DIGGING FOR VOTES: ELECTORAL RESPONSES TO MACHINE-LEARNING DETECTION OF ILLEGAL MINING*

Juan Felipe Riaño† Santiago Saavedra‡

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Abstract

What are the electoral consequences of providing government authorities with state capacity-enhancing technologies to detect illegal activities? Governments worldwide struggle to monitor illicit practices, especially when creating distributional tensions within communities. Some individuals may benefit economically from illegal activities, while others suffer from their negative externalities. How this divide ultimately affects political outcomes, specially political competition, remains uncertain, but we argue that hinges on whether most community members benefit from illegal practices or primarily bear their costs. To combat the rise of illegal mining, and as a part of an RCT, national and local authorities in Colombia received machine-learning predictions of illegal mine locations. We found that this intervention reduced illegal mining activities and significantly impacted political accountability: It increased voting concentration and generated a shift in support toward non-incumbent parties. Our findings align with a theory suggesting that both the proximity to disclosed illegal activities and their intensity influence the extent of electoral responses. Overall, our research highlights the transformative role of technology-driven state interventions in reshaping political behavior and reinforcing democratic accountability, especially in areas with weak state capacity.

Keywords: Monitoring technology, Political accountability, Illegal mining.
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†Department of Economics, Georgetown University, E-mail: jr2009@georgetown.edu
‡School of Economics, Universidad del Rosario. E-mail: santisaap@gmail.com

1 Introduction

Illegal mining[1] is a major obstacle to achieving sustainable development around the world (IISD, 2024; UN, 2002). Environmentally, it leads to severe land degradation, including deforestation, soil erosion, and water contamination with toxic substances like mercury and arsenic. Economically, it undermines legitimate extractive operations, reducing government revenue and disrupting the incentives to operate in formal markets. Its activities are usually linked to organized crime (Idrobo et al., 2014), human trafficking, and child labor (UNODC, 2023), exacerbating inequality and institutional instability in most affected areas (Bonilla Mejia, 2020). Understanding how governments can improve enforcement against this activity and the political economy incentives behind its regulation is crucial to mitigate its deleterious impacts worldwide.

Detecting and controlling illegal mining is particularly challenging in Low and Middle-Income Countries (Madimu, 2022; Rozo, 2020; Rettberg & Ortiz-Riomalo, 2016; Banchirigah, 2008). Officials often lack the technical capacity to enforce mining regulations and are sometimes unaware of the exact locations of the extractive activities in real-time (Johnson, 2019). Additionally, authorities in these countries face non-trivial incentive constraints because, despite its harmful effects, illegal mining can be highly economically beneficial for politically active segments of society. This dichotomy further complicates the endogenous implementation of policies to curb illegal mining, as their political support may depend on the distribution of the economic winners and losers from these reforms (Acemoglu & Robinson, 2000).

Considering these challenges, in this paper, we ask: What are the electoral consequences of providing a state capacity-enhancing technology to detect and reduce illegal mining? Do voters reward or punish the authorities responsible? How does this reaction reshape political competition? Voter responses to this type of intervention are theoretically ambiguous. On the one hand, monitoring technologies and subsequent enforcement can preserve environmental integrity, protect formal economic sectors, and increase government revenues, thus improving public welfare and, therefore, the support for curbing activities and the politicians/parties implementing them. On the other hand, enforcement measures may face significant resistance from local communities economically dependent on illegal mining, potentially leading to social unrest and backlash against authorities, particularly at the polls. Consequently, the political costs of acting against illegal mining can deter policymakers from exercising enforcement, making the effectiveness of this technology contingent upon the political importance of the impacted communities and the endogenous use of the technology when available. Importantly, these effects should then depend on

[1] Throughout the paper, "illegal mining" refers specifically to opencast mining operations conducted without officially approved mining titles. This activity should not be conflated with artisanal mining, which, despite often operating concurrently, differs significantly in its regulatory and operational context and consequences (Botchwey, Nest, & D'Emidio, 2023).

whether citizens can correctly attribute enforcement actions to the responsible tier of government.

