A Natural Resource Curse: The Unintended Effects of Gold Mining on Malaria

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Abstract

This paper aims at analyzing whether there is an ecological response from extractive resource activities that exert an influence on the emergence and proliferation of malaria. More specifically, I analyze the effects that gold mining activities have on the incidence of malaria through a nation-wide reform that improved the investment climate in the Philippines' mining sector. In January 2004, the government of the Philippines launched the Minerals Action Plan (MAP) with the goal of revitalizing the mining sector, which significantly reduced the average lag between application and grant of a mining permit. Using the MAP reform, I exploit two sources of variation in the timing of the reform as well as spatial variation in the distribution of mineral endowments through a difference-in-differences (DID) approach that compares provinces with and without gold deposits before and after the reform. I find evidence that is consistent with an ecological response, where the MAP reform had a statistically significant effect on the incidence of malaria. After the MAP reform, provinces with deposits of gold had 32 percent more malaria cases relative to provinces without gold deposits. In order to reinforce the empirical strategy, I perform several falsification tests as well as investigate other potential mechanisms to confirm that the main mechanism is through gold mining's creation of slow-moving bodies of stagnant water, which provide an ideal breeding site for *Anopheles* mosquitos to propagate and reproduce.

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1 Gold mining and its unintended effects on malaria

In 2018, the World Health Organization (2019) estimated 228 million cases of malaria occurred worldwide, of which approximately 405,000 resulted in death. Despite billions of dollars in investments, approximately one-third of the world (2 billion people) still live in areas infected by malaria, and more people die from it than 40 years ago (Pattanayak and Pfaff, 2009).[1] As the environment continues to be altered, particularly through land transformation and land clearance activities, there are likely to be continued increases in diseases. Roughly one quarter of the global burden of disease can be attributed to environmental changes (Prüss-Üstün et al., 2008).

This paper aims at analyzing whether there is an ecological response from extractive resource activities that exert an influence on the emergence and proliferation of malaria. More specifically, in this study I analyze the effects that gold mining activities have on the incidence of malaria through a nation-wide reform that improved the investment climate in the Philippines' mining sector. The Philippines is the fifth most mineral-rich country in the world for gold, nickel, copper, and chromite. In 2010, the value of its known mineral reserves was estimated at over 1.3 trillion U.S. dollars (Pavlova and Hincks, 2013). The Philippines' largest mineral exports are gold, copper and nickel, which make up over 97 percent of the country's total mineral production. Gold alone accounts for approximately 68 percent of the total value of mineral production in the country.

In January 2004, the government of the Philippines launched the Minerals Action Plan (MAP) with the goal of revitalizing the mining sector through an executive order. The program included over 100 regulatory measures with the main objective to increase both foreign and domestic investment in the mining sector. Ultimately the mining reform led towards a more extractive resource policy by streamlining the application process for mining permits, increasing the number of issued permits, and made it more difficult to hold up operations through legal challenges. As a result of the reform, the mining permit process reduced the average lag between application and grant of a permit from 3-5 years to 6 months in 2005 (Fong-Sam, 2005). Additionally, the reform is estimated to have generated around $5 billion worth of commitments for new investments by February 2005 (Cruz et al., 2005; Fong-Sam, 2005).

Using the MAP reform, I exploit two sources of variation in the timing of the reform

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[1] In 2018, governments of malaria endemic countries and international partners invested approximately $2.7 billion in malaria control and elimination efforts (World Health Organization, 2019).

as well as spatial variation in the distribution of mineral endowments through a difference-in-differences (DID) approach that compares provinces with and without gold deposits before and after the reform. This study estimates how a shift in national policy towards a more extractive resource position in the mining sector led to an unintended ecological response regarding an increase in the incidence of malaria. Gold mining sites are typically located within or close to water surfaces, where large pits known as open sky mines are dug and filled with water. If the gold mines are not properly filled back in, slow-moving bodies of stagnant water provide the ideal breeding environment for the *Anopheles* mosquito that carries the malaria disease to propagate and reproduce. I find evidence that is consistent with an ecological response, where the MAP reform had a statistically significant effect on the incidence of malaria. After the MAP reform, provinces with deposits of gold had 32 percent more malaria cases relative to provinces without gold deposits. Additionally, I use an event study approach to shed light on the yearly dynamics of the MAP reform as well as show that the effects on malaria were persistent 10 years beyond the implementation of the policy. In order to reinforce the empirical strategy, I perform several falsification tests. The first test exploits differences in disease ecology to see whether gold mining had an effect on other diseases. In each of these tests, I find no evidence that gold mining after the MAP reform had an effect on dengue, HIV, lower respiratory infections, pneumonia and gastric or duodenal peptic ulcers. Second, I test whether other types of minerals such as copper, nickel, chromium, manganese and iron had an effect on the incidence of malaria, where I find no evidence of an effect. Third, I perform a permutation inference exercise where provinces are randomly selected to be treated by gold deposits to show that the causal impacts are not likely to be randomly generated. Lastly, I examine other possible mechanisms such as migration or deforestation and find that neither can explain the increase in malaria, further suggesting that the causal mechanism is running through gold mining.

This study makes several important contributions to existing work in the literature. First, it provides the first nation-wide estimates of the impact gold mining has on the incidence of malaria. This substantially differentiates from the previous literature that has been focused on small geographical areas and localized effects of malaria (Rozo, 2020; De Santi et al., 2016; Valle and Lima, 2014) or other health outcomes (von der Goltz and Barnwal, 2019). Additionally, the Philippines context provides a large country to analyze that has substantial spatial heterogeneity in terms of economic, social and ecological diversity. Second, much of the previous literature has focused on a corollary relationship between gold mining and malaria (De Santi et al., 2016; Barbieri et al., 2005; Castellanos et al., 2016). This study moves beyond corollary results to provide causal estimates by exploiting the timing of the reform as well as the spatial distribution of geological endowments. Third, this national policy encouraged the expansion of legal mining operations and made it much easier to obtain mining permits. This differentiates from the context of Rozo (2020) that was focused on illegal gold mining with a bulk of the argument placed on the fact that illegal gold miners do not comply with the rules and have limited knowledge of measures needed to protect themselves against malaria or prevent the reproduction of mosquitoes as the reason for increased incidence of malaria. Evidence from this study indicate that this is not necessarily the case as a legal expansion of the resource extraction sector through the MAP reform led to an increase in the incidence of malaria.

While much of the existing evidence on malaria incidence and gold exploitation has been concentrated on qualitative studies or on documenting correlations, the detection of large-scale effects or causal estimates between the two is rare. In general, an association has been described in the literature between the proximity to gold mining operations and the risk of malaria (Barbieri et al., 2005; Crompton et al., 2002). Barbieri et al. (2005) find an association between malaria prevalence and small-scale gold mining in Northern Mato Grosso of Brazil. In the Brazilian Amazon, Valle and Lima (2014) find that an important predictor of malaria incidence is the proximity to gold mining operations, because high migration rates are often associated with artisanal gold mining. Rozo (2020) investigates the effect of illegal gold mining on malaria incidence in Colombia by exploiting pre-existing geochemical gold anomalies through an instrumental variable approach and shows that there are positive and large effects of illegal gold mining on malaria incidence. Estimates suggest that when areas that contain an illegal gold mine increase by 1 hectare, the annual parasite index for malaria increases by 1.04 cases per 100,000 inhabitants.

Additionally, this study contributes to the literature on the effects mining has on health and well-being, with a particular emphasis on the direct effects. On one side, mining has been shown to have indirect effects on health and well-being. Benshaul-Tolonen (2019) examines the expansion of large-scale gold mining throughout sub-Saharan Africa and finds that local infant mortality rates decrease by more than 50 percent as a result, where the reduction in child mortality is likely due to women's improved access to market opportunities and health care facilities. By assessing the health and wealth impacts of mineral mining from about 800 mines in 44 developing countries, von der Goltz and Barnwal (2019) find that communities exposed to mining enjoy important economic benefits in the medium and long-term, but there are serious health impacts such as an increase in anemia by three to ten percentage points for adult women and an impaired ability to recover hemoglobin levels after blood loss due to pregnancy and delivery. Additionally, Parker et al. (2016) investigate the effects of the Dodd-Frank Act that discouraged companies from sourcing minerals from the Democratic Republic of Congo. The authors find that the policy increased the probability of infant deaths in villages near the policy-targeted mines by at least 143 percent, and present suggestive evidence that the underlying mechanism is through a reduction in mothers' consumption of infant health care goods and services. On the other side, mining has been shown to have direct effects on health and well-being. High concentrations of particulate matter that are common in close proximity to opencast mines have been shown to increase respiratory disorders (Hedlund et al., 2006; Ross and Murray, 2004).

Last, this study broadly contributes to the strand of literature on negative externalities of mining and extractive resources. Crost and Felter (2020) analyze the MAP to find that the reform led to a large increase in violent conflict, which was most likely due to an increase in competition over control for resource-rich areas. Politically, mining has been shown to increase rent-seeking behavior, conflict and political corruption (Caselli and Michaels, 2013; Berman et al., 2017; Adhvaryu et al., 2020) as well as fuel repressive or destructive activities (Acemoglu and Robinson, 2001; Caselli and Tesei, 2016; Dube and Naidu, 2015; Mitra and Ray, 2014; Nunn and Qian, 2014). Resource booms additionally increase the value of being in power and provide politicians with more resources to exert their influence on the outcome of elections as well as increase resource misallocation to the rest of the economy (Robinson et al., 2006). Large-scale gold mining has been shown to decrease total factor productivity by almost 40 percent in Ghana, with the likely mechanism being the release of environmental pollutants (Aragón and Rud, 2016). In terms of environmental effects, gold mining has been shown to have long-lasting effects which include air, soil and water pollution from arsenic, cyanide and mercury (Eisler, 2004; Veiga et al., 2006). Furthermore, the pollutants released from gold mining activities can travel through rivers and tributaries, which negatively affect the water quality for humans, fish and other wildlife (Uryu et al., 2001). Last, mining has been shown to increase deforestation (Austin et al., 2019; Balietti et al., 2018; Recht et al., 2017).

The paper is structured as follows. Section 2 describes what malaria is, the environments in which it persists, and malaria's relationship to mining. Section 3 describes the mining and malaria data. Section 4 outlines the empirical strategies, identifying assumptions, and the model to be estimated. Section 5 presents the main results, performs several robustness tests of the main specification and estimates an event study specification. Section 6 performs several falsification tests to reinforce the empirical strategy. Section 7 investigates other potential mechanisms through which malaria may be exacerbated such as migration or deforestation. Section 8 outlines several policy responses and provides concluding remarks.

