child Birth Weight	Preterm	Low weight	Very low weight	Fetal growth rate
Treated	-82.301*** (33.114)	0.0154 (0.0118)	0.0073** (0.0036)	0.0009** (0.0004)	-1.611* (0.8306)	-23.973 (31.456)	-0.0067 (0.0184)	0.0057** (0.0024)	0.0024** (0.0011)	0.2606 (0.6406)
Control mean	[3221.13]	[0.0740]	[0.0768]	[0.0088]	[83.245]	[3241.71]	[0.0506]	[0.0754]	[0.0102]	[84.442]
Observations	1,441,116	1,418,541	1,441,116	1,441,116	1,405,062	265,797	259,844	265,797	265,797	248,802

*Note: This table contains the estimation of the effect of the Amazon Gold Rush (gold mining pollution exposure) from 1997 to 2015 on potential mechanisms in the Brazilian Amazon at the individual level. The econometric model follows equation 1. Columns (1) to (5) display the results for less educated women. Columns (6) to (10) display the results for women with a higher level of education. The regression includes year times states, municipality fixed effects, and control variables. "Treated" is the interaction between the post-period and the treatment dummy, which identifies the Brazilian municipalities affected. Control variables encompass population vaccination coverage, the number of municipal environmental fines, per capita municipal spending on health and education, GDP (expressed in logarithmic form), and agrarian GDP per capita. Additionally, per capita allocations for Bolsa Familia and Programa Saúde da Família are included as control variables. Values in parentheses are the municipality cluster-robust standard errors. 'Control mean' mean indicates the outcome variable for the control group. The symbols *, **, and *** represent statistical significance at 10%, 5%, and 1% respectively.*

Table A.9: Heterogeneous Effects of Amazon Gold Rush on Infant Mortality Across Brazilian States

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	State of Rondônia (RO)					State of Amazonas (AM)				
Treated	5.076*** (1.376)	6.662*** (0.717)	6.662*** (0.717)	6.388*** (0.601)	6.680*** (0.661)	5.003* (2.847)	6.555** (2.710)	6.555** (2.710)	6.243*** (2.293)	4.426* (2.395)
Control mean	[12.953]	[12.953]	[12.953]	[12.953]	[12.953]	[19.198]	[19.198]	[19.198]	[19.198]	[19.198]
Observations	634	634	634	634	634	989	989	989	989	989
Mun FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Year. FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sample weights		✓	✓	✓	✓		✓	✓	✓	✓
State × Year FE			✓	✓	✓			✓	✓	✓
Basic Controls				✓	✓				✓	✓
Social Program Controls					✓					✓

*Note: This table contains the estimation of the effect of the Amazon Gold Rush (gold mining pollution exposure) from 1997 to 2015 on the infant mortality rates in the Brazilian Amazon rainforest at the municipality level. The econometric model follows equation 1. “Treated” is the interaction between the post-period and the treatment dummy, which identifies the Brazilian municipalities affected. Values in parentheses are the municipality cluster-robust standard errors, while values brackets are the Wild-Bootstrap (WB) p-value. Control variables were omitted for space considerations. The regression includes year times states, municipality fixed effects, and control variables. Control variables encompass population vaccination coverage, the number of municipal environmental fines, per capita municipal spending on health and education, GDP (expressed in logarithmic form), and agrarian GDP per capita. Additionally, per capita allocations for Bolsa Família and Programa Saúde da Família are included as control variables. “Control mean”, values brackets, indicates the mean value of the outcome variable for the control group. The symbols *, **, and *** represent statistical significance at 10%, 5%, and 1% respectively.*

Table A.10: Effects of Amazon Gold Rush on Infant Mortality Rates by the Children Sex

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Infants - Girls					Infants - Boys				
Treated	1.520 (1.186)	3.106** (1.231)	2.438*** (0.723)	2.232*** (0.592)	2.192*** (0.613)	2.368** (1.128)	5.030*** (1.548)	4.077*** (0.847)	3.624*** (0.701)	3.460*** (0.706)
Control mean	[7.213]	[7.213]	[7.213]	[7.213]	[7.213]	[9.119]	[9.119]	[9.119]	[9.119]	[9.119]
Observations	1,623	1,623	1,623	1,623	1,623	1,623	1,623	1,623	1,623	1,623
Mun FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Year. FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sample weights		✓	✓	✓	✓		✓	✓	✓	✓
State × Year FE			✓	✓	✓			✓	✓	✓
Basic Controls				✓	✓				✓	✓
Social Program Controls					✓					✓

*Note: This table contains the estimation of the effect of the Amazon Gold Rush (gold mining pollution exposure) from 1997 to 2015 on the infant mortality rates by the children sex in the Brazilian Amazon rainforest at the municipality level. The econometric model follows equation 1. “Treated” is the interaction between the post-period and the treatment dummy, which identifies the Brazilian municipalities affected. Values in parentheses are the municipality cluster-robust standard errors at the municipality level. Control variables were omitted for space considerations. “Control mean”, values brackets, indicates the mean value of the outcome variable for the control group. The regression includes year times states, municipality fixed effects, and control variables. Control variables encompass population vaccination coverage, the number of municipal environmental fines, per capita municipal spending on health and education, GDP (expressed in logarithmic form), and agrarian GDP per capita. Additionally, per capita allocations for Bolsa Familia and Programa Saúde da Família are included as control variables. The symbols *, **, and *** represent statistical significance at 10%, 5%, and 1% respectively.*

Table A.11: Potential Mechanisms of Amazon Gold Rush Effects on Infant Health by Brazilian States

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	State of Rondônia (RO)					State of Amazonas (AM)				
	Child Birth Weight	Preterm	Low weight	Very low weight	Fetal growth rate	Child Birth Weight	Preterm	Low weight	Very low weight	Fetal growth rate
Treated	-94.397*** (14.451)	0.0286*** (0.0082)	0.0088*** (0.0023)	0.0004 (0.0006)	-2.212*** (0.3302)	-3.5675 (12.662)	-0.0302 (0.0194)	0.0035 (0.0023)	0.0004 (0.0029)	-0.0005 (0.0006)
Control mean	[3255.89]	[0.0740]	[0.0768]	[0.0088]	[83.245]	[3241.71]	[0.0506]	[0.0754]	[0.0102]	[0.0096]
Observations	467,810	467,810	467,810	467,810	467,810	1,291,479	1,291,479	1,291,479	1,291,479	1,291,479