To answer this question, we examine the electoral consequences of a Randomized Control Trial (RCT) that provided geo-located machine-learning predictions of illegal mining activities to local and national authorities in Colombia (Saavedra, 2024). The trial, launched in 2017, used a two-by-two factorial design that allocated all mining municipalities across three experimental arms and one control group. In the first arm, local authorities were informed about the new technology and five predicted locations of mining activities. In the second arm, only the national authority (the Air Force) was informed about predicted mine locations in the municipality. In the third arm, both local and national authorities received the information, while in the control group, no government agent received information. The intervention reduced illegal mining by 11 percentage points in the disclosed areas.[2] In this paper we document how the treatment affected voter behavior and the political accountability of incumbent parties post-intervention.

Since voters were not directly informed about the technology or its predictions during the implementation of the RCT, we hypothesize that the implications for the electoral outcomes differ substantially between local and national authorities. When mayors are informed, they are responsible for enforcement actions within their jurisdictions, and their actions are likely visible to the electorate, leading to a potential increase in political accountability as voters may reward or punish local incumbents based on their perceived actions against illegal mining. Conversely, when only national authorities are informed, the voters do not associate the enforcement action with local authorities, potentially reducing the political accountability of local incumbents. Therefore, we expect that electoral outcomes in municipalities where local authorities were informed will differ significantly from those where only national authorities were informed, with greater political repercussions for local incumbents in the former group. Moreover, we expect that such repercussions would work only through voter responses where mayors' actions were easier to observe (i.e., closer to disclosed mines). This distinction allows us to test whether voters correctly attribute responsibility for enforcement, rather than misattributing outcomes to the wrong level of government, a pattern often observed in response to national shocks such as oil price fluctuations or natural disasters (Wolfers, 2002; Cole, Healy, & Werker, 2012; Ashworth, de Mesquita, & Friedenberg, 2017).

Our analysis proceeds in four steps. In the first part of the paper, we propose a theoretical model that studies the decision of mayors to act depending on enforcement costs, voters benefited by illegal mining, and rents while in office. The model shows that when enforcement costs are high compared to office rents, there is no enforcement and vote concentration is low. But when the enforcement cost is low and there is a larger fraction

[2] According to Saavedra (2024) this intervention leads to similar reductions in illegal activities regardless of the authority informed. The overall impact depends on the assessment of negative spillovers.

of voters affected by mining, the mayor enforce illegal mining reductions that leads to a concentration of votes. We interpret this concentration not as a loss of competition per se but as evidence that voters coordinate around clearer political options once enforcement becomes visible and attributable.

Based on these results, in the second part of the paper, we document how, despite a significant reduction in illegal mining, there are no significant intervention effects on overall political participation or continuity outcomes. More specifically, we find no effects on turnout, blank or invalid votes. Similarly, we find that the winning party in 2019 was not typically the incumbent in 2015, and that the local treatment did not significantly affect the probability of the incumbent parties running again or their chances of being re-elected.

In the third part of the paper, we document how this intervention may have helped resolve the collective action problem between green (i.e., environmentally focused) and non-green political preferences. The disclosure of illegal mining activities and the resulting issue salience appear to have facilitated a re-composition of votes within treated municipalities. This result is further supported by the slight increase in the effective number of green parties, their vote share, and the probability of coalitions with green parties winning in municipalities that received the local treatment. Crucially, we document how in municipalities where mayors received predictions of illegal mining, there is a notable increase in vote share concentration, as evidenced by higher Herfindahl-Hirschman Indexes (HHI) with respect to vote shares compared to control municipalities. This trend contrasts with the increasing political competition in control municipalities over the same period. Importantly, this increase in vote concentration did not result from a reduction in the total number of running parties or through changes in turnout rates or voter registration but rather from a significant concentration of vote shares towards the winning party in the treated municipalities. This pattern is consistent with voters accurately attributing local enforcement success and coordinating politically around it, rather than reacting through misinformation or partisan bias.

Even though enforcement did not alter overall participation or incumbency prospects, it significantly changed the structure of political competition. By increasing vote concentration, the intervention made political preferences more cohesive and reduced fragmentation, consistent with voters coordinating on clearer platforms when illegal mining enforcement became salient. This is an important dimension of political accountability because it shows how state-capacity interventions can reconfigure electoral markets beyond simple turnout or incumbency effects.

In the final part of the paper, we explore the mechanism driving this voter response based on the predictions of the model. We argue that the observability of the mayors' enforcement actions by citizens drives the political accountability results. We show that the estimated electoral effects for municipalities where mayors were treated are driven only by polling stations close to mining activity.