2 Malaria ecology

Malaria is an infectious disease that is spread through female *Anopheles* mosquitoes. Transmission occurs after a mosquito becomes infected with malaria by biting an infected person and then the infected mosquito bites a non-infected person.[2] *Anopheles* first take up a sexually differentiated form of the Plasmodium parasite which undergo reproduction in the mosquito, then the resulting sporozoite forms travel to the salivary glands and are injected into a potential host during the mosquitoes next blood meal (Garg, 2019). According to the World Health Organization (2016), malaria is transmitted to humans by five species of parasites that belong to the genus Plasmodium including P. Falciparum, P. Vivax, P. Malariae, P. Ovale, and P. Knowlesi.[3] The first four species of parasite are the most common with an average lifespan of approximately 2 weeks and can travel distances as far as 2km. Figure 1 presents data on the number of reported cases and incidence of malaria in the Philippines. Despite a recent decrease, the number of yearly cases is still high. Additionally, the World Health Organization (2019) estimates that the population at risk of malaria in the Philippines has been increasing from 54.4 million in 2010 to 61.9 million in 2018.

Malaria is typically found in tropical and subtropical countries, where higher temperatures allow the *Anopheles* mosquito to thrive. Furthermore, environmental changes either through natural phenomenon or human intervention can alter the ecological balance within which vectors and their parasites breed, develop and transmit disease. Ecosystem changes, particularly land transformation, profoundly impact breeding sites, survival probability, density, biting rates, and incubation periods (Pattanayak and Yasuoka, 2008). Additionally, geo-climatic factors

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[2] Malaria causes flulike symptoms that may include fever, chills, muscle aches, headache, nausea and in the most severe cases in which the parasite travels to vital organs such as the brain can lead to seizures, coma and in 20-50 percent of cases, death (Gilles et al., 1996). Malaria also causes morbidity through fever, weakness, malnutrition, anemia, spleen diseases, and vulnerability to other diseases (Pattanayak and Pfaff, 2009).

[3] While there is great diversity in the *Anopheles* mosquito species that carry the malaria disease and cases can be classified into each of the five species of parasites, the data to be employed in this analysis only report the general number of malaria cases. However, The Centers for Disease Control and Prevention estimate that 70-80 percent of mosquitoes in the Philippines are P. Falciparum and 20-30 percent are P. Vivax, and P. Knowlesi are rare (Arguin and Tan, 2017).

such as altitude, climate, temperature and weekly rainfall intensity determine the presence of *Anopheles* breeding sites, vector densities, adult mosquito survival rate, longevity and vector capacity (Imbahale et al., 2011; Texier et al., 2013). Among the various environmental or land-use factors that determine the transmission of malaria, stagnant or slow-moving bodies of water are the most important because they provide the basic requirement for the presence of breeding sites for the occurrence of the *Anopheles* vectors.

The basic pathway in which gold mining can accelerate the reproductive environment of the *Anopheles* mosquito is through the process of leaving behind slow-moving bodies of water, which happen to be the common location of many gold mines. Miners search for alluvial gold deposits, where they dig what are known as open sky mines near rivers and then fill these holes with water. The idea is to separate the heavier gold pieces from the dirt, and when the miners are done they leave pools of water behind. In particular, if these stagnant pools of water are left open, they can provide an ideal breeding site for the *Anopheles* mosquito to reproduce.[4] Previous research has only established a corollary relationship between gold mining and malaria. Moreno et al. (2007) find that malaria transmission occurs throughout the year, with the main focus on anthropogenic factors such as gold and gem mining, logging and urbanization.

3 Data

This study puts together several sources of administrative data at the provincial level. Data on malaria comes from yearly health reports by the Department of Health and provides the number of malaria cases at the province level. According to Sachs (2003), even deaths due to malaria are often unreported as some deaths may be attributed to other causes and have malaria as a co-factor, but not the principal cause. Digitized geological maps provide data on gold deposits from the Mines of Geosciences Bureau (MGB) which is a part of the Department of Environment and Natural Resources. In Figure 2, the left panel presents data on gold deposits throughout the Philippines, showing the spatial variation of provinces with and without gold deposits, while the right panel combines the two main data sources to illustrate the geographic dispersion of mineral deposits along with the incidence of malaria. Socioeconomic variables used as covariates in the analysis come from the census of the Philippines in 2000 and 2010. Geographic variables such as air temperature and precipitation come from Harris et al. (2020)

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[4] According to the World Health Organization (1982) shaded pools, seepages in forests, footprints, mining pits and irrigation ditches in the open sunlight provide areas for mosquitoes to deposit eggs.

and elevation comes from Jarvis et al. (2008). Table A.1 in Appendix A.1 provide summary statistics for each of the variables used in the analysis.

4 Identification and empirical strategy

In order to measure how the MAP reform affected the incidence of malaria, a DID empirical strategy is employed that exploits the subsequent reduction in the average lag between application and grant of a mining permit from 3-5 years to 6 months. Using this reform, I exploit the timing as well as the spatial distribution of mineral reserves that compares provinces with and without gold deposits before and after the reform.

There are several key assumptions that must be met in order to check the validity of the DID empirical strategy. The first is the parallel trends assumption, which is intended to show that there are no time-varying differences between the treatment and control areas in the absence of treatment. If the trends of the treatment and control groups moved in tandem before the MAP reform, then they likely would have continued moving in tandem in the absence of the reform. In order to check for parallel trends, at least two serial observations on the treatment and comparison groups are needed before the start of the reform (Gertler et al., 2016). Figure 3 shows that before the 2004 MAP reform, the number of malaria cases decreased at a similar rate in both groups but after the reform the number of cases in provinces with gold deposits first increased and then converged with non-gold provinces. Additionally, results from an event study specification (see below, Section 5.2) shows that provinces with or without gold deposits prior to the MAP reform were not statistically distinguishable from one another in terms of malaria cases. Provinces with deposits of gold only started experiencing higher levels of malaria and in a timely fashion around the introduction of the MAP reform. Each of these pieces of evidence provide a compelling argument in support of the parallel trends assumption.

The other set of assumptions have to deal with the exogeneity of gold deposits. First is the location of gold deposits. A necessary condition for the presence of a gold mine is a gold deposit, which is a geological anomaly and random (Eggert, 2002). Additionally, Bazillier and Girard (2020) argue that gold deposits are exogenously determined by the geological environment. Second is whether the reform led to the discovery of entirely new deposits in provinces that previously had no known deposits. As Crost and Felter (2020) point out, the approximate location of mineral deposits in the Philippines has been known for decades.

In order to estimate a causal effect of the MAP reform on the incidence of malaria, I estimate the following equation that takes advantage of a DID stemming from the timing of the reform's implementation and the location of gold deposits from 2002 and 2015. The equation to be estimated is:

$$\begin{aligned} Malaria_{p,t} = \beta_0 + \beta_1 MiningReform_t + \beta_2 Gold_p + \beta_3 MiningReform_t \cdot Gold_p \\ + X'_{p,t} \cdot \delta + \rho_p + \tau_t + \epsilon_{p,t} \end{aligned} \tag{1}$$

where $Malaria_{p,t}$ is estimated for the inverse hyperbolic sine of malaria cases for province p, in time t.[5] The main independent variable will be the interaction between $MiningReform_t$, which is a dummy variable indicating before or after the MAP reform in 2004 and the variable $Gold_p$ which is a dummy variable indicating whether the province has gold deposits. Furthermore, X' is a vector of geographical and province level socioeconomic covariates which include: the poverty incidence level, log of population, log of deforestation, elevation, mean air temperature, mean precipitation, ethnic fractionalization, religious fractionalization, average years of education of the household head, fraction of houses with roofs made of strong materials, fraction of houses with walls made of strong materials, fraction of households with access to electricity, access to indoor toilet and running water. The intercept term is represented as β_0, while province and time fixed effects are denoted as ρ_p and τ_t, respectively, which control for the unobserved provincial-time-invariant effect. Throughout the analysis, standard errors are clustered at the province level, to account for the arbitrary correlation within the province in terms of spatial autocorrelation and serial correlation over time.

5 Results

Table 1 presents the main results. The main finding from the preferred specification in column 4 is that provinces with gold deposits after the MAP reform experience 32 percent more malaria cases relative to provinces without gold deposits. The baseline results in column 1 are

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[5] Since some provinces did not experience any cases of malaria, it is more appropriate to use the inverse hyperbolic sine (IHS) transformation of malaria cases in order to accommodate provinces that had zero cases or an undefined log transformation. The IHS transformation approximates the natural logarithm and allows for retaining zero-valued observations (Bellemare and Wichman, 2020) and contrary to the logarithm is well defined around zero (Card and DellaVigna, 2020). The IHS function approximates the log function except for values close to 0, for which it approximates $ln(x) + ln(2)$. Using the absolute measure of malaria cases, the IHS function is constructed as: $IHSMalaria_{p,t} = ln(Malaria_{p,t} + \sqrt{Malaria^2_{p,t} + 1})$.

robust to the inclusion of geographic controls in column 2, socioeconomic controls in column 3 as well as to the inclusion of both geographic and socioeconomic controls in column 4.[6] The robustness of the results across various specifications, even with the inclusion of socioeconomic controls indicate that the underlying mechanisms is through an ecological response rather than a socioeconomic response. In Table A.2, I look at the intensive margin with the number of gold mine deposits within a province, where the estimated coefficients point in the same direction, but are not statistically significant at conventional thresholds of significance.[7]

5.1 Robustness tests

In order to document the stability of the estimates more generally, I perform several robustness checks of the main estimation. First I re-estimate equation (1) and drop each province in turn. Figure A.1 then plots each of the estimated coefficients to illustrate their stability and demonstrate that the standard errors continue to be significant at conventional levels. This exercise additionally indicates that no single province is driving the main results in Table 1. Second Bauhoff and Busch (2020) argue that access to local health services affects malaria. In Table A.6 I control for the number of rural health facilities within a province. As expected, health facilities are estimated to have a negative corollary relationship with the number of malaria cases. Regardless of controlling for the number of rural health facilities, the results remain similar to Table 1. Third, malaria and gold mines are both located near bodies of water and thus could present a potential threat to the validity of the empirical strategy by introducing spurious correlations to the main estimation. In order to address this possibility, Table A.7 tests the sensitivity of the results to the inclusion of the total surface area of bodies of water within each province and the results remain qualitatively similar. Fourth previous literature argues that malaria risk is highest at intermediate values of temperature and precipitation (Beck-Johnson et al., 2013; Mordecai et al., 2013; Parham and Michael, 2010). Table A.8 tests the sensitivity of the results by additionally controlling for squared terms of temperature and precipitation and the results remain unchanged. Fifth in Table A.9 I test the sensitivity of the results by clustering the standard errors at the regional level and the results still hold. Sixth I additionally control for quadratic time trends in the main specification and the

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[6] In Table A.3, I estimate equation (1) using an absolute measure of malaria that accounts for the number of cases as the dependent variable, where I find consistent evidence of a significant impact.