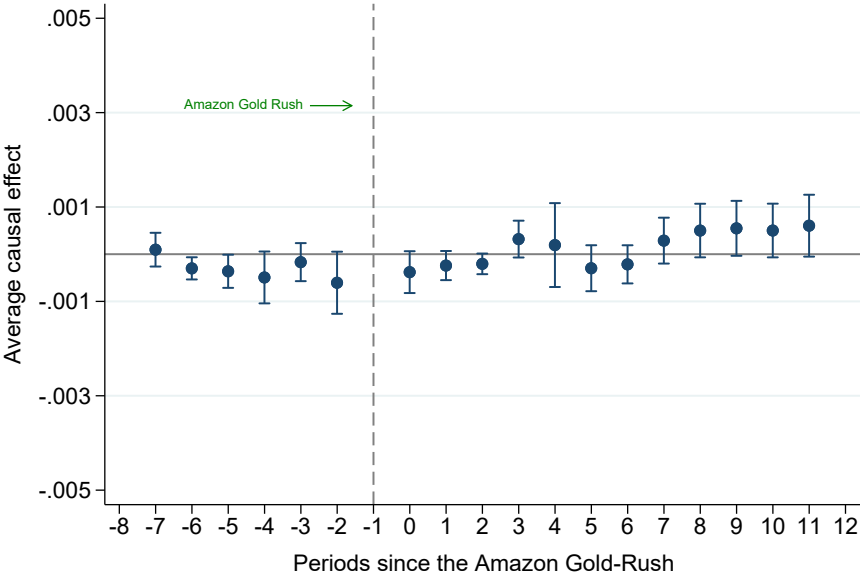
*Note: This table contains the estimation of the effect of the Amazon Gold Rush (gold mining pollution exposure) from 1997 to 2015 on potential mechanisms in the Brazilian Amazon at the individual level by the Brazilian States. The econometric model follows 1, where each column represents a different outcome variable. The regression includes year times states, municipality fixed effects, and control variables. Control variables encompass population vaccination coverage, the number of municipal environmental fines, per capita municipal spending on health and education, GDP (expressed in logarithmic form), and agrarian GDP per capita. Additionally, per capita allocations for Bolsa Familia and Programa Saúde da Família are included as control variables. All regressions include sample weights. "Treated" is the interaction between the post-period and the treatment dummy, which identifies the Brazilian municipalities affected. Columns (1) to (5) display the results for less educated women. Columns (6) to (10) display the results for women with a higher level of education. Values in parentheses are the municipality cluster-robust standard errors. "Control mean", values brackets, indicates the mean value of the outcome variable for the control group. The symbols *, **, and *** represent statistical significance at 10%, 5%, and 1% respectively.*

Table A.12: Effects of Amazon Gold Rush Exploring the Mechanisms of Holy Week as a Period of Increased Contaminated Fish Consumption on Infant Mortality Rates

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Non-Gestational Exposure to Holy Week					Gestational Exposure to Holy Week				
Treated	0.418 (0.578)	1.753** (0.738)	1.293*** (0.378)	1.273*** (0.341)	1.246*** (0.351)	3.464** (1.742)	6.545*** (2.105)	5.311*** (1.161)	4.675*** (0.913)	4.497*** (0.950)
Control mean	[7.213]	[7.213]	[7.213]	[7.213]	[7.213]	[9.119]	[9.119]	[9.119]	[9.119]	[9.119]
Observations	1,623	1,623	1,623	1,623	1,623	1,623	1,623	1,623	1,623	1,623
Mun FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Year. FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sample weights		✓	✓	✓	✓		✓	✓	✓	✓
State × Year FE			✓	✓	✓			✓	✓	✓
Basic Controls				✓	✓				✓	✓
Social Program Controls					✓					✓

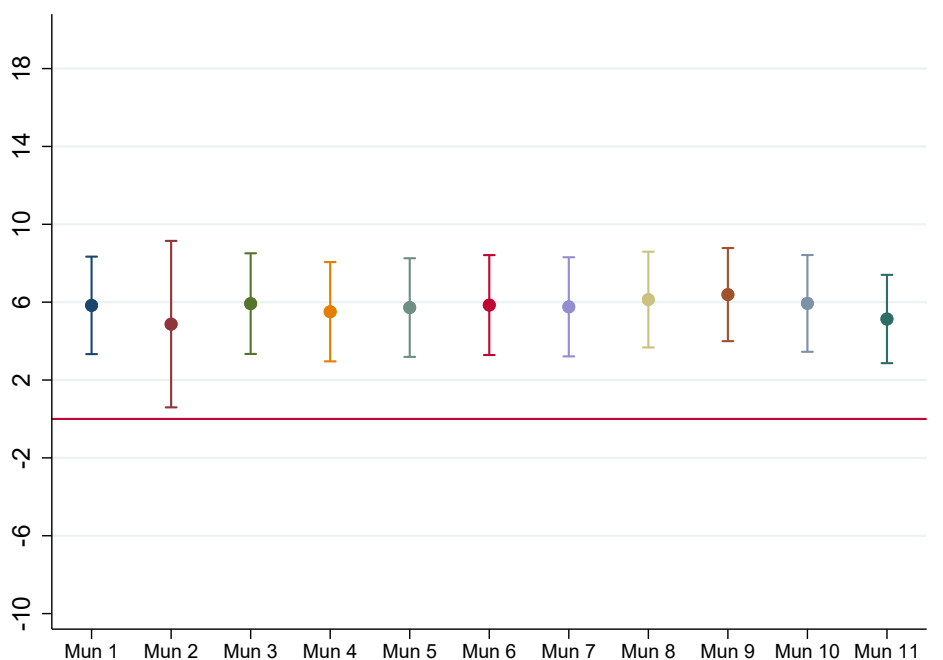
Note: This table presents the estimated effect of the Amazon Gold Rush (gold mining pollution exposure) from 1997 to 2015 on infant mortality rates in the Brazilian Amazon rainforest at the municipality level. “Holy Week exposure” refers to periods during and around Holy Week, a time associated with increased consumption of locally sourced, potentially contaminated fish. The econometric model follows equation 1. “Treated” represents the interaction between the post-period and the treatment dummy, identifying the Brazilian municipalities affected by gold mining pollution. Standard errors, clustered at the municipality level, are shown in parentheses. The “Control mean” values (in brackets) represent the mean outcome for the control group. The model includes municipality-fixed effects, state-year fixed effects, and additional control variables, which include vaccination coverage, municipal environmental fines, per capita spending on health and education, GDP (in logarithmic form), agrarian GDP per capita, and per capita allocations for the Bolsa Família and Programa Saúde da Família. Statistical significance levels are indicated by * $p < 0.10$, ** $p < 0.05$, and *** $p < 0.01$.

Figure A.7: Effects of Amazon Gold Rush in Brazilian Municipalities Environmental Fines



Note: This figure presents the timing of heterogeneous effects of the Amazon Gold Rush (gold mining pollution exposure) on Brazilian environmental fines per capita from 1997 to 2015, measured in thousands of Reais. The econometric model follows equation 2, where all estimated coefficients come from the same regression. The regression includes year-by-state interactions, municipality-fixed effects, control variables, and sample weights. Control variables encompass population vaccination coverage and per capita municipal spending on health and education. Additionally, GDP and agricultural GDP per capita are both expressed in logarithmic form. Per capita allocations for Bolsa Familia and Programa Saúde da Família are also included as control variables. The confidence intervals are at the 95% level and are calculated in pointwise form using cluster-robust standard errors at the municipality level. The omitted category is the -1 period.