This paper contributes to three strands of the economics literature. First, we contribute to the recent literature on the electoral effects of mayors' actions. The only other paper we are aware is (Goyal, 2024), that finds that road provision in India fails to boost electoral support for the ruling party. We similarly find no electoral effects for incumbents, but we are able to study heterogeneous voters responses.

Second we contribute to the literature on information provision experiments and electoral effects of informing voters (Haaland, Roth, & Wohlfart, 2023; Garbiras-Diaz & Montenegro, 2022; Kendall, Nannicini, & Trebbi, 2015; Humphreys & Weinstein, 2012; Banerjee, Kumar, Pande, & Su, 2011; Arias, Larreguy, Marshall, & Querubin, 2022) Information about a widespread and hard-to-detect illegal activity and its effects on electoral outcomes, in general, and voter concentration, in particular.

Finally, we contribute to the literature on interventions that strengthen local state capacity (Knebelmann, Pouliquen, & Sarr, 2023; Bergeron, Balan, Tourek, & Weigel, 2022). We employ a monitoring technology that identifies possible illicit mining sites and discloses this information to government agents, thereby enhancing their enforcement capabilities. Moreover, this technology is now publicly available (through CoMimo) and is being shared with local governments, offering a scalable solution for reducing illegal activities and informing public policy.

The rest of the paper is organized as follows. Section 2 presents the institutional background on illegal mining and elections in Colombia. Section 3 presents out theoretical framework and the model that discipline our analysis. Section 4 presents the empirical strategy and the experimental design. Section 5 presents the main empirical results and finally Section 6 concludes.

2 Institutional Background

2.1 Mining titling, enforcement, and illegal mining in Colombia

According to the Colombian Constitution of 1991, all mineral resources are owned by the National Government. Therefore, if landowners wish to mine on their land, they still have to obtain a mining title from the National Government. Local governments are responsible for monitoring and enforcing mining regulations. Consequently, upon detecting unauthorized mining activity, local authorities must issue a closure notice. If the closure notice is ineffective, local governments are required to report the violation to the National Government, which then takes physical enforcement actions through the National Police and the Air Force to destroy machinery and imprison miners. As of 2022, 73% of the mined area in Colombia is mined illegally, i.e., without a mining title. These illegal mining activities are often linked to organized crime, with armed groups controlling mining operations and contributing to significant environmental damage and human rights abuses.

Figure 1: Opencast mining operations

Notes: This figure showcases three illustrative images of opencast mining operations resulting from illegal mining activities in Colombia.

Throughout this paper, "illegal mining" will denote opencast mining operations carried out without officially approved mining titles (see, e.g., Figure 1). This term should not be confused with artisanal mining, which, although often occurring simultaneously, differs significantly in its regulatory and operational context as well as its consequences (Botchwey et al., 2023).

2.2 Local elections in Colombia and the timing of the intervention

In Colombia, voting is not mandatory, but around half of eligible citizens turnout in all elections. All municipalities hold their mayoral elections on the same date every four years. These elections coincide with those for state governors, state assemblies, and municipal councils. Colombian mayors are elected by majority vote and serve a single term, with no option for re-election.

Political parties While political parties in Colombia receive some state funding and have traditional roots, they remain relatively weak. The political landscape is often shaped by particularistic politics and the influence of local elites (Fergusson & Riaño, 2013). Environmental parties are marginal in most municipalities and do not consistently contest elections. Non-traditional and environmentally oriented parties, such as *Partido Verde*, *Polo Democratico*, and *Union Patriotica*, remain on the political periphery and struggle to maintain consistent electoral participation. (Neumayer, 2004)

RCT Timing around elections of 2015 The mayors who received the treatment letters studied in this paper were elected in October 2015 and were in office from January

1st, 2016, until December 31st, 2019. The information letters were sent in September 2017 and February 2019, so the mayors had time to act on illegal mining before the 2019 election. The elections analyzed in this paper took place in October 2019.

3 Theoretical Framework

To discipline our analysis, we consider a two-period electoral game played within a representative municipality. There is an incumbent party, denoted by I, which holds office in Period 1 and faces electoral competition from a set of challenger parties $\{C_1, C_2, \ldots, C_N\}$. The population of citizens is a continuum with total mass 1. A fraction $\lambda \in (0, 1)$ of the population ("pro-mining") economically benefits from illegal mining, while the remaining fraction $1 - \lambda$ ("anti-mining") suffers from the externalities (e.g., environmental damage).