[7] In Table A.4, I look at the intensive margin using an absolute measure of malaria cases and find a positive and statistically significant impact.

results in Table A.10 remain qualitatively similar. Last, in addition to defining malaria in either the level or IHS transformation, I also test the sensitivity of the main results by defining malaria cases as $log(1 + MalariaCases)$. Thus, in Table A.11 I show that the alternative transformation of the dependent variable does not qualitatively change the results in Table 1.

5.2 Event study specification

Estimates in Table 1 represent a weighted average of the MAP reform and gold deposit effects by year, and thus do not provide information on the magnitude of the effects over time. To further examine and uncover the dynamic effects of the MAP reform and gold deposits, I estimate the following event study specification:

$$Malaria_{p,t} = \rho_p + \tau_t + X'_{p,t} \cdot \delta + \sum_{\phi=-1}^{m} \beta_{-\phi} D_{i,t-\phi} + \sum_{\phi=0}^{q} \beta_{+\phi} D_{i,t+\phi} + \epsilon_{p,t} \tag{2}$$

where $D_{i,t-\phi}$ estimates the leads and $D_{i,t+\phi}$ the lags of the treatment dummy in order to decompose the treatment effect for each year preceding and following the MAP reform. I take the year of the MAP reform as the omitted baseline year of comparison and make all estimates relative to 2004.

This specification is advantageous for two main reasons. The first advantage is to test whether there was any anticipatory behavior prior to the treatment. This is an intuitive way to test for Granger causality (Tewari, 2014) and check whether the pre-policy coefficients are insignificant and display no trend. Instead of controlling for differential pre-MAP trends across provinces, the specification directly tests for the existence of such differentials without imposing a linear structure on the time pattern related to the reform. Insignificant coefficients prior to the reform provide some reassurances to the identifying assumptions of the DID. The second advantage is the ability to trace out the full dynamic trajectory as well as the persistence of the effects.

Results from the estimated equation (2) are plotted in Figure 4. First, there does not appear to be any anticipatory effect as the point estimates prior to the reform are insignificant. This result offers evidence that provinces with gold deposits and provinces without gold deposits had similar evolutions in cases of malaria prior to treatment. Second, the effect on malaria is immediately experienced in 2005. Immediately following the MAP reform, provinces with gold deposits experience 46 percent more malaria cases relative to provinces without gold deposits.

The estimated yearly effects remain fairly stable between 30 and 60 percent. Last, the figure illustrates how persistent the effects are in that more than 10 years after the reform the effects are still significant.

6 Falsification tests

Now that it has been established that provinces with gold deposits after the MAP reform experienced an increase in the number of malaria cases relative to provinces without gold deposits, the study now moves to reinforce the empirical strategy. This section performs several falsification tests by investigating 1) whether gold mining has an effect on other diseases through differences in disease ecology; 2) whether other mineral deposits have an effect on malaria; and 3) a permutation inference exercise where provinces are randomly selected to be treated with gold deposits.

6.1 Other diseases

One threat to the validity of the empirical strategy would be if there are unobserved variables that are correlated with both human health outcomes and gold mining deposits that might have an impact on other diseases other than malaria. An important aspect to determine is whether the established relationship between gold mining deposits and the incidence of malaria is specific to the disease ecology of malaria and not generically to other health outcomes. To perform this analysis, this section maintains the same empirical structure as equation (1), but will test the effects of the MAP reform and gold deposits on other diseases such as dengue, HIV, lower respiratory infections, pneumonia and gastric or duodenal peptic ulcers. This follows similar falsification tests performed by Garg (2019) and Rozo (2020) that exploit different epidemiological mechanisms of transmission across diseases. Garg (2019) uses the health measures of measles, diarrhea, respiratory infections and dengue, while Rozo (2020) uses skin rashes, abortion rates, fetal malformation, respiratory, and digestive diseases.[8]

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[8] The disease ecology of malaria differs significantly from dengue even though they are both spread via disease carrying vectors and are predominantly maintained in a human-to-mosquito-to-human cycle. The *Aedes* species (Ae. Aegypti or Ae. Albopictus) which carries dengue have a much shorter flight span compared to the *Anopheles*. Additionally, the *Aedes* species are almost stationary and mostly prevalent in urban areas (Garg, 2019). Since gold mining typically occurs in rural areas, I do not expect there to be a discernible effect between gold mining and dengue.

Table 2 reports the results of the falsification tests, where I find no evidence of an effect that provinces with gold deposits after the reform had an effect on the number of dengue, HIV, lower respiratory infections, pneumonia or gastric or duodenal peptic ulcer cases. These results indicate that the main channel is through the ecological response of altering the reproductive environment that is specific to malaria.

6.2 Other minerals

The next falsification test investigates whether the increased incidence of malaria is specific to gold mining, or mining in general. It could be argued that mining in general may have the same negative externalities and that there is nothing particular about gold mining that leads to more cases of malaria. There are several reasons as to why we can expect there to be a link between gold mining and malaria, rather than a link between mining for other minerals and malaria. First, gold mining typically happens near rivers or bodies of water as well as typically demands water in the extraction process. Second, alluvial gold mining areas have more stagnant water surfaces, which provide an ideal breeding site for mosquitoes that transmit malaria. Third, gold mining typically happens on a much smaller scale and is therefore likely to happen near villages. Last, gold mining is likely to be performed in hard to reach places.

To investigate whether there is a link between other mining activities and malaria, this section maintains the same empirical structure as equation (1), but will test the effects of the MAP reform and other mineral activities such as copper, nickel, chromium, manganese and iron on the inverse hyperbolic sine of malaria cases. Figure 5 presents data on nickel, manganese, iron, gold, chromium and copper deposits throughout the Philippines, to further illustrate the geographic dispersion of mineral deposits. Table 3 then presents the results of the falsification tests, where I find no evidence that the presence of other mineral deposits after the MAP reform had an effect on the number of malaria cases relative to provinces without other mineral deposits.

6.3 Falsification tests with permutation inference

Last, I run a permutation inference analysis by randomly selecting half of the control provinces to receive the "treatment" of having a gold deposit and see whether the "treatment" has an effect on the incidence of malaria. This analysis is similar to Hoang et al. (2020) and Benshaul-Tolonen (2019) and asks if there is a possibility that the effects shown in the main analysis are simply due to a "lucky draw" that is entirely unrelated to gold deposits. I randomly select half of the control provinces to receive the "treatment" status of having gold deposits, while the other half is assigned to be the "control". I then replicate the DID regression from equation (1) using the falsified treatment and control groups. The permutation inference test is run through 10,000 iterations and then the distributions of the estimated coefficients and their t-statistics are plotted in Figure 6. Each of the distributions exhibit strong normal distributions centered at 0. In each of the panels, the red vertical line indicates the preferred estimation's estimated coefficient and t-statistic obtained from column 4 in Table 1, respectively. Both are right-tail outliers and indicate that causal impacts estimated in Table 1 are not likely to be randomly generated.

7 Other potential mechanisms

The most likely mechanism at play is through the ecological response in which gold mining activities leave behind pools of water that provide the *Anopheles* mosquitoes with an environment to reproduce. This study now investigates whether there are other possible mechanisms though which malaria may be exacerbated such as migration or deforestation.

7.1 Migration

Mining is often correlated with migratory behavior either through the labor-intensity that requires migrant labor or through other commercial activities around the mines that attract migrants. Mining activities which often rely on highly mobile populations who migrate, are exposed to mosquito bites due to either long periods of time outdoors or through the living conditions in camps. Additionally, migration of previously unexposed populations to malaria into malaria endemic areas has often led to spikes in malaria cases, as well as returning migrants may introduce malaria parasites to new regions depending on the climate, activities and vector species present (Recht et al., 2017). Migrants can be further exposed to malaria as latent hosts, since they typically have lower incomes and less access to medical facilities (Garg, 2019). Mining operations are typically performed in rural areas and the settlement of these areas can make them more susceptible to outbreaks of malaria due to contact with settlers and vectors, and land clearing activities. Barbieri et al. (2005) show that after the initial stage of settlement, the prevalence of malaria declines for several reasons: 1) less interaction between humans and vectors; 2) the larger extent of cleared land; 3) improvements to housing conditions; 4) better access to health care; 5) greater personal resistance to malaria; and 6) greater knowledge about the disease.

To explore this hypothesis, the following equation is estimated:

$$\begin{aligned} Y_{p,t} = {} & \beta_0 + \beta_1 MiningReform_t + \beta_2 Gold_p + \beta_3 MiningReform_t \cdot Gold_p \\ & + X'_{p,t} \cdot \delta + \rho_p + \tau_t + \epsilon_{p,t} \end{aligned} \tag{3}$$

where $Y_{p,t}$ is estimated separately for 1) the log of population; 2) the log of population that migrated; and 3) the log of younger population who are between the ages of 15 and 49 that migrated to a given province p in time t. The population that migrated is broken-down into two categories as it is likely that the majority of individuals migrating to work in the minerals and extractive sector are of a younger age. Table 4 presents the estimated results. In column 1 there is some evidence that after the reform, provinces with gold deposits experienced a corollary increase in population, but in columns 2 and 3, there is no evidence of a change in the population migrating into provinces with gold deposits after the reform.

7.2 Deforestation

Next, I explore a second mechanism that may explain the increase in malaria, which could be related to deforestation. One of the main negative externalities from mining is the loss of forest coverage. Deforestation has been linked to a wide variety of human activities including agriculture development, logging, transmigration programs, road, construction, mining and hydropower (Austin et al., 2019; Patz et al., 2000; Walsh et al., 1993). Gold mining can affect the ecosystem as it starts with vast deforestation (Recht et al., 2017). Additionally, Indian districts with a higher proportion of small mines exhibit significantly greater deforestation per hectare (Balietti et al., 2018), while in the Amazon, mining significantly increased deforestation up to 70 km beyond the mining lease boundaries (Sonter et al., 2017).

Deforestation can alter the disease ecology of malaria in several ways. Cleared lands are generally more exposed to sunlight and prone to puddle formation with more neutral pH levels that can favor *Anopheline* larvae development (Patz et al., 2000). A loss of biodiversity can also affect malaria incidence by reducing or eliminating species that prey on *Anopheline* larvae and *Anopheles* mosquitoes (Laporta et al., 2013; Yasuoka and Levins, 2007). There is a longstanding literature linking deforestation with an alteration of the disease ecology of malaria (MacDonald and Mordecai, 2019; Tucker et al., 2017; Pattanayak and Pfaff, 2009; Keesing et al., 2010; Chakrabarti, 2018). Garg (2019) provides the first causal estimates of the effect that forest loss has on the increased incidence of malaria in Indonesia. Additionally, Berazneva and Byker (2017) find similar evidence that the loss of forest coverage increased malaria incidence around 4.5 percent in children under five in Nigeria.