Figure A.8: Robustness Check - Effects of Amazon Gold Rush Effects on Infant Mortality Rates using a Sequential Exclusion of Treated Municipalities



Note: This figure plots the results from the additional exercises of the effects of the Amazon Gold Rush (gold mining pollution exposure) on infant mortality rates by excluding one treated municipality at a time (sequential exclusion of treated municipalities). Each estimated coefficient comes from a distinct regression. The econometric model used is displayed in equation 1. All regressions include year-by-state interactions, municipality-fixed effects, control variables, and sample weights. Control variables encompass population vaccination coverage, the number of Brazilian municipal environmental fines, and per capita municipal spending on health and education. Additionally, GDP and agricultural GDP per capita are both expressed in logarithmic form. Per capita allocations for Bolsa Família and Programa Saúde da Família are also included as control variables. The confidence intervals are at the 95% level and are calculated in pointwise form using cluster-robust standard errors at the municipality level.

10 Appendix B - Variables Definition

Variables Definition

In this subsection, we present a detailed overview of the key variables used in our empirical analysis, intending to provide clarity on their definitions and categorization. These variables play a central role in our econometric models, serving to capture both the primary treatment effects and various health-related outcomes of interest. Table [A.13](#) organizes these variables into four main categories for ease of reference and comprehension.

Treatment Variable. The first category pertains to the treatment variable, referred to as “Treated” This binary variable indicates whether a municipality is exposed to mercury contamination due to the Amazon Gold Rush. A value of 1 signifies that the municipality is located along the Madeira River and is downstream from the mining activities in the Madre de Dios region. In contrast, a value of 0 denotes municipalities outside the contamination zone. This variable is central to identifying the causal impact of gold mining on infant health outcomes in our difference-in-differences framework.

Mortality Dependent variables. The second category focuses on the dependent variables related to infant mortality, which captures the adverse health outcomes associated with exposure to mercury pollution. These variables include both overall infant mortality rates and fetal mortality rates, allowing us to measure the broader and more specific effects of environmental contamination on vulnerable populations. Each mortality variable is expressed per thousand live births to standardize the outcomes across municipalities and facilitate comparability.

Additional Dependent Variables. The third category covers **dependent variables** related to infant health, which provides further insights into the broader health impacts of gold mining pollution. These variables include birth weight, gestational length, and other neonatal health indicators, such as the incidence of low birth weight and preterm births. These health measures

allow us to assess potential mercury exposure’s more subtle, yet equally important, consequences on infant development during gestation. The health indicators are designed to capture both acute and chronic impacts, offering a comprehensive view of how pollution affects the physical well-being of infants.

Control and Additional Variables. Finally, the fourth category consists of control variables. These variables are critical for isolating the treatment effect from other confounding factors that might influence infant mortality or health outcomes. The control variables include a set of municipality-level characteristics that vary over time, such as population coverage by the government cash-transfer program *Bolsa Família*, population coverage by the primary healthcare program *Programa Saúde da Família*, municipal spending on education and culture, vaccination coverage rates, and municipal environmental fines. Additionally, economic indicators such as GDP per capita and agricultural GDP per capita are included to account for the broader economic conditions in each municipality. All control variables are expressed in per capita terms to standardize the data across different population sizes.

Moreover, the additional variables in Panel (D) of Table [A.13](#) focus on potential mechanisms of mercury exposure and its downstream effects. These include measurements of airborne mercury from artisanal gold mining, which serve as a proxy for environmental contamination. Agricultural variables, such as total harvested area, total rice, total corn, harvested soybeans, temporary crops, and milk production, are included to examine the impact of mercury pollution on agricultural productivity. The inclusion of these variables highlights the potential indirect effects of the Amazon Gold Rush on local economies, as mercury contamination degrades essential agricultural resources and impacts livestock. Together, these additional variables provide valuable insights into the broader implications of mercury exposure, linking environmental degradation to economic and public health outcomes in affected regions.

By structuring the variables into these four categories, we ensure a comprehensive and transparent presentation of the data used in our empirical exercises. This categorization also high-

lights the diverse range of outcomes and controls incorporated into the analysis, reinforcing the robustness of our identification strategy and the depth of our investigation into the health impacts of mercury contamination from gold mining activities.

Table A.13: Description of the dataset variables - treatment, dependent, and control variables

	Panel (A) - <i>Treatment Variable</i>	Database Source
Treatment	1 If the municipality receives its water supply directly from the Madeira River, 0 otherwise	Administrative data
<i>Panel (B) - Infant Mortality Dependent Variables</i>		
Infant Mortality Rate (IMR)	Number of deaths of Infants under one year of age (per 1,000 live new births)	Sinasc/SIM
Fetal Mortality Rate (FMR)	Number of fetal deaths of Infants (per 1,000 live births)	Sinasc/SIM
Neonatal Mortality Rate (NMR)	Number of neonatal deaths (per 1,000 live new births)	Sinasc/SIM
Infant Mortality in 24hs Rate	Number of deaths Infants in 24 hours (per 1,000 live new births)	Sinasc/SIM
Infant Mortality in first-week Rate	Number of deaths Infants in the first week of life (per 1,000 live new births)	Sinasc/SIM
Infant Mortality in 7d-27d Rate	Number of deaths Infants 7 to 27 days (per 1,000 live new births)	Sinasc/SIM
Infant Mortality in 27d-1y Rate	Number of deaths Infants 27 days to 1 year (per 1,000 live new births)	Sinasc/SIM
Respiratory IMR	Number of infant deaths by respiratory causes (per 1,000 live new births)	Sinasc/SIM
Congenital IMR	Number of infant deaths by congenital causes (per 1,000 live new births)	Sinasc/SIM
Infectious IMR	Number of infant deaths by respiratory causes (per 1,000 live new births)	Sinasc/SIM
Nutritional IMR	Number of infant deaths by nutritional causes (per 1,000 live new births)	Sinasc/SIM
Circulatory IMR	Number of infant deaths by circulatory causes (per 1,000 live new births)	Sinasc/SIM
External IMR	Number of infant deaths by external causes (per 1,000 live new births)	Sinasc/SIM
Others Cause IMR	Number of infant deaths by other causes (per 1,000 live new births)	Sinasc/SIM
Non-classified Causes IMR	Number of infant deaths by non-classified causes (per 1,000 live new births)	Sinasc/SIM
<i>Panel (C) - Infant Health Dependent Variables</i>		
Child Birth Weight Rate	Average birth weight per total number of infant	SIM/Datasus
Preterm	Number of infants that are born with less than 37 weeks per total number of infants	Sinasc/Datasus
Low birth weight (<2500g)	Number of infants that are born with less than 2500 grams per total number of infant	Sinasc/Datasus
Very Low birth weight (<1500g)	Number of infants that are born with less than 1500 grams per total number of infants	Sinasc/Datasus
Fetal Growth rate	Childbirth weight per gestational period of infants	Sinasc/Datasus
Prenatal care rate	Number of infants that did prenatal care in gestational period per total number of infants	Sinasc/Datasus
<i>Panel (D) - Control and Additional Variables</i>		
Programa Saúde da Família	Number of families coverage by Programa Saúde da Família per total of families	Ipeadata
Bolsa Família Program	Number of families covered by Programa Bolsa Família per total of families	Ipeadata
Mun. educ. and cult. expenditure	Municipal educational and culture expenditure per total of the population	Ipeadata
Brazilian environmental fines	Number of environmental fines per total of the population	Ipeadata
GDP per capita	Number of the GDP per total of the population	IBGE
Agro GDP per capita	Number of the agricultural GDP per total of the population	IBGE
Agro GDP per capita	Number of the agricultural GDP per total of the population	IBGE
Airborne Mercury Particulars	Number of the Airborne Mercury Particulars from Artisanal mining in Brazilian side	EDGAR
Total Harvested Area	Total municipality area of land used for crop harvesting	Ipeadata
Total Rice	Total municipality area harvested for rice	Ipeadata
Total Corn	Total municipality area harvested for corn	Ipeadata
Harvested Soybeans	Total municipality area harvested for soybeans	Ipeadata
Temporary Crops	Total municipality area used for temporary crops	Ipeadata
Total Cattle (per capita)	Total number of cattle divided by the population	Ipeadata
Milk (cows per capita)	Total Milk municipality Cow divided by the population	Ipeadata
Milk Production	Total municipality milk production divided by the population	Ipeadata