State of Illegal Mining. Let $M_1 \in \{\text{Low}, \text{High}\}$ denote the (ex ante) state of illegal mining in Period 1. We assume Nature draws $M_1 = \text{High}$ with probability p, and Low with probability $1 - p$. The incumbent does not observe M_1 directly but faces a private binary signal $\ell \in \{\ell_L, \ell_H\}$. The *informativeness* of this signal, $\theta \in (0.5, 1]$, measures the probability that ℓ_H (resp. ℓ_L) correctly indicates $M_1 = \text{High}$ (resp. Low). We interpret θ as the initial *state capacity* or detection technology available to the incumbent: higher θ corresponds to more reliable detection of illegal mining. Critically, θ is privately known by the incumbent; voters and challengers hold only a prior belief about θ.

In our empirical application, a randomized trial provides mayors (the incumbents) with geo-located predictions of illegal mining, thus effectively raising θ. Voters and challengers, however, remain uncertain about the exact value of θ, making the incumbent's enforcement actions informative about the state of the nature and the incentives of the politician.

Policy Choices and Costs After observing (ℓ, θ) in Period 1, the incumbent chooses an enforcement level $r_1 \geq 0$. A higher r_1 represents more intensive (and costlier) crackdowns on illegal mining. The cost of this enforcement is $c(r_1, M_1)$ which satisfies the following properties:

1. For any fixed M_1, $c(\cdot, M_1)$ is strictly increasing in r_1.
2. For each $r_1 > 0$, $c(r_1, \text{High}) > c(r_1, \text{Low})$, reflecting higher enforcement costs when illegal mining is widespread.
3. If $r_1 = 0$, then $c(0, M_1) = 0$ (no enforcement, no cost).

Timing The sequence of events is as follows:

1. *Nature* It draws M_1 (Low or High) with probabilities $\{1 - p, p\}$, and simultaneously draws a private signal ℓ. The incumbent observes (ℓ, θ) but not M_1.
2. *Period 1 (Incumbent's Action).* The incumbent chooses $r_1 \geq 0$, incurring a cost $c(r_1, M_1)$.
3. *Mining Evolution.* The state of illegal mining transitions to $M_2 = M_1 - r_1 \cdot \mathbb{1}(r_1 > 0) + \bar{m} \cdot \mathbb{1}(r_1 = 0)$, where $\bar{m} > 0$ captures the growth of illegal mining in the absence

of enforcement.

4. *Campaign Phase.* The incumbent and challengers simultaneously announce their intended Period 2 enforcement levels, $\{r_2^I, r_2^{C_1}, \ldots, r_2^{C_N}\}$.
5. *Election.* Voters observe r_1 but not M_1, ℓ, or θ. Each voter supports the candidate whose proposed (r_2) maximizes her expected utility. The candidate with the majority of votes (or winning the tie-breaker) takes office in Period 2.
6. *Period 2 (Policy Implementation).* The winning candidate implements her proposed enforcement level r_2, incurring the cost $c(r_2, M_2)$. Citizens receive their payoffs based on the resulting extent of illegal mining.

Utilities, Voting, and Political Competition A fraction λ of citizens (pro-mining) enjoys higher utility when illegal mining is more prevalent; let their utility be $u_B(M)$ with $u_B'(M) > 0$. The remaining $1 - \lambda$ (anti-mining) suffers from mining-related externalities and prefers a lower level of illegal mining; let their utility be $u_H(M)$ with $u_H'(M) < 0$. Hence, pro-mining citizens prefer weaker enforcement, whereas anti-mining citizens favor stricter crackdowns.

At the time of the election, each voter observes only r_1 and the proposed $\{r_2^I, r_2^{C_j}\}$. Voters form Bayesian beliefs about M_1 (and possibly θ) based on r_1. Each citizen then votes for the candidate whose second-period policy yields the highest expected utility given her type.

Every party values winning office in Period 2, which yields a payoff $R > 0$. Thus, the incumbent's payoff is

$$\Pi_I \;=\; \mathbf{1}\{\text{I wins}\} \cdot R_I \;-\; c(r_1, M_1) \;-\; \mathbf{1}\{\text{I wins}\}\, c(r_2^I, M_2), \tag{1}$$

while challenger C_j has

$$\Pi_{C_j} \;=\; \mathbf{1}\{\text{C}_j \text{ wins}\} \cdot R_j \;-\; \mathbf{1}\{\text{C}_j \text{ wins}\}\, c(r_2^{C_j}, M_2). \tag{2}$$

Because only the incumbent observes (ℓ, θ), her first-period enforcement can signal information about the extent of illegal mining.