I investigate the deforestation channel through several exercises. The first estimated equation explores whether the reform had an effect on deforestation:

$$\begin{aligned} Deforestation_{p,t} = {} & \beta_0 + \beta_1 MiningReform_t + \beta_2 Gold_p + \beta_3 MiningReform_t \cdot Gold_p \\ & + X'_{p,t} \cdot \delta + \rho_p + \tau_t + \epsilon_{p,t} \end{aligned} \tag{4}$$

where $Deforestation_{p,t}$ is the log of deforestation for a given province p in time t. Data on deforestation are derived from a satellite-generated forest cover database (Hansen et al., 2013), which provides global information about forest cover in 2000 and subsequent forest changes between 2001 and 2018.[9]

The second exercise explores whether the reform, gold deposits and deforestation had an effect on malaria. The following equation is estimated:

$$\begin{aligned} Malaria_{p,t} = {} & \beta_0 + \beta_1 MiningReform_t + \beta_2 Gold_p + \beta_3 Deforestation_{p,t} \\ & + \beta_4 MiningReform_t \cdot Gold_p + \beta_5 MiningReform_t \cdot Deforestation_{p,t} \\ & + \beta_6 Gold_p \cdot Deforestation_{p,t} + \beta_7 MiningReform_t \cdot Gold_p \cdot Deforestation_{p,t} \\ & + X'_{p,t} \cdot \delta + \rho_p + \tau_t + \epsilon_{p,t} \end{aligned} \tag{5}$$

where $Malaria_{p,t}$ is the inverse hyperbolic sine of malaria cases for province p in time t. The main variable of interest is the triple interaction between the mining reform, gold deposits and deforestation. Since deforestation has been linked as a negative externality to mining, one could expect that these three factors may together explain the increase in malaria.

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[9] Landsat satellites capture pixel-level images with a 1 arc-second resolution, where GFC classifies forest cover and loss at a spatial resolution of 30 m x 30 m. The GFC defines forest cover as an area in which the biophysical presence of trees or vegetation higher than five meters accounts for more than 50 percent of the land and may take the form of natural forests or plantations over a range of canopy densities.

Table 5 presents the results. Columns 1-4 present the results on whether the reform had an effect on deforestation, where I find no evidence that provinces with gold deposits after the reform suffered more deforestation relative to provinces without gold deposits. The results of the triple interaction term in columns 5-8 find no statistical effect that malaria is being effected by deforestation, gold mining and the MAP reform. Additionally, the main results in Table 1 control for the level of provincial deforestation. Each of these pieces of evidence suggest that the mechanism through which malaria is increasing is through gold mining, so we can rule out that the effect is running through the deforestation channel.

8 Conclusion

As the environment continues to be anthropogenically altered particularly in the form of land transformation and land clearance activities, there is likely to be an increase in the incidence of different diseases. This study improves our understanding of the relationship between natural resource policy and ecology by exploiting how a major shift in the Philippines' extraction policy to reduce the lag in granting mining permits had unintended health effects. More specifically, I provide causal evidence that provinces with gold mining deposits experienced 32 percent more malaria cases relative to provinces without gold deposits after the MAP reform. The main mechanism is argued to be through gold mining's creation of slow-moving bodies of stagnant water, which provide an ideal breeding site for *Anopheles* mosquitoes to propagate and reproduce. Then an event study approach estimates that the MAP reform had persistent effects on malaria 10 years beyond the implementation of the policy. Several falsification tests are performed, which reinforce the empirical strategy and suggest that the effect on malaria is specific to gold mining. An analysis of other possible mechanisms such as migration or deforestation provide no evidence of a statistical relationship, further supporting the ecological mechanism underpinning the relationship between malaria and gold mining.

From a public health policy standpoint, the results indicate that more attention should be given to the challenges ecosystem transformation or degradation poses to the health of individuals. Several different policies can be targeted to mitigate the incidence of malaria resulting from gold mining activities. First, clinics within gold mining communities can provide malaria specific information as to the transmission of malaria and proven anti-malarial interventions. Figure A.2 presents data from the 2003 Demographic and Health Survey for the Philippines that indicates 80 percent of respondents know malaria comes from mosquitoes, while Figure A.3

suggests over 60 percent of respondents believe malaria is spread by mosquitoes. When asked the ways in which malaria can be prevented, the majority of respondents answered eliminate breeding places, followed by mosquito nets, spray house, other and avoid certain foods (Figure A.4). While there is a large portion of the surveyed population who understand where malaria comes from, the share drops substantially when asked about the transmission or methods of malaria prevention. Second, clinics within gold mining regions can provide specialized resources on proven anti-malarial interventions such as insecticide-treated bed nets, indoor residual spraying, or prompt clinical treatment as well as certain environmental management strategies such as drainage or canal linings. The third area for reform is related to mitigation efforts through monitoring and enforcement. This study suggests that the most likely mechanism leading to an increase in malaria is through the stagnant bodies of water that are left behind from gold mining activities. Monitoring compliance with proper mining protocols or rules may limit the stagnant water conditions needed for malaria to propagate and persist.

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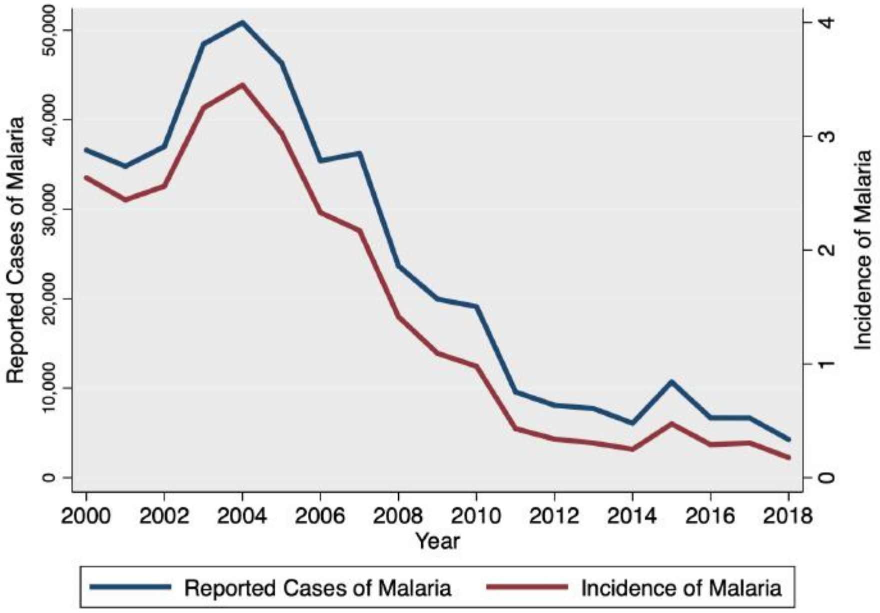
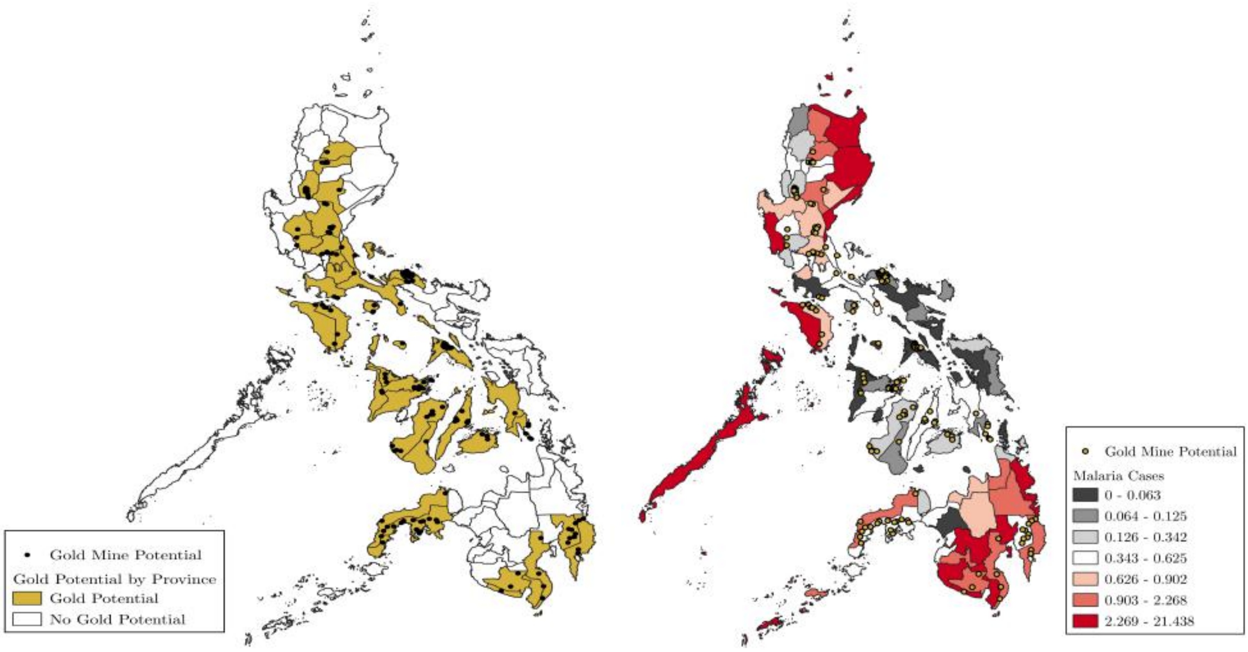
Figure 1: Reported cases and incidence of malaria in the Philippines, 2000 – 2018



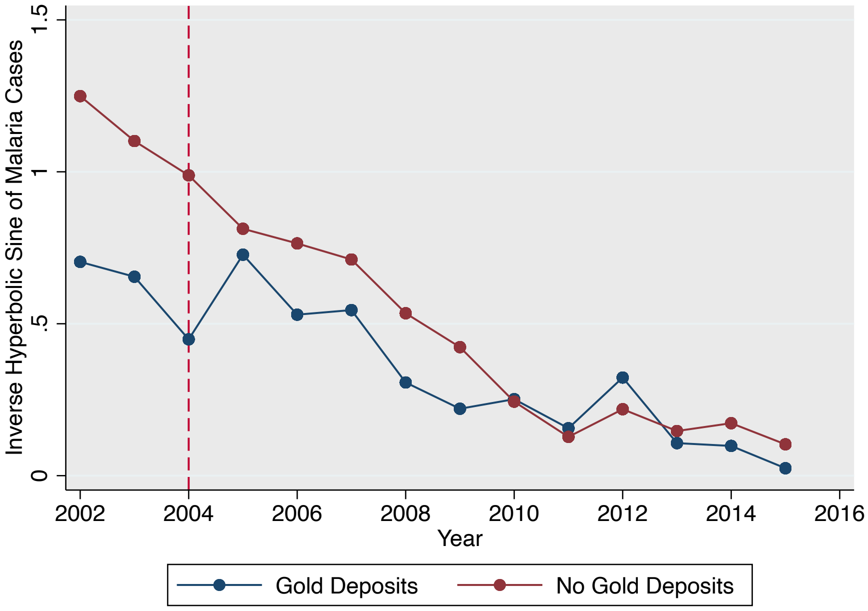
Notes: This figure presents data on the number of reported cases of malaria and the incidence of malaria as the number of new cases of malaria in a year per 1,000 population at risk. *Source*: World Development Indicators.