Note: These variables correspond to some of the variables in the panel data defined in the first paper table. Panel (A) provides the definition of our treatment status. Panel (B) provides the definition of all infant mortality rate outcome variables. “IMR” is the acronym for Infant Mortality Rate. All mortality outcomes are expressed as rates per thousand new births. Panel (C) provides the definition of the other infant health indicators used as dependent variables. Panel (D) provides the definition of the control and other supplementary variables used in robustness check exercise. The variables may vary according to each specification of analysis. Note that the “treatment” variable indicates whether a municipality receives its water supply directly from the Madeira River. The “treated” variable is the interaction of this treatment variable with the post-2004 period.

11 Appendix C - Robustness check from the main results using different control groups

In our main econometric analysis, we operate under the assumption that there are no significant spillover effects or contamination of treatment effects within the control group. However, given the geographic scope and potential for environmental spillovers from the Amazon Gold Rush, it is plausible that nearby municipalities, even those considered part of the control group, may have experienced some indirect effects. To rigorously investigate for this possibility, we conduct a series of robustness checks by replicating the core exercises from the main manuscript with different compositions of control groups. This approach, detailed in Figure A.9, allows us to systematically explore the influence of geographical proximity and distance from the Madeira River on the validity of our control group selection, ultimately ensuring the robustness of our estimates.

The primary framework in the manuscript involves in defining red-colored municipalities as the treatment group (comprising 11 municipalities), which were directly affected by the Amazon Gold Rush. The control group, represented in green (comprising 105 municipalities), consists of municipalities that were theoretically unaffected by the event. Nevertheless, some of these green municipalities may have been indirectly exposed to the treatment due to their proximity to the treated areas, particularly through environmental pathways such as waterborne mercury contamination. To visually account for this, we classify the first and second nearest neighbor municipalities within the control group as potentially affected: the first nearest neighbor municipalities are shown in purple, while the second nearest neighbor municipalities are displayed in beige.

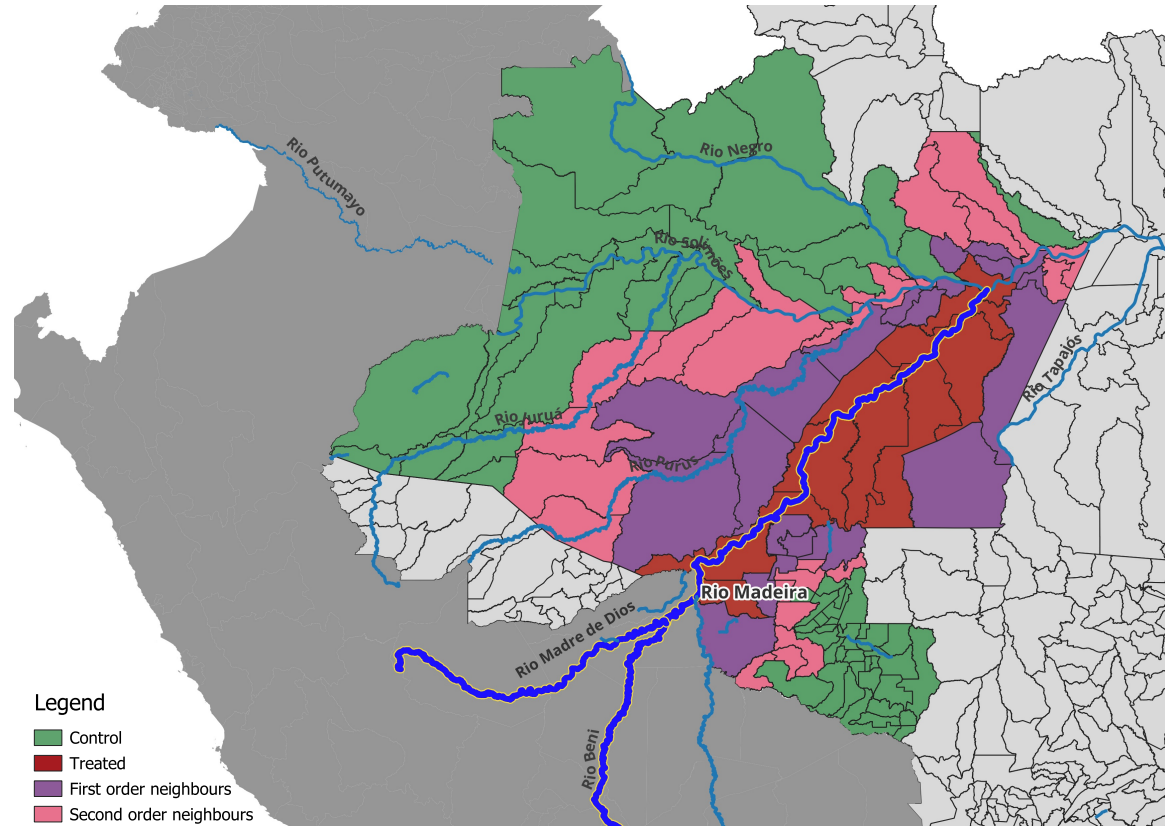
Recognizing that such spillovers could compromise the validity of our control group, we proceed to refine our analysis by excluding these potentially contaminated control areas. Specifically, we modify the control group by sequentially excluding (i) first nearest neighbor municipalities and (ii) second nearest neighbor municipalities from the control group. This approach

ensures that any indirect effects arising from proximity to treated municipalities do not bias our identification, thereby improving the reliability of the counterfactual comparison.

The adjusted control groups are reflected in Figures A.10 and A.11, and the corresponding results are presented in columns (2) and (3) of Table A.14. The results across all specifications remain remarkably consistent with those obtained using the original control group, suggesting that spillover effects from the Amazon Gold Rush are either negligible or well-contained within the directly treated municipalities. Moreover, the robustness of our findings across these different control group compositions strongly reinforces the validity of our identification strategy. The stability of the estimates indicates that the municipalities in the control group were not significantly affected by the spillover impacts of the event, thus confirming the integrity of our causal estimates.