3.1 Strategies and Second-Period Equilibrium

Definition 1. *Strategy Profile: A tuple* $\Big\{\sigma_{I,1}(\ell,\theta), \sigma_{I,2}(\ell,\theta), \{\sigma_{C_j}(r_1)\}, \{\sigma_i\big(r_1,\ r_2^I,\ \{r_2^{C_j}\}\big)\}\Big\}$ *constitutes a strategy profile for this game, if:*

- The Incumbent's Strategy *satisfies:*

$$\sigma_{I,1}(\ell,\theta) = r_1 \quad \textit{and} \quad \sigma_{I,2}(\ell,\theta) = r_2^I.$$

That is, the incumbent chooses a first-period enforcement level r_1 after observing (ℓ, θ), *and then announces (before the election) a second-period policy* r_2^I.

- *The Challengers' Strategies: For each challenger* C_j *satisfies*

$$\sigma_{C_j}(r_1) = r_2^{C_j},$$

i.e., after observing r_1 *(but not* ℓ *or* θ*), challengers propose a policy* $r_2^{C_j}$*, while,*

- *The Voters' Strategies follow:*

$$\sigma_i\big(r_1,\ r_2^I,\ \{r_2^{C_j}\}\big)\ \in\ \{I, C_1, \ldots, C_N\}.$$

That is, each voter i *chooses who to vote for based on the strategies of the rest of the players.*

Definition 2. *Perfect Bayesian Equilibrium (PBE): A profile of strategies and beliefs* $\Big\{\sigma_{I,1}(\ell,\theta), \sigma_{I,2}(\ell,\theta), \{\sigma_{C_j}(r_1)\}, \{\sigma_i\big(r_1,\ r_2^I,\ \{r_2^{C_j}\}\big)\}, \mu(r_1)\Big\}$*, where* $\mu(r_1)$ *denote voters' posterior beliefs about* (ℓ,θ) *(and hence about* M_1*) upon observing* r_1*, constitutes a PBE if:*

1. *All players' strategies are sequentially rational given their beliefs.*
2. *On the equilibrium path, beliefs follow from Bayes' rule wherever possible.*

In such equilibria, the incumbent's decision to crack down or not in Period 1 may fully or partially reveal her private information about illegal mining's severity, thereby shaping second-period electoral competition and policy choices.

Assumption 1. *We impose the following simplifying assumptions:*

1. *The incumbent's first-period enforcement is binary:* $r_1 \in \{0, 1\}$.
2. *Let* $c_L = c(1, \mathit{Low})$ *and* $c_H = c(1, \mathit{High})$.
3. *The payoff from winning office is* $R > 0$.
4. *The fraction of pro-miners* $\lambda \in (0, 1)$

Under these assumptions, we can characterize three canonical equilibrium outcomes:

Proposition 1 (Pooling Equilibrium)**.** *If* $c_H > R$*, then in every PBE the incumbent chooses* $r_1 = 0$ *regardless of her signal. All types of incumbent "pool" on no enforcement, preventing voters from learning about illegal mining. Consequently, second-period policies exhibit minimal differentiation, vote fragmentation is high, and overall vote concentration remains low.*

Proof. When $c_H > R$, even an incumbent suspecting $M_1 = \text{High}$ finds enforcement ($r_1 = 1$) too costly relative to the office prize R. Hence, no type of incumbent has an incentive to deviate from $r_1 = 0$. Voters cannot distinguish high from low signals, so announced policies converge, and the vote share fragments across multiple parties. □

Proposition 2 (Separating Equilibrium with Incumbent Win). *If $R \geq c_H$ and the fraction of anti-mining voters $(1 - \lambda)$ is large enough, there exists a separating PBE in which the incumbent enforces ($r_1 = 1$) only upon receiving ℓ_H. This credibly signals that illegal mining is likely severe. As anti-mining voters reward early enforcement, the incumbent secures re-election with a concentrated vote share.*