Figure 2: Identifying variation of gold deposits and average yearly number of malaria cases



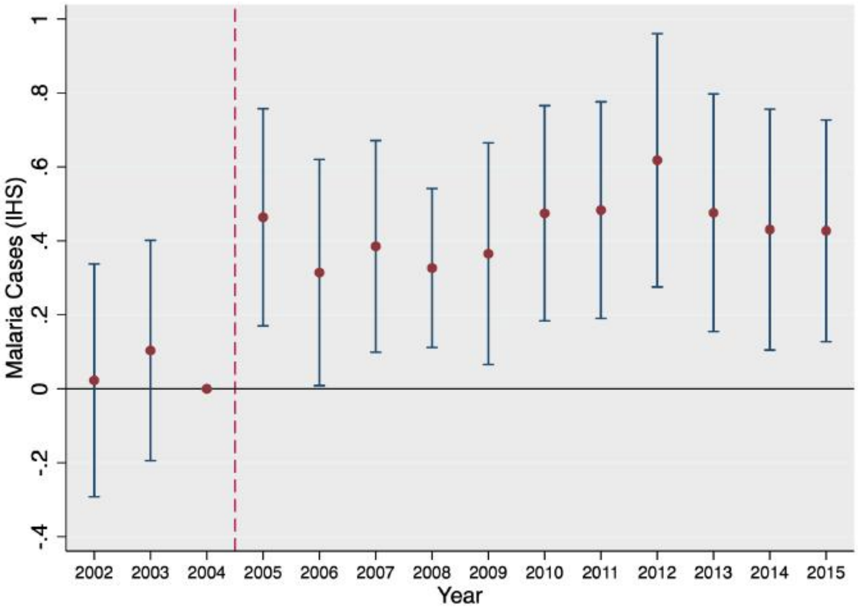
Notes: The left panel presents the identifying variation, where provinces with gold deposits are shaded in yellow, while provinces without gold deposits are white. Each of the dots represent the potential for a gold mine. The right panel combines the two main data sources on malaria incidence and gold mine deposits. The map presents identifying variation, where the shaded provinces represent the average yearly number of malaria cases and the yellow dots represent gold mine potential. *Source*: Author's calculations using digitized mining maps from the Mines of Geosciences Bureau (MGB) and health reports from the Department of Health.

Figure 3: Malaria cases by whether provinces have gold deposits



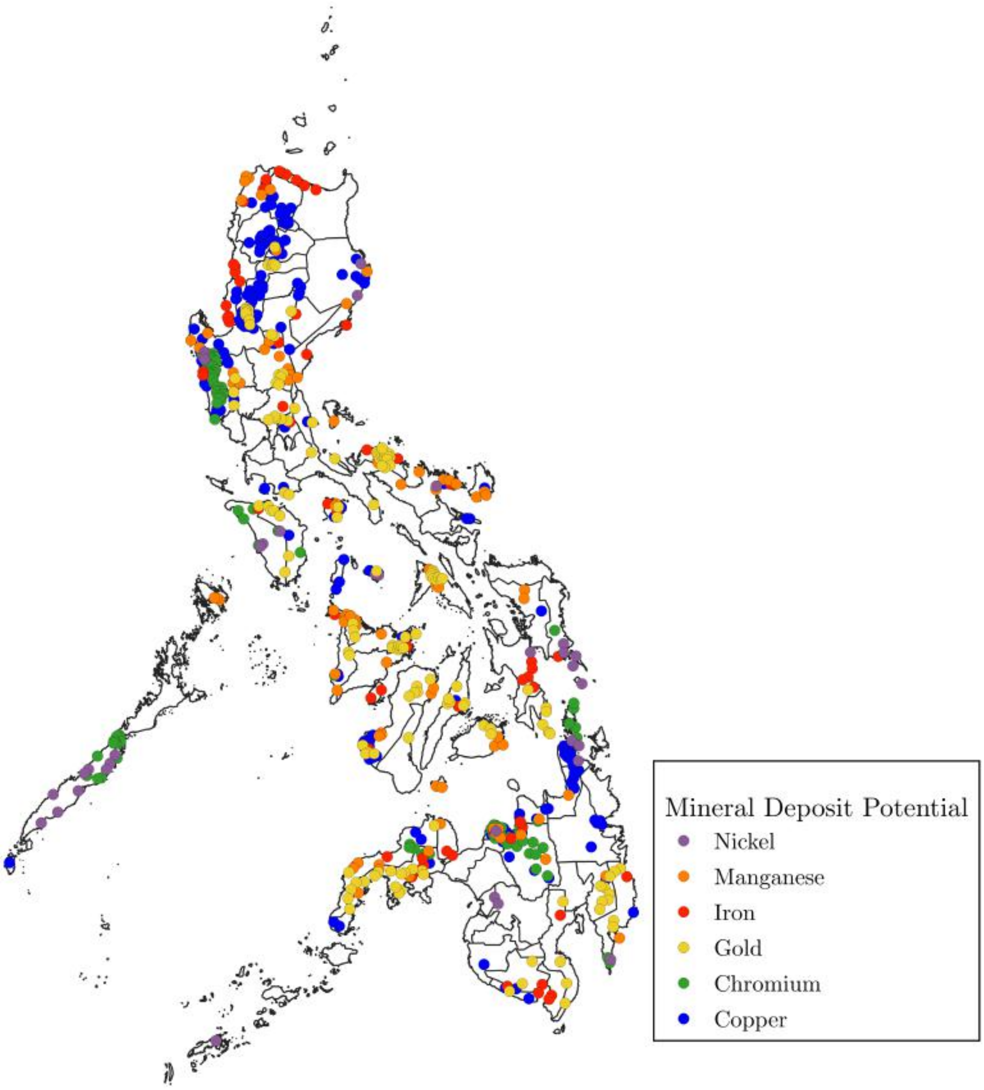
Notes: This figure displays parallel trends of malaria cases between provinces that have gold deposits and provinces that do not have gold deposits. *Source*: Author's own calculations.

Figure 4: Gold, MAP and the effect on malaria at the extensive margin, 2002 - 2015



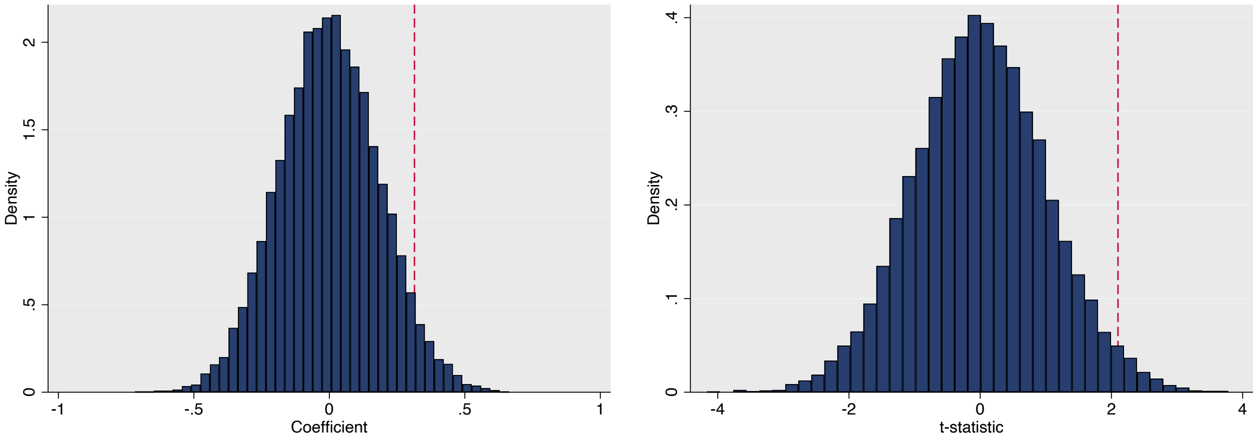
Notes: This figure presents estimates from an event study specification for the effect gold mining deposits have on the log of malaria cases for each year preceding and following the MAP reform. The year immediately preceding the treatment is omitted to make all estimates relative to this year. All treatment estimates are statistically insignificant prior to exposure to the reform. Immediately following the MAP reform, provinces with gold deposits experience 46 percent more malaria cases relative to provinces without gold deposits. Standard errors are clustered at the provincial level. Each regression includes province and time fixed effects. The independent variables include: elevation, mean air temperature, mean precipitation, the poverty incidence level, log of population, log of deforestation, ethnic fractionalization, religious fractionalization, average years of education of the household head, fraction of houses with roofs made of strong materials, fraction of houses with walls made of strong materials, fraction of households with access to electricity, access to indoor toilet and running water.

Figure 5: Mineral deposits in the Philippines



Notes: This figure presents the geographical dispersion of mineral deposits throughout the Philippines, where each of the dots represent the potential for nickel, manganese, iron, gold, chromium, and copper deposits. *Source*: Author's calculations using mining maps from the Mines of Geosciences Bureau (MGB).

Figure 6: Distributions from permutation inference



Notes: These figures show the distribution of coefficients and t-statistics from a permutation inference where half of the municipalities from the main analysis in the control are randomly selected to either receive the "treatment" of having gold deposits or remain in the "control" of having no gold deposits. The permutation test is run through 10,000 iterations. The red line indicates the estimated coefficient and t-statistic obtained from column 4 of Table 1, respectively. The independent variables include: poverty incidence level, log of population, log of deforestation, elevation, mean air temperature, mean precipitation, ethnic fractionalization, religious fractionalization, average years of education of the household head, fraction of houses with roofs made of strong materials, fraction of houses with walls made of strong materials, fraction of households with access to electricity, access to indoor toilet and running water.