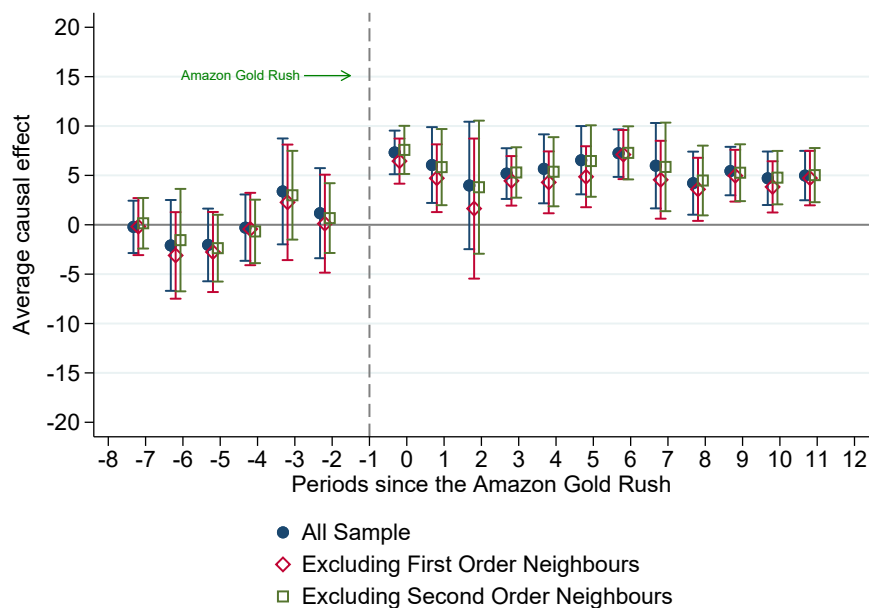
In conclusion, by accounting for potential contamination and spillover effects through robustness checks with varied control group compositions, we bolster the credibility of our identification strategy, and as consequence our results interpretation. This thorough approach further substantiates our claim that the adverse health impacts observed in the treated municipalities are a direct consequence of mercury pollution from the Amazon Gold Rush, rather than an artifact of indirect effects or flawed control group selection.

Figure A.9: Geographical Context - Distribution of Brazilian municipalities, their principal rivers within the Amazon Rainforest, and the Gold Rush treatment status using different control groups



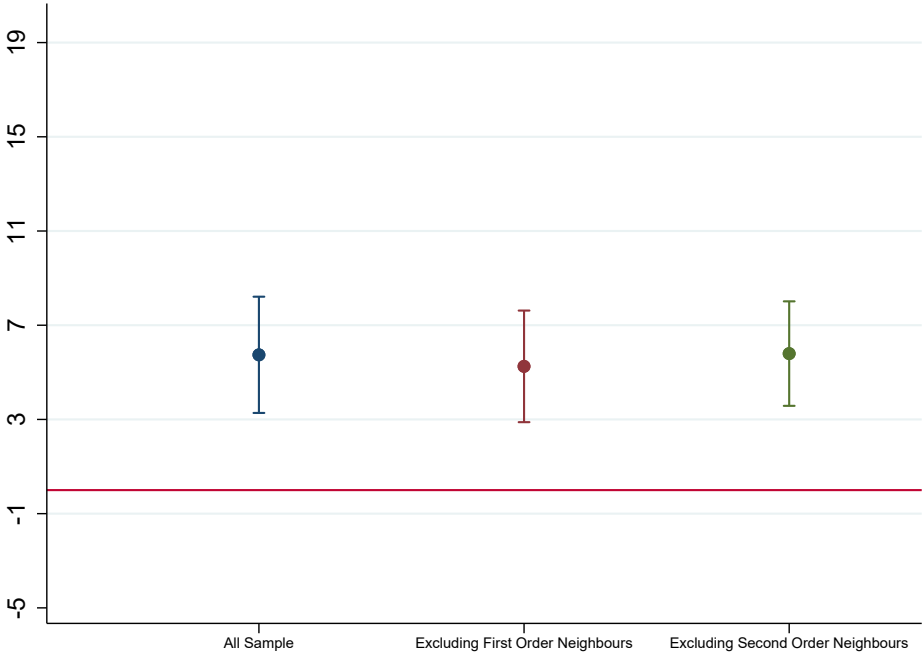
Note: This map was created by the authors. This figure depicts the map of the Amazon River drainage basin in South America, including parts of Brazil, Bolivia, Colombia, Ecuador, and Peru, with the Brazilian Madeira River, Beni, and the Madre de Dios Basin highlighted. Red municipalities represent those defined as “Treated” observations (11 municipalities) and were affected by the Madre de Dios Gold Rush. Green municipalities serve as “Control” observations (105 municipalities) and were unaffected by the event. Purple municipalities are those classified as first-order neighbors. Beige municipalities are those classified as second-order neighbors. Gray municipalities are those for which we do not use data.

Figure A.10: Robustness Check - Timing Heterogeneous Effects of Gold Mining Pollution Exposure on Infant Mortality Rates Across Different Control Groups



Note: This figure plots the results for the heterogeneous effects of the Amazon Gold Rush event on infant mortality rates (Brazilian municipalities gold mining pollution exposure) varying the control group. The econometric model used is displayed in equation 2. Each color represents a different control group, where all estimated coefficients within the colors come from the same regression. All regressions include municipality, year times state fixed effects, and control variables. Control variables encompass population vaccination coverage, the number of municipal environmental fines, per capita municipal spending on health and education, GDP (expressed in logarithmic form), and agrarian GDP per capita. Additionally, per capita allocations for Bolsa Familia and Programa Saúde da Família are included as control variables. The omitted category is the -1 period. All regressions include sample weights. The confidence interval is at 95% and calculated in pointwise form using cluster robust standard error at the municipality level. There are three different control groups (see text). The time interval for this analysis spans from 1997 to 2015 at the municipality level.

Figure A.11: Robustness Check - Effects of Gold Mining Pollution Exposure on Infant Mortality Rates Across Different Control Groups



Note: This figure plots the results for the effects of the Amazon Gold Rush on infant mortality rates using different control groups. Each color represents a different control group, where all estimated coefficients within the colors come from the same regression. Particularly in those specifications, we do not include control variables due to the sample size of the control groups. The econometric model for each one of the models estimated follows equation 1. Control variables encompass population vaccination coverage, the number of municipal environmental fines, per capita municipal spending on health and education, GDP (expressed in logarithmic form), and agrarian GDP per capita. Additionally, per capita allocations for Bolsa Familia and Programa Saúde da Família are included as control variables. All regressions include sample weights. The confidence interval is at 95% and calculated in pointwise form using cluster robust standard error at the municipality level. There are three different control groups (see text). The time interval for this analysis spans from 1997 to 2015 at the municipality level.