Proof. If $R \geq c_H$, the office prize can offset the cost of enforcement in the event M_1 is high. Anti-mining voters prefer enforcement if M_1 is likely high, so observing $r_1 = 1$ signals ℓ_H. Thus, the incumbent captures the anti-mining majority. If ℓ_L is received (i.e., M_1 is likely low), the incumbent chooses $r_1 = 0$ to avoid the unnecessary cost c_L. Voters interpret $r_1 = 0$ as "likely low" and do not punish the incumbent. This yields high vote concentration in favor of I. □

Proposition 3 (Separating Equilibrium with Challenger Win). *Suppose $R \geq c_H$ but λ (the fraction of pro-mining voters) is sufficiently large. Even though the incumbent enforces upon ℓ_H, thereby signaling high illegal mining, the pro-mining majority is alienated by such enforcement and coordinates on a single challenger offering low (or zero) enforcement in Period 2. Consequently, a challenger wins and vote concentration increases.*

Proof. If pro-mining voters form a majority, they oppose strong crackdowns. Observing $r_1 = 1$ identifies the incumbent as "tough on mining," so pro-mining citizens rally around a challenger promising minimal enforcement in Period 2. This consolidated support ensures the challenger wins decisively. □

3.2 Connection to the RCT and Empirical Implementation

In our randomized control trial setting, an information treatment provides mayors (the incumbents) with high-quality data about illegal mining (θ increases). According to the model:

- If $R \geq c_H$, the improved precision θ makes the incumbent more likely to detect (and thus crack down on) severe illegal mining, which induces a *separating* outcome. Depending on whether $\lambda < 0.5$ or $\lambda > 0.5$, vote concentration can favor either the incumbent (Proposition 2) or a single pro-mining challenger (Proposition 3).
- If $c_H > R$, no enforcement occurs (i.e., a pooling equilibrium), and the vote remains fragmented (Proposition 1).

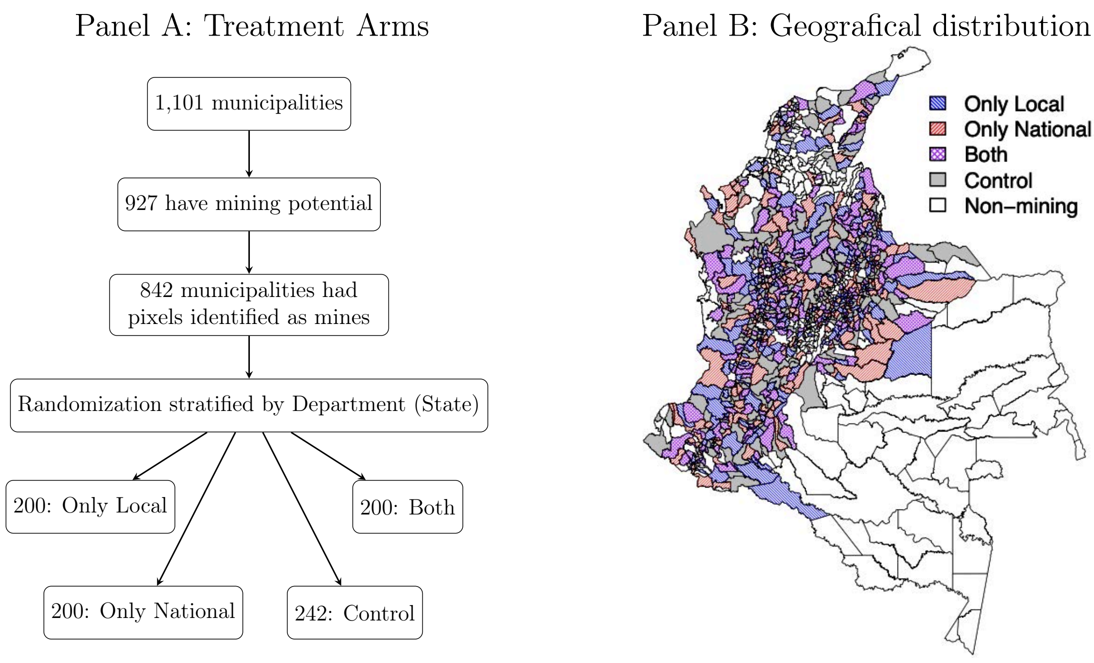
Consequently, we can derive two main empirical predictions. First, the *information treatment* potentially raises vote concentration when office benefits outweigh enforcement costs. Second, the identity of the winning candidate (incumbent vs. challenger) hinges on whether a pro-mining or anti-mining majority prevails (λ vs. $1 - \lambda$). Our empirical analysis aligns with these predictions by examining the effects of the information treatment on electoral outcomes. More specifically, by looking at its effects on vote concentration and the direction of voter support (toward “green” parties or those favoring extractive activities).