Table 1: Gold, MAP and the effect on malaria at the extensive margin, 2002 - 2015

	(1) Malaria Cases (IHS)	(2) Malaria Cases (IHS)	(3) Malaria Cases (IHS)	(4) Malaria Cases (IHS)
Gold	0.0427	-0.957***	0.390	-0.442
	(0.145)	(0.248)	(1.640)	(1.568)
Mining Reform	-1.091***	-1.152***	-2.388***	-2.380***
	(0.162)	(0.163)	(0.503)	(0.501)
Gold x Mining Reform	0.361**	0.358**	0.319**	0.317**
	(0.164)	(0.165)	(0.149)	(0.150)
Observations	1,110	1,110	1,110	1,110
R-squared	0.561	0.562	0.604	0.604
Geographic Controls	No	Yes	No	Yes
Socioeconomic Controls	No	No	Yes	Yes
Mean Incidence	0.459	0.459	0.459	0.459

Notes: This table presents estimates for the effects that gold mining deposits have on the log of malaria cases, identified using a DID based on the timing of the MAP reform as well as the distribution of gold deposits. Standard errors are clustered at the provincial level. Each regression includes province and time fixed effects. Geographic controls include: elevation, mean air temperature, and mean precipitation. Socioeconomic controls include: the poverty incidence level, log of population, log of deforestation, ethnic fractionalization, religious fractionalization, average years of education of the household head, fraction of houses with roofs made of strong materials, fraction of houses with walls made of strong materials, fraction of households with access to electricity, access to indoor toilet and running water. Significant at *p $<$ 0.10, ** p $<$ 0.05, *** p $<$ 0.01.

Table 2: Gold, MAP and the effect on other diseases, 2002 - 2015

	(1) Dengue Cases (IHS)	(2) HIV Cases (IHS)	(3) Lower Respiratory Cases (IHS)	(4) Pneumonia Cases (IHS)	(5) Gastric or Duodenal Peptic Ulcer Cases (IHS)
Gold	3.853***	-1.262	0.714	-0.906	1.441***
	(1.161)	(0.782)	(0.766)	(0.884)	(0.486)
Mining Reform	-1.992***	0.665***	0.669**	0.875***	0.00659
	(0.400)	(0.216)	(0.331)	(0.286)	(0.178)
Gold x Mining Reform	-0.0379	0.0883	0.0189	-0.0253	-0.000250
	(0.159)	(0.0619)	(0.0682)	(0.0582)	(0.0597)
Observations	1,110	1,110	1,104	1,104	1,025
R-squared	0.681	0.472	0.940	0.940	0.926
Geographic Controls	Yes	Yes	Yes	Yes	Yes
Socioeconomic Controls	Yes	Yes	Yes	Yes	Yes
Mean Incidence	1.664	0.192	5.338	5.974	4.309

Notes: This table presents estimates for the effects that gold mining has on the inverse hyperbolic sine of Dengue, HIV, Lower Respiratory Infections, Pneumonia and Gastric or Duodenal Peptic Ulcer cases, identified using a DID based on the timing of the MAP reform as well as the distribution of gold deposits. Standard errors are clustered at the provincial level. Each regression includes province and time fixed effects. The independent variables in columns 1-5 include: the poverty incidence level, log of population, log of deforestation, elevation, mean air temperature, mean precipitation, ethnic fractionalization, religious fractionalization, average years of education of the household head, fraction of houses with roofs made of strong materials, fraction of houses with walls made of strong materials, fraction of households with access to electricity, access to indoor toilet and running water. Significant at $*p < 0.10$, $** p < 0.05$, $*** p < 0.01$.

Table 3: Other types of minerals, MAP and the effect on malaria, 2002 - 2015

	(1)	(2)	(3)	(4)	(5)
	Malaria Cases (IHS)				
	Copper	Nickel	Chromium	Manganese	Iron
Mineral	-0.109	-0.684	-0.0368	-0.391	-0.0917
	(0.515)	(0.728)	(0.395)	(1.608)	(0.360)
Mining Reform	-2.293***	-2.295***	-2.288***	-2.299***	-2.298***
	(0.515)	(0.505)	(0.505)	(0.508)	(0.499)
Mineral x Mining Reform	-0.00975	-0.0104	-0.0664	0.00381	0.00182
	(0.163)	(0.216)	(0.175)	(0.169)	(0.176)
Observations	1,110	1,110	1,110	1,110	1,110
R-squared	0.599	0.599	0.600	0.599	0.599
Geographic Controls	Yes	Yes	Yes	Yes	Yes
Socioeconomic Controls	Yes	Yes	Yes	Yes	Yes
Mean Incidence	0.459	0.459	0.459	0.459	0.459

Notes: This table presents estimates for the effects other minerals have on the log of malaria cases, identified using a DID based on the timing of the MAP reform as well as the distribution of mineral deposits. Standard errors are clustered at the provincial level. Each regression includes province and time fixed effects. The independent variables in columns 1-5 include: the poverty incidence level, log of population, log of deforestation, elevation, mean air temperature, mean precipitation, ethnic fractionalization, religious fractionalization, average years of education of the household head, fraction of houses with roofs made of strong materials, fraction of houses with walls made of strong materials, fraction of households with access to electricity, access to indoor toilet and running water. Significant at *p $<$ 0.10, ** p $<$ 0.05, *** p $<$ 0.01.

Table 4: Gold, MAP and the effect on population and migration, 2002 - 2015

	(1) Log Population	(2) Log Migration	(3) Log Younger Migration
Gold	2.123***	2.644*	-7.075
	(0.239)	(1.338)	(4.853)
Mining Reform	0.483***	0.495	0.502
	(0.0694)	(0.547)	(0.473)
Gold x Mining Reform	0.0171*	0.0430	0.0384
	(0.01000)	(0.0483)	(0.0419)
Observations	1,110	1,110	1,110
R-squared	0.997	0.971	0.982
Geographic Controls	Yes	Yes	Yes
Socioeconomic Controls	Yes	Yes	Yes
Dependent Mean	11.253	7.608	6.753

Notes: This table presents estimates for the effects that gold mining deposits have on the log of population, log of population that migrated, and log of younger population that migrated, identified using a DID based on the timing of the MAP reform as well as the distribution of gold deposits. Standard errors are clustered at the provincial level. Each regression includes province and time fixed effects. Geographic controls include: elevation, mean air temperature, and mean precipitation. Socioeconomic controls include: the poverty incidence level, log of population, log of deforestation, ethnic fractionalization, religious fractionalization, average years of education of the household head, fraction of houses with roofs made of strong materials, fraction of houses with walls made of strong materials, fraction of households with access to electricity, access to indoor toilet and running water. Significant at $^*p < 0.10$, $^{**} p < 0.05$, $^{***} p < 0.01$.

Table 5: Gold, MAP and deforestation, 2002 - 2015

	(1) Log Deforestation	(2) Log Deforestation	(3) Log Deforestation	(4) Log Deforestation	(5) Malaria Cases (IHS)	(6) Malaria Cases (IHS)	(7) Malaria Cases (IHS)	(8) Malaria Cases (IHS)
Gold	1.195***	1.717***	0.00264	0.00264	3.671*	2.839	3.570	2.777
	(0.153)	(0.225)	(1.133)	(1.133)	(1.905)	(1.995)	(2.319)	(2.369)
Mining Reform	0.0176	-0.0183	-0.00409	-0.00409	4.088***	4.136***	1.984**	2.073**
	(0.203)	(0.197)	(0.247)	(0.247)	(0.762)	(0.789)	(0.924)	(0.932)
Gold x Mining Reform	0.123	0.127	0.127	0.127				
	(0.176)	(0.175)	(0.178)	(0.178)				
Gold x Mining Reform x Deforestation					0.171	0.189	0.149	0.156
					(0.120)	(0.117)	(0.126)	(0.123)
Observations	1,110	1,110	1,110	1,110	1,110	1,110	1,110	1,110
R-squared	0.836	0.836	0.840	0.840	0.592	0.594	0.622	0.622
Geographic Controls	No	Yes	No	Yes	No	Yes	No	Yes
Socioeconomic Controls	No	No	Yes	Yes	No	No	Yes	Yes
Mean Deforestation	15.162	15.162	15.162	15.162				
Mean Incidence					0.459	0.459	0.459	0.459

Notes: Columns 1-4 present estimates for the effects that gold mining deposits have on the log of deforestation, identified using a DID based on the timing of the MAP reform as well as the distribution of gold deposits. Columns 5-8 present estimates for the effects that gold mining, the MAP reform as well as deforestation have on the log of malaria cases, identified using a DID based on the timing of the MAP reform as well as the distribution of gold deposits. Standard errors are clustered at the provincial level. Each regression includes province and time fixed effects. Geographic controls include: elevation, mean air temperature, and mean precipitation. Socioeconomic controls include: the poverty incidence level, log of population, log of deforestation, ethnic fractionalization, religious fractionalization, average years of education of the household head, fraction of houses with roofs made of strong materials, fraction of houses with walls made of strong materials, fraction of households with access to electricity, access to indoor toilet and running water. Significant at $^*p < 0.10$, $^{**}\ p < 0.05$, $^{***}\ p < 0.01$.

A Appendix

A.1 Summary statistics

Table A.1: Summary statistics, 2002 - 2015

Dependent Variables	Observations	Mean	Std. Dev.	Min	Max
Malaria Cases	1,110	1.04	3.32	0.00	36.00
Malaria Cases (IHS)	1,110	0.46	0.82	0.00	4.28
Independent Variables					
Gold	1,110	0.45	0.50	0.00	1.00
Gold Deposits	1,110	1.88	3.08	0.00	17.00
Poverty Incidence	1,110	35.44	14.68	4.98	71.31
Log of Population	1,110	11.25	0.84	9.01	12.94
Log of Deforestation	1,110	15.16	1.56	6.80	19.13
Elevation	1,110	319.74	232.58	36.60	1268.83
Mean Air Temperature	1,110	25.97	1.31	21.10	28.00
Mean Precipitation	1,110	220.07	47.38	107.61	398.71
Ethnic Fractionalization	1,110	0.48	0.27	0.02	0.89
Religious Fractionalization	1,110	0.33	0.18	0.03	0.72
Average Years of Education of the Household Head	1,110	7.53	1.03	4.19	10.10
Fraction of Households with Roofs Made of Strong Materials	1,110	0.70	0.19	0.25	0.99
Fraction of Households with Walls Made of Strong Materials	1,110	0.73	0.15	0.25	0.99
Fraction of Households with Access to Electricity	1,110	0.66	0.19	0.16	0.97
Access to Running Water	1,110	0.43	0.17	0.11	0.98
Access to Indoor Toilet	1,110	0.89	0.10	0.53	1.00

A.2 Additional results

Table A.2: Gold, MAP and the effect on malaria at the intensive margin, 2002 - 2015

	(1) Malaria Cases (IHS)	(2) Malaria Cases (IHS)	(3) Malaria Cases (IHS)	(4) Malaria Cases (IHS)
Gold Deposits	0.0170	0.105*	0.0456	0.0512
	(0.0190)	(0.0586)	(0.209)	(0.326)
Mining Reform	-0.986***	-1.046***	-2.336***	-2.307***
	(0.142)	(0.144)	(0.509)	(0.507)
Gold Deposits x Mining Reform	0.0316	0.0310	0.0231	0.0221
	(0.0211)	(0.0217)	(0.0204)	(0.0206)
Observations	1,110	1,110	1,110	1,110
R-squared	0.557	0.558	0.600	0.601
Geographic Controls	No	Yes	No	Yes
Socioeconomic Controls	No	No	Yes	Yes
Mean Incidence	0.459	0.459	0.459	0.459