Table A.14: Robustness check - Effects of gold mining pollution exposure on infant mortality rates using different control groups

	(1)	(2)	(3)
	All Sample	Without First Neighbors	Without Second Neighbors
Treated	5.743*** (1.243)	5.253*** (1.190)	5.795*** (1.113)
Control mean	[16.475]	[17.048]	[16.390]
Observations	1,623	1,353	1,262

*Note: This table contains the estimation of the effect of the Amazon Gold Rush from 1997 to 2015 on the infant mortality rates in the Brazilian Amazon rainforest at the municipality level by different control groups. Each column represents a different control group. This context can be seen in Figure A.9. The econometric model follows equation 1. “Treated” is the interaction between the post-period and the treatment dummy, which identifies the Brazilian municipalities affected. Values in parentheses are the municipality cluster-robust standard errors. Control variables were omitted for space considerations. “Control mean”, values brackets, indicates the mean value of the outcome variable for the control group. Control variables encompass population vaccination coverage, the number of municipal environmental fines, per capita municipal spending on health and education, GDP (expressed in logarithmic form), and agrarian GDP per capita. Additionally, per capita allocations for Bolsa Familia and Programa Saúde da Familia are included as control variables. The symbols *, **, and *** represent statistical significance at 10%, 5%, and 1% respectively.*

12 Appendix D - Holy Week, Potential Contaminated Fish Consumption, and Mercury Exposure

Holy Week (*Semana Santa* in Portuguese) is a significant religious observance in Brazil, celebrated with customs and traditions leading up to Easter Sunday. With deep roots in Catholic and Christian communities across Latin America, Holy Week holds particular cultural importance in Brazil. Notably, it includes practices that discourage meat consumption, prompting many to substitute fish for meat. This widespread tradition results in a marked increase in fish consumption, influenced by cultural factors and the increased availability of fish in restaurants, markets, street fairs, and other informal sales channels, further driving population consumption.

In Brazil, Holy Week typically falls in March or April, with its timing determined by the lunar calendar as the first Sunday following the Paschal full moon (the first full moon after the spring equinox in the Northern Hemisphere). Although the exact dates vary annually, this period consistently influences dietary habits nationwide, especially in riverside and coastal regions where fresh fish is readily available. This seasonal shift provides a natural experiment for studying mercury exposure mechanisms, as the increase in fish consumption during Holy Week offers a unique opportunity to examine the pathways through which dietary shifts elevate mercury exposure.

In our analysis, Holy Week serves as an exogenous factor that increases fish consumption, allowing us to isolate a key pathway of mercury exposure during early pregnancy. We hypothesize that this seasonal dietary shift elevates mercury exposure among pregnant women in regions affected by mining-related water contamination, thereby increasing the risk of adverse health outcomes for infants. This measure serves as a proxy for mercury exposure linked to fish consumption in polluted regions, capturing the seasonal effect of this dietary behavior. By comparing gestational Holy Week exposure in affected regions to periods of no exposure, we evaluate the differential impact of increased fish consumption on adverse infant health outcomes, such as infant mortality rates and delivery metrics like birth weight. This framework enables us to

assess whether the seasonal increase in fish consumption during Holy Week intensifies the adverse health effects of mercury exposure on infants, underscoring Holy Week as a critical period when dietary customs amplify mercury’s impact on infant health.

Using Holy Week as a proxy, we capture the effects of mining contamination, as mercury-laden fish are likely consumed during this time. The robustness of this approach lies in the broad adherence to dietary customs and the consistency of Holy Week, enabling us to examine the link between increased fish consumption and mercury exposure impacts on infant health. Table A.15 presents the dates of Holy Week from 1996 to 2015, illustrating the timing variation across years. This variation offers a unique exogenous factor for our empirical analysis. As Holy Week’s timing shifts each year due to the lunar calendar, it provides a consistent influence on dietary practices during early gestation across Brazil’s diverse demographics.

Leveraging this temporal variability, we conduct additional empirical analyses to isolate the causal impact of increased fish consumption during early pregnancy on mercury exposure. Our approach treats Holy Week as a natural experiment, where the increase in fish consumption serves as an instrumental variable for mercury exposure. These results highlight Holy Week’s regularity, allowing us to identify periods when dietary shifts likely increase exposure, providing robust evidence for analyzing mercury exposure’s health impacts in the context of gold mining pollution.

Figures A.12 to A.15 present additional analyses using gestational exposure to Holy Week as a mechanism for elevated mercury contamination risk. Across these figures, nearly all categories of infant mortality and birth weight exhibit more pronounced adverse effects under gestational exposure. This is evident when comparing the estimated outcomes for gestational Holy Week exposure, shown in red, with those for non-gestational exposure, shown in green. For instance, Figure A.12 reveals a striking impact of the Amazon Gold Rush on infant mortality rates during gestational Holy Week exposure, with rates higher in magnitude than those observed for non-gestational exposure. These findings indicate that Holy Week significantly amplifies mercury exposure risks, likely due to the traditional surge in fish consumption during this period.

A similar pattern appears in Figure A.13, which examines heterogeneous effects on infant mortality rates based on proximity to the Brazilian Bordering, further stratified by Holy Week exposure. Results indicate a more intense adverse outcomes linked to the mercury contamination risk, with red coefficients (gestational exposure) consistently showing larger impacts on mortality rates than green coefficients (non-gestational exposure).

Moreover, Figure A.14 illustrates the heterogeneous effects of the Amazon Gold Rush on birth weight, using Holy Week as a mechanism across different maternal categories. This figure offers a detailed perspective on how gestational exposure to mercury pollution—particularly during Holy Week, when fish consumption increases—affects birth weight across various maternal demographics. While there is a slight reduction in the difference between the red and green coefficients, the effect of gestational exposure (red coefficients) remains more pronounced than non-gestational exposure. These findings underscore the persistent negative impact of mercury exposure during Holy Week on infant health outcomes.

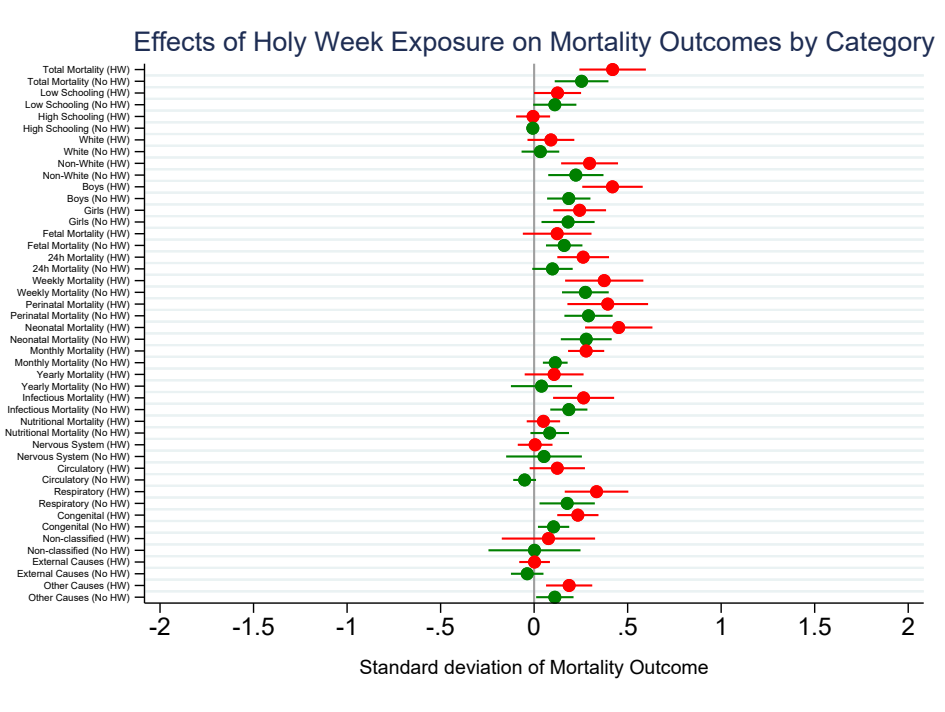
Finally, Figure A.15 displays coefficients for each trimester of gestational exposure, capturing impacts from the first, second, and third trimesters separately, allowing us to identify which trimester is most strongly associated with adverse infant mortality outcomes. The heightened fish intake during Holy Week appears to exacerbate mercury exposure, intensifying health risks for newborns in riverside communities.