4 Empirical Framework

4.1 Study design

Using satellite data and a newly developed machine-learning algorithm that identifies areas likely to be mined, Saavedra (2024) generated 30×30 meter pixel predictions of mining activity to share with local and national authorities. The overall information of the technology and 5 predictions per municipality were disclosed in a randomized control trial. The experimental design consisted of a 2×2 factorial scheme including all 842 municipalities with mining potential in the subsoil and with at least one predicted mine. For half of the municipalities, mayors received a letter with information on the technology and its five predictions. For an orthogonal half of municipalities, a national authority, the Air Force, received them. Figure 2 presents the resulting four treatment arm design with the number of municipalities included in each group (Panel A) and the geographical distribution of those municipalities across treatment arms (Panel B).

Figure 2: Structure of the experiment



Notes: This figure presents the process of filtering and randomization of the municipalities across treatment arms in Panel A and the geographical distribution of the treatment arms in Panel B.

The information was distributed through treatment letters that were directly addressed to the mayor’s inbox or to a contact in the Air Force. All letters were sent as “Freedom of Information Act” requests (*Derechos de peticion*) appealing for the verification of such mining activities. Once mining activity was detected, mayors could have assessed its legality based on the geo-referenced mining permits issued by the National Government. Figure 3 presents one example of identified mines (highlighted purple squares) and a legal mining title (the yellow polygon). All mines outside the mining titles are considered illegal.

Figure 3: Example of mining predictions, legal and illegal mining

Notes: This figure shows in purple 30×30 meter pixel predictions of mining activity according to the machine learning algorithm within one municipality in Cordoba. It also indicates in yellow a legal mining title. Mining activities outside the legal title are considered illegal mining.

4.2 Data and Summary Statistics

4.2.1 Electoral data

We used several data sources to measure the electoral consequences of interventions targeting illegal mining in municipalities where information about illegal mining activities was disclosed. First, we collect electoral data from the official Colombian electoral authority, the Registraduria Nacional del Estado Civil (RNEC) [3], the Electoral Observation Mission (MOE) [4], and the Center for Economic Development Studies (CEDE) [5]. Second, we use expert-validated data on gold mining provided by the United Nations and incorporate validations of mining activity predictions revealed by geolocated machine learning predictions of mining activity.

Our analysis of 842 municipalities in which illegal mining has been identified, some of which revealed to them the coordinates of illegal mining in their territory using an RCT. In order to identify deeper effects on the intervention, we analyze both the election results at the municipal and polling station levels. First, at the municipal level, we work with CEDE and MOE electoral information for the years 2015 and 2019 in which there were regional elections for mayors. Those sources of information let us relate and compare the

[3] RNEC is the official institution that has in its duties develop the electoral act in Colombia; count and store data related with the electoral act. Official website: https://wapp.registraduria.gov.co/

[4] MOE is a platform of civil society organizations that promotes the exercise of civil and political rights of citizens.

[5] Center for Economic Development Studies, School of Economics, Universidad de los Andes.

electoral performance of the parties and independent candidates in the regional elections before and after the intervention.

In order to extract deeper and more localized effects, we also worked with RNEC information at the polling station in the mining municipalities. There are 7013 polling stations in 2015 and 7341 in 2019. However, only 6218 could be perfectly related, the rest were segmented by those that belong to the urban municipal seat and those that belong to the rural area of the municipality. After segmentation, we assigned them a pseudo-artificial polling station that stores all the information of the different polling stations voting points that belong to it. It gives us a total of 6816 units of observation at the polling-point station level.

Table A-1 presents the summary statistics for electoral variables at the level of the polling point station for the years 2015 and 2019. In our analysis, the green parties are non-traditional and environmentally oriented parties. The incumbent represents the performance of the winning party in the 2015 election in the 2019 mayoral election.

4.3 Mining activities and titling

We used data on mining activity at the municipality and 1kmX1km grid square level from Saavedra (2024). That paper used satellite data and machine learning to detect open pit mining every year. The legality of the detected mining activity is determined with the map of legal titles from the National Mining Agency.