Notes: This table presents estimates for the effects that the number of gold mining deposits has on the log of malaria cases, identified using a DID based on the timing of the MAP reform as well as the distribution gold deposits. Standard errors are clustered at the provincial level. Each regression includes province and time fixed effects. Geographic controls include: elevation, mean air temperature, and mean precipitation. Socioeconomic controls include: the poverty incidence level, log of population, log of deforestation, ethnic fractionalization, religious fractionalization, average years of education of the household head, fraction of houses with roofs made of strong materials, fraction of houses with walls made of strong materials, fraction of households with access to electricity, access to indoor toilet and running water. Significant at $^*p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.3: Gold, MAP and the effect on malaria cases at the extensive margin, 2002 - 2015

	(1) Malaria Cases	(2) Malaria Cases	(3) Malaria Cases	(4) Malaria Cases
Gold	-1.483*	-1.973*	0.0773	0.501
	(0.782)	(1.104)	(6.496)	(5.712)
Mining Reform	-3.714***	-3.610***	-6.507***	-6.428***
	(1.062)	(0.933)	(1.814)	(1.784)
Gold x Mining Reform	2.257**	2.265**	2.270**	2.276**
	(0.913)	(0.919)	(0.918)	(0.920)
Observations	1,110	1,110	1,110	1,110
R-squared	0.558	0.558	0.606	0.607
Geographic Controls	No	Yes	No	Yes
Socioeconomic Controls	No	No	Yes	Yes
Mean Incidence	1.038	1.038	1.038	1.038

Notes: This table presents estimates for the effects that gold mining deposits have on the absolute number of malaria cases, identified using a DID based on the timing of the MAP reform as well as the distribution of gold deposits. Standard errors are clustered at the provincial level. Each regression includes province and time fixed effects. Geographic controls include: elevation, mean air temperature, and mean precipitation. Socioeconomic controls include: the poverty incidence level, log of population, log of deforestation, ethnic fractionalization, religious fractionalization, average years of education of the household head, fraction of houses with roofs made of strong materials, fraction of houses with walls made of strong materials, fraction of households with access to electricity, access to indoor toilet and running water. Significant at $^*p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.4: Gold, MAP and the effect on malaria cases at the intensive margin, 2002 - 2015

	(1) Malaria Cases	(2) Malaria Cases	(3) Malaria Cases	(4) Malaria Cases
Gold Deposits	-0.153	-0.215	-0.0470	-0.506
	(0.0982)	(0.350)	(0.827)	(1.239)
Mining Reform	-3.135***	-3.026***	-6.198***	-6.110***
	(0.854)	(0.737)	(1.795)	(1.770)
Gold Deposits x Mining Reform	0.242**	0.243**	0.215*	0.216**
	(0.112)	(0.112)	(0.108)	(0.108)
Observations	1,110	1,110	1,110	1,110
R-squared	0.550	0.550	0.597	0.598
Geographic Controls	No	Yes	No	Yes
Socioeconomic Controls	No	No	Yes	Yes
Mean Incidence	1.038	1.038	1.038	1.038

Notes: This table presents estimates for the effects that the number of gold mining deposits has on the absolute number of malaria cases, identified using a DID based on the timing of the MAP reform as well as the distribution gold deposits. Standard errors are clustered at the provincial level. Each regression includes province and time fixed effects. Geographic controls include: elevation, mean air temperature, and mean precipitation. Socioeconomic controls include: the poverty incidence level, log of population, log of deforestation, ethnic fractionalization, religious fractionalization, average years of education of the household head, fraction of houses with roofs made of strong materials, fraction of houses with walls made of strong materials, fraction of households with access to electricity, access to indoor toilet and running water. Significant at *$p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table A.5: Gold, MAP and the effect on other diseases, 2002 - 2015

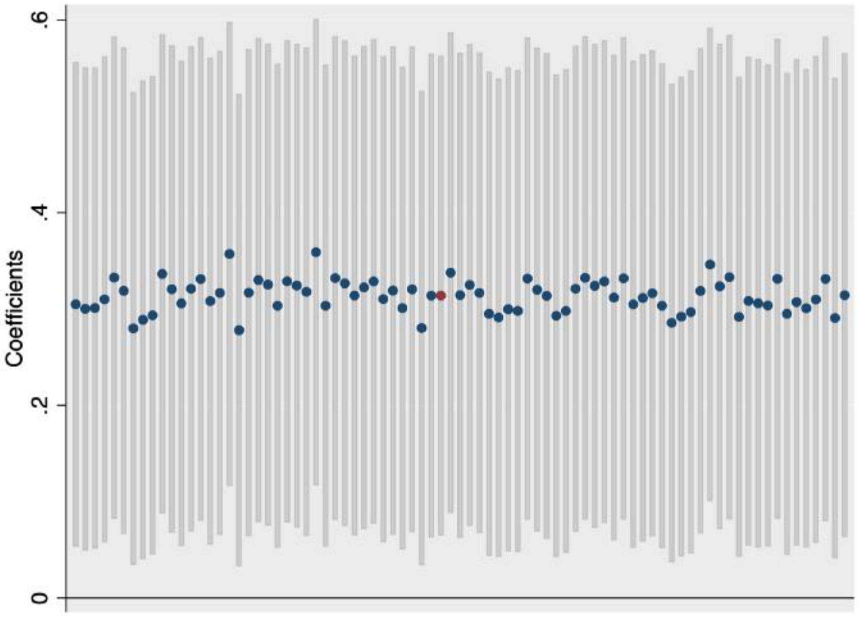
	(1) Dengue Cases	(2) HIV Cases	(3) Lower Respiratory Cases	(4) Pneumonia Cases	(5) Gastric or Duodenal Peptic Ulcer Cases
Gold	3.853***	-1.262	0.714	-0.906	1.441***
	(1.161)	(0.782)	(0.766)	(0.884)	(0.486)
Mining Reform	-1.992***	0.665***	0.669**	0.875***	0.00659
	(0.400)	(0.216)	(0.331)	(0.286)	(0.178)
Gold x Mining Reform	-0.0379	0.0883	0.0189	-0.0253	-0.000250
	(0.159)	(0.0619)	(0.0682)	(0.0582)	(0.0597)
Observations	1,110	1,110	1,104	1,104	1,025
R-squared	0.681	0.472	0.940	0.940	0.926
Geographic Controls	Yes	Yes	Yes	Yes	Yes
Socioeconomic Controls	Yes	Yes	Yes	Yes	Yes
Mean Incidence	5.273	0.293	181.265	347.637	55.304

Notes: This table presents estimates for the effects that gold mining has on the absolute number of Dengue, HIV, Lower Respiratory, Pneumonia and Gastric or Duodenal Peptic Ulcer cases, identified using a DID based on the timing of the MAP reform as well as the distribution of gold deposits. Standard errors are clustered at the provincial level. Each regression includes province and time fixed effects. The independent variables in columns 1-5 include: the poverty incidence level, log of population, log of deforestation, elevation, mean air temperature, mean precipitation, ethnic fractionalization, religious fractionalization, average years of education of the household head, fraction of houses with roofs made of strong materials, fraction of houses with walls made of strong materials, fraction of households with access to electricity, access to indoor toilet and running water. Significant at *$p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

A.3 Robustness tests

A.3.1 Change of comparison groups

Figure A.1: Gold, MAP and the effect on malaria at the extensive margin, 2002 - 2015



Notes: This figure presents a robustness test that estimates the effects that gold mining deposits has on the log of malaria cases by dropping each province one at a time, identified using a DID based on the timing of the MAP reform as well as the distribution of gold deposits. This exercise illustrates the stability of the estimated coefficients and standard errors. The red coefficient is the point estimate obtained in Table 1, column 4. Each regression includes province and time fixed effects. Standard errors are clustered at the provincial level. The independent variables include: elevation, mean air temperature, mean precipitation, the poverty incidence level, log of population, log of deforestation, ethnic fractionalization, religious fractionalization, average years of education of the household head, fraction of houses with roofs made of strong materials, fraction of houses with walls made of strong materials, fraction of households with access to electricity, access to indoor toilet and running water.

A.3.2 Controlling for health facilities

Table A.6: Controlling for health facilities, 2002 - 2015

	(1) Malaria Cases (IHS)	(2) Malaria Cases (IHS)	(3) Malaria Cases (IHS)	(4) Malaria Cases (IHS)
Gold	-0.0135	0.400	0.332	7.023**
	(0.143)	(0.717)	(1.639)	(3.479)
Mining Reform	-1.091***	-1.152***	-2.388***	-2.380***
	(0.162)	(0.163)	(0.503)	(0.501)
Gold x Mining Reform	0.361**	0.358**	0.319**	0.317**
	(0.164)	(0.165)	(0.149)	(0.150)
Health Facilities	-0.00511***	-0.0107***	-0.00528***	-0.0588*
	(0.000242)	(0.00388)	(0.000295)	(0.0313)
Observations	1,110	1,110	1,110	1,110
R-squared	0.561	0.562	0.604	0.604
Geographic Controls	No	Yes	No	Yes
Socioeconomic Controls	No	No	Yes	Yes
Mean Incidence	0.459	0.459	0.459	0.459

Notes: This table presents a robustness test that additionally controls for the number of rural health facilities within each province. Standard errors are clustered at the provincial level. Each regression includes province and time fixed effects. Geographic controls include: elevation, mean air temperature, and mean precipitation. Socioeconomic controls include: the number of health facilities, the poverty incidence level, log of population, log of deforestation, ethnic fractionalization, religious fractionalization, average years of education of the household head, fraction of houses with roofs made of strong materials, fraction of houses with walls made of strong materials, fraction of households with access to electricity, access to indoor toilet and running water. Significant at *$p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

A.3.3 Controlling for bodies of water

Table A.7: Controlling for bodies of water, 2002 - 2015

	(1) Malaria Cases (IHS)	(2) Malaria Cases (IHS)	(3) Malaria Cases (IHS)	(4) Malaria Cases (IHS)
Gold	-0.534	-0.620***	0.184	-0.622***
	(1.056)	(0.226)	(1.898)	(0.180)
Mining Reform	-1.059***	-1.102***	-2.377***	-1.103***
	(0.154)	(0.173)	(0.495)	(0.191)
Gold x Mining Reform	0.362**	0.341**	0.319**	0.371**
	(0.165)	(0.167)	(0.149)	(0.165)
Bodies of Water	1.56e-06	2.52e-07	7.16e-07	1.44e-07
	(2.73e-06)	(2.32e-07)	(2.08e-06)	(1.18e-07)
Observations	1,110	1,110	1,110	1,110
R-squared	0.562	0.325	0.604	0.438
Geographic Controls	No	Yes	No	Yes
Socioeconomic Controls	No	No	Yes	Yes
Mean Incidence	0.459	0.459	0.459	0.459