Table A.15: Holy Week Dates from 1996 to 2015

Holy Week Dates by Year (from 1996 to 2015)		
Year	Palm Sunday Beginning of the Holy-week	Easter Sunday Ending of the Holy-week
1996	1996-03-31	1996-04-07
1997	1997-03-23	1997-03-30
1998	1998-04-05	1998-04-12
1999	1999-03-28	1999-04-04
2000	2000-04-16	2000-04-23
2001	2001-04-08	2001-04-15
2002	2002-03-24	2002-03-31
2003	2003-04-13	2003-04-20
2004	2004-04-04	2004-04-11
2005	2005-03-20	2005-03-27
2006	2006-04-09	2006-04-16
2007	2007-04-01	2007-04-08
2008	2008-03-16	2008-03-23
2009	2009-04-05	2009-04-12
2010	2010-03-28	2010-04-04
2011	2011-04-17	2011-04-24
2012	2012-04-01	2012-04-08
2013	2013-03-24	2013-03-31
2014	2014-04-13	2014-04-20
2015	2015-03-29	2015-04-05

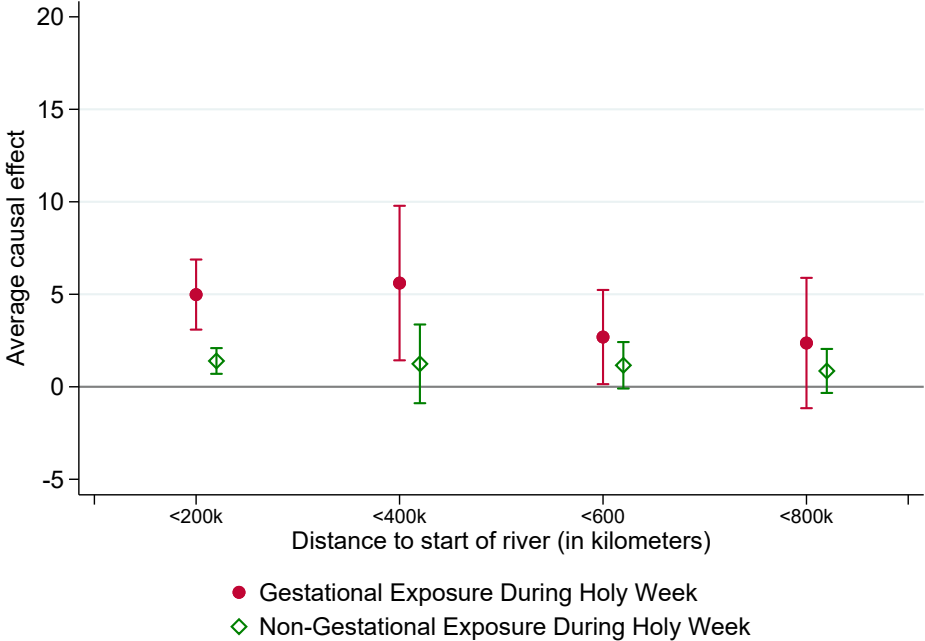
Note: This table provides the Holy Week dates from 1996 to 2015, starting with Palm Sunday and ending on Easter Sunday. Holy Week is observed following the first full moon after the spring equinox, causing its dates to shift each year. For this analysis, Holy Week serves as a culturally significant period associated with heightened fish consumption, providing insight into behavioral patterns that may influence health outcomes, particularly in regions where fish is a primary protein source and potential mercury contamination is a concern.

Figure A.12: Heterogeneous Effects of the Amazon Gold Rush on Infant Mortality Rates using Holy Week as a Mechanism across Infant Mortality Categories



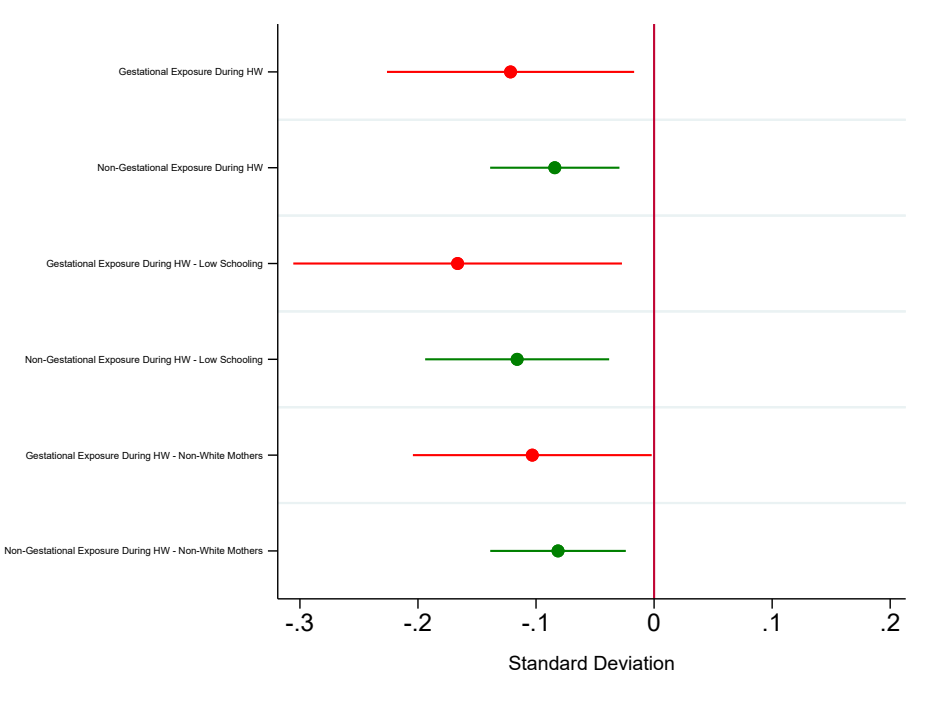
Note: illustrates the impact of Amazon Gold Rush-related pollution on infant mortality rates across multiple infant mortality categories, considering Holy Week as a key mechanism of contained fish consumption. “HW” refers to Holy Week exposure to periods during and around Holy Week, displayed as red coefficients, a time associated with increased consumption of locally sourced, potentially contaminated fish. While “No HW” refers to no Holy Week exposure to periods during and around Holy Week, displayed as green coefficients. Each color within the figure corresponds to a distinct regression model using a different sample, with all coefficients within the same color derived from the same model. Control variables include population vaccination rates, municipal environmental fines, per capita municipal spending on health and education, GDP and agrarian GDP (both in logarithmic form), and allocations for Bolsa Familia and Programa Saúde da Familia, as well as municipality, and year-state fixed effects. By stratifying control groups, this figure provides a comprehensive overview of the robustness of our findings. Regressions are weighted and clustered by the municipality, with a 95% confidence interval. The analysis period spans 1997 to 2015, enabling a longitudinal view of pollution effects across various infant mortality outcomes.