Notes: This table presents a robustness test that additionally controls for the total surface area of bodies of water within each province. Standard errors are clustered at the provincial level. Each regression includes province and time fixed effects. Geographic controls include: total surface area of bodies of water, elevation, mean air temperature, and mean precipitation. Socioeconomic controls include: the poverty incidence level, log of population, log of deforestation, ethnic fractionalization, religious fractionalization, average years of education of the household head, fraction of houses with roofs made of strong materials, fraction of houses with walls made of strong materials, fraction of households with access to electricity, access to indoor toilet and running water. Significant at *$p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

A.3.4 Sensitivity to squared values of temperature and precipitation

Table A.8: Sensitivity to squared values of temperature and precipitation, 2002 - 2015

	(1) Malaria Cases (IHS)	(2) Malaria Cases (IHS)
Gold	-0.502*	-0.101
	(0.261)	(1.552)
Mining Reform	-1.165***	-2.384***
	(0.161)	(0.498)
Gold x Mining Reform	0.358**	0.319**
	(0.163)	(0.148)
Observations	1,110	1,110
R-squared	0.565	0.606
Geographic Controls	Yes	Yes
Socioeconomic Controls	No	Yes
Mean Incidence	0.459	0.459

Notes: This table presents a robustness test that additionally controls for the squared terms of temperature and precipitation within each province. Standard errors are clustered at the provincial level. Each regression includes province and time fixed effects. Geographic controls include elevation, mean air temperature, mean air temperature squared, mean precipitation, and mean precipitation squared. Socioeconomic controls include: the poverty incidence level, log of population, log of deforestation, ethnic fractionalization, religious fractionalization, average years of education of the household head, fraction of houses with roofs made of strong materials, fraction of houses with walls made of strong materials, fraction of households with access to electricity, access to indoor toilet and running water. Significant at *p $<$ 0.10, ** p $<$ 0.05, *** p $<$ 0.01.

A.3.5 Sensitivity to changes in clustering of standard errors

Table A.9: Sensitivity to changes in clustering of standard errors, 2002 - 2015

	(1) Malaria Cases (IHS)	(2) Malaria Cases (IHS)	(3) Malaria Cases (IHS)	(4) Malaria Cases (IHS)
Gold	0.0427	-0.957	0.390	-0.442
	(0.188)	(0.632)	(1.650)	(1.668)
Mining Reform	-1.091***	-1.152***	-2.388***	-2.380***
	(0.214)	(0.189)	(0.541)	(0.535)
Gold x Mining Reform	0.361*	0.358*	0.319*	0.317*
	(0.189)	(0.192)	(0.174)	(0.176)
Observations	1,110	1,110	1,110	1,110
R-squared	0.561	0.562	0.604	0.604
Geographic Controls	No	Yes	No	Yes
Socioeconomic Controls	No	No	Yes	Yes
Mean Incidence	0.459	0.459	0.459	0.459

Notes: This table presents a robustness test that changes the clustering of the standard errors to the regional level. Each regression includes province and time fixed effects. Geographic controls include: elevation, mean air temperature, and mean precipitation. Socioeconomic controls include: poverty incidence level, log of population, log of deforestation, ethnic fractionalization, religious fractionalization, average years of education of the household head, fraction of houses with roofs made of strong materials, fraction of houses with walls made of strong materials, fraction of households with access to electricity, access to indoor toilet and running water. Significant at $*p < 0.10$, $** p < 0.05$, $*** p < 0.01$.

A.3.6 Controlling for quadratic time trends

Table A.10: Controlling for quadratic time trends, 2002 - 2015

	(1) Malaria Cases (IHS)	(2) Malaria Cases (IHS)	(3) Malaria Cases (IHS)	(4) Malaria Cases (IHS)
Gold	0.0436	-0.925***	2.668*	1.619
	(0.144)	(0.150)	(1.582)	(1.542)
Mining Reform	-0.107	-0.128	-0.0827	-0.110
	(0.105)	(0.117)	(0.103)	(0.117)
Gold x Mining Reform	0.361**	0.360**	0.361**	0.361**
	(0.163)	(0.164)	(0.154)	(0.155)
Observations	1,110	1,110	1,110	1,110
R-squared	0.556	0.559	0.583	0.584
Geographic Controls	No	Yes	No	Yes
Socioeconomic Controls	No	No	Yes	Yes
Province-Trends	Quadratic	Quadratic	Quadratic	Quadratic
Mean Incidence	0.459	0.459	0.459	0.459

Notes: This table presents estimates for the effects that gold mining deposits have on the log of malaria cases, identified using a DID based on the timing of the MAP reform as well as the distribution of gold deposits. Standard errors are clustered at the provincial level. Each regression includes province fixed effects and quadratic time trends. Geographic controls include: elevation, mean air temperature, and mean precipitation. Socioeconomic controls include: the poverty incidence level, log of population, log of deforestation, ethnic fractionalization, religious fractionalization, average years of education of the household head, fraction of houses with roofs made of strong materials, fraction of houses with walls made of strong materials, fraction of households with access to electricity, access to indoor toilet and running water. Significant at *$p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

A.3.7 Alternative transformation of the dependent variable

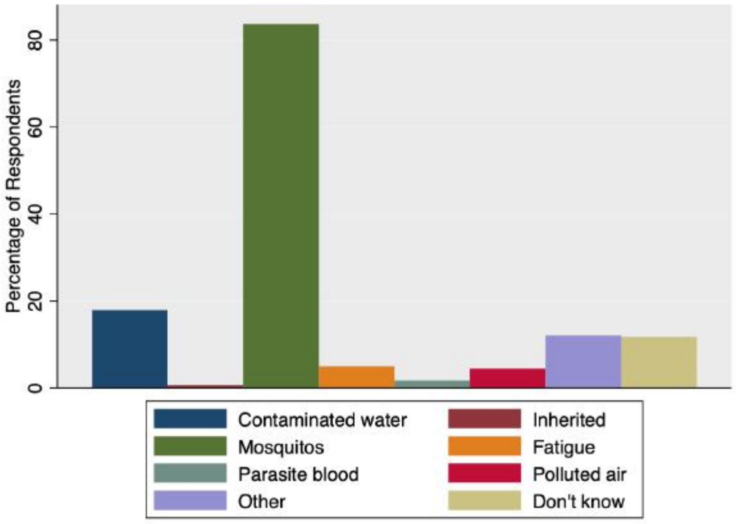
Table A.11: Alternative transformation of the dependent variable, 2002 - 2015

	(1) Log Malaria Cases	(2) Log Malaria Cases	(3) Log Malaria Cases	(4) Log Malaria Cases
Gold	0.0171	-0.737***	0.274	-0.341
	(0.115)	(0.197)	(1.292)	(1.229)
Mining Reform	-0.865***	-0.909***	-1.876***	-1.868***
	(0.132)	(0.130)	(0.397)	(0.396)
Gold x Mining Reform	0.299**	0.297**	0.268**	0.266**
	(0.130)	(0.131)	(0.118)	(0.119)
Observations	1,110	1,110	1,110	1,110
R-squared	0.567	0.568	0.610	0.610
Geographic Controls	No	Yes	No	Yes
Socioeconomic Controls	No	No	Yes	Yes
Mean Incidence	0.459	0.459	0.459	0.459

Notes: This table presents a robustness test that changes the definition of the dependent variable to $log(1 + MalariaCases)$. Each regression includes province and time fixed effects. Geographic controls include: elevation, mean air temperature, and mean precipitation. Socioeconomic controls include: poverty incidence level, log of population, log of deforestation, ethnic fractionalization, religious fractionalization, average years of education of the household head, fraction of houses with roofs made of strong materials, fraction of houses with walls made of strong materials, fraction of households with access to electricity, access to indoor toilet and running water. Significant at *p < 0.10, ** p < 0.05, *** p < 0.01.

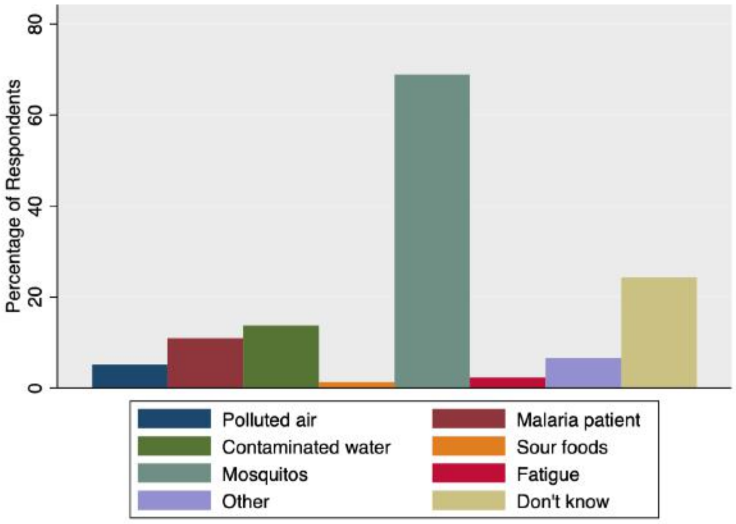
A.4 Additional figures using demographic and health survey (DHS) data

Figure A.2: What causes malaria?



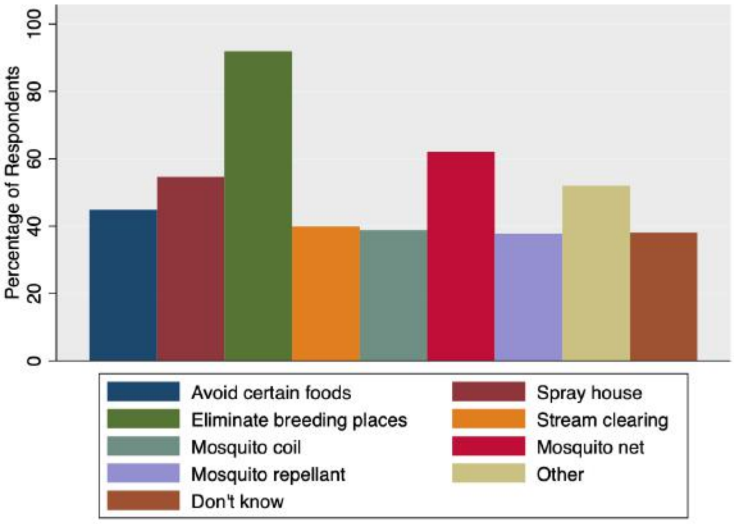
Source: Demographic and Health Survey (DHS) Data (2003)

Figure A.3: How is malaria spread?



Source: Demographic and Health Survey (DHS) Data (2003)

Figure A.4: Ways to prevent malaria



Source: Demographic and Health Survey (DHS) Data (2003)