Figure A.13: Heterogeneous Effects of the Amazon Gold Rush on Infant Mortality Rates by Distance to the Source of the Madeira River (to the Bolivian border) using Holy Week as a Mechanism across Infant Mortality Categories



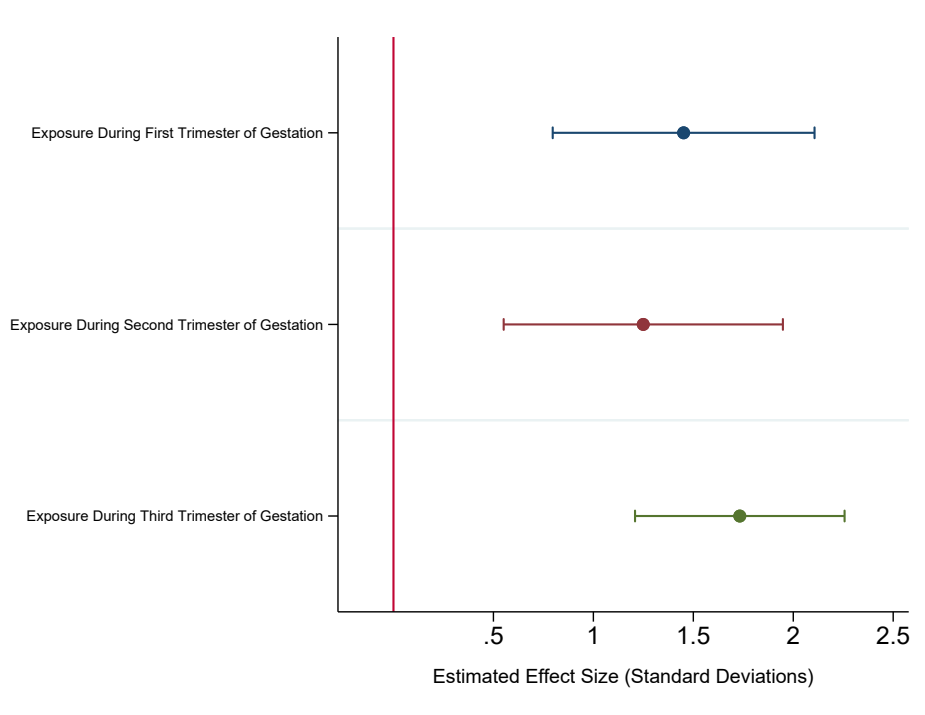
Note: This figure presents the heterogeneous impacts of the Amazon Gold Rush (gold mining pollution exposure) on infant mortality rates as a function of distance from the Madeira River’s starting point, examining Holy Week as a potential mechanism related to locally sourced fish consumption. The “Gestational Exposure During Holy Week” estimates, shown in red, represent periods coinciding with Holy Week, a time associated with increased consumption of locally sourced, potentially mercury-contaminated fish. In contrast, the “Non-Gestational Exposure During Holy Week” estimates, shown in green, represent periods not coinciding with Holy Week. These separate color-coded estimates for each group allow comparison across cohorts to isolate the specific impacts of Holy Week exposure. Each color within the figure corresponds to a distinct regression model, with all coefficients within the same color derived from the same model. The estimates for both models were obtained using equation 2, with a slight modification of the treated dummy variables. Regressions incorporate relevant population weights and control for factors including population vaccination rates, municipal environmental fines, per capita municipal spending on health and education, GDP (total and agricultural, both in logarithmic form), and per capita allocations for Bolsa Família and Programa Saúde da Família, as well as municipality, and year-state fixed effects. The time period for this analysis spans from 1997 to 2015 at the municipality level. Confidence intervals are displayed at the 95% level, calculated with cluster-robust standard errors at the municipality level.

Figure A.14: Heterogeneous Effects of the Amazon Gold Rush on Childbirth Weight Using Holy Week as a Mechanism across Different Mother Categories



Note: This figure presents the heterogeneous impacts of the Amazon Gold Rush (gold mining pollution exposure) on childbirth weight, examining Holy Week as a mechanism related to locally sourced fish consumption across different maternal categories. The “Gestational Exposure During Holy Week (HW)” estimates, shown in red, represent periods coinciding with Holy Week (HW), a time associated with increased consumption of locally sourced, potentially mercury-contaminated fish. In contrast, the “Non-Gestational Exposure During Holy Week (HW)” estimates, shown in green, represent periods not coinciding with Holy Week. These separate color-coded estimates for each group allow comparison across cohorts to isolate the specific impacts of Holy Week exposure. Each color within the figure corresponds to a distinct regression model using a different sample, with all coefficients within the same color derived from the same model. The estimates for all models were obtained using equation 1. Regressions incorporate relevant population weights and control for factors including population vaccination rates, municipal environmental fines, per capita municipal spending on health and education, GDP (total and agricultural, both in logarithmic form), and per capita allocations for Bolsa Família and Programa Saúde da Família, as well as municipality and year-state fixed effects. The time period for this analysis spans from 1997 to 2015 at the municipality level. Confidence intervals are displayed at the 95% level, calculated with cluster-robust standard errors at the municipality level.

Figure A.15: Heterogeneous Effect of Holy Week Exposure During Amazon Gold Rush on Infant Mortality by Gestational Trimester



Note: This figure presents the heterogeneous impacts of the Amazon Gold Rush (gold mining pollution exposure) on infant mortality, examining Holy Week as a potential mechanism linked to locally sourced fish consumption. All estimated coefficients represent gestational exposure during Holy Week. Each one represents exposure during different stages of gestational periods that coincided with Holy Week, potentially associated with a time of increased consumption of locally sourced, potentially mercury-contaminated fish. The figure displays three distinct coefficients for each trimester of gestational exposure—capturing impacts from the first, second, and third trimesters separately. These separate color-coded estimates for each group enable a comparison across cohorts to isolate the specific impacts of Holy Week exposure. Each color within the figure corresponds to a distinct regression model, with all coefficients within the same color derived from the same model. The estimates for all models are based on equation 1. Regressions incorporate relevant population weights and control for factors including population vaccination rates, municipal environmental fines, per capita municipal spending on health and education, GDP (total and agricultural, both in logarithmic form), and per capita allocations for Bolsa Família and Programa Saúde da Família, as well as municipality and year-state fixed effects. The time period for this analysis spans from 1997 to 2015 at the municipality level. Confidence intervals are displayed at the 95% level, calculated with cluster-robust standard errors at the municipality level.