4.4 Econometric specifications

We study the effect of providing state capacity-enhancing technologies to detect illegal activities on electoral results by estimating the following reduced form specification:

$$\Delta y_m^{2019-2015} = \beta^L \cdot Local_m + \beta^N \cdot National_m + \beta^B \cdot Both_m + \gamma_{d(m)} + \varepsilon_m, \qquad (3)$$

where $\Delta y_m^{2019-2015}$ is the change in electoral outcome y from 2015 to 2019 in municipality m at department d. The variables $Local_m$ and $National_m$ are dummies that indicate, respectively, whether only the local authorities (L) or the Air Force (N) were informed about predicted mines in municipality m. Similarly, $Both_m$ is an indicator of the treatment in which both authorities (L and N) received the disclosure mines. Finally, $\gamma_{d(m)}$ represents department fixed effects and ε_m an error term. The randomization strata are at the department level. We report robust standard errors, but do not cluster at the strata level since there are only 25 departments with mining municipalities in the sample.

The coefficients of interest are β^L, β^N, and β^B, which capture the impact of the different treatments on the change in electoral outcomes with respect to the municipalities in the control group. Since treatments were randomized, we can give the estimated β's a causal interpretation.

We run similar specifications at the poll station level using equations of the form:

$$\Delta y_p^{2019-2015} = \alpha^L \cdot Local_{m(p)} + \alpha^N \cdot National_{m(p)} + \alpha^B \cdot Both_{m(p)} + \gamma_{d(p)} + \varepsilon_p, \quad (4)$$

We analyze multiple electoral outcomes y_p. We look at changes in electoral census, turnout, the fraction of blank votes, the fraction of invalid votes, the vote share of winning parties, and indicators of re-election and participation of incumbent parties. To measure changes in political contestation, we compute the municipal measures of vote share concentration using Herfindahl-Hirschman Indexes (HHIs). Such indexes are calculated as $\sum_{p=1}^{P_m} s_p^2$, for each municipality where $1, \cdots, P_m$ are the N_m parties running in municipality m, and s_p represents the vote share of party p in municipality m. To account for the potential variation in the number of parties and to make the indexes comparable across space and time, we also compute standardized HHIs given by $\frac{\left(\sum_{p=1}^{P_m} s_p^2 - \frac{1}{N_m}\right)}{1-\frac{1}{N_m}}$. We also look at electoral results of green parties defined as those part of the *Partido Alianza Verde, UP, Polo Democratico, and Colombia Humana.*

5 Empirical Results

Effect of the intervention on illegal mining

We start our analysis by re-stating the effect of the intervention on the percentage of gold-mined areas within municipalities that ended up being mined illegally after the intervention. Figure A-1 replicates the main results in (Saavedra, 2024) by documenting the significant and sizable 10 percentage points reduction in illegal mining in treated municipalities compared to its evolution in control municipalities. Although there was a reduction in illegal mining across all treatment groups, we do not anticipate discovering any effects on political outcomes in areas where only the National government was informed of the potential locations of illegal mines. This is because the voter would not relate the enforcement to the mayor, and would not exhert political accountability in the urns. Although the mayor could claim credit for the actions of the national government, we do not observe, for the most part, any effects on political outcomes within municipalities where only theNational Air Force was informed.

Balance tests

We continue our analysis by documenting and verifying the balance in electoral outcomes at baseline. Since the randomization blocks in the original intervention did not consider these outcomes, it could have been the case that some municipalities were systematically different across treatment groups, preventing us from analyzing convincingly any differences post-intervention. Table A-2 presents our balance results for electoral outcomes at the municipality level –our level of randomization.[6] We find no systematic differences across

[6] Please refer to Saavedra (2024) who reports the balance tests with respect to non-electoral outcomes.

treatment arms in turnout, blank ballots, or invalid votes as a proportion of the electoral census, nor differential levels in the number of individuals registered to vote.

These findings are crucial for two reasons. First, they provide confidence that the randomization successfully controlled for pre-intervention differences in the electoral domain, ensuring that any observed differences in post-intervention outcomes can be attributed to the treatment rather than to pre-existing discrepancies among municipalities. Second, confirming balance in electoral indicators–particularly turnout and vote invalidation–strengthens the internal validity of the study by ruling out the possibility that the municipalities in one treatment arm might have exhibited systematically higher or lower political engagement from the outset. This verification lays the groundwork for the subsequent analysis of incumbent party outcomes by showing that our comparison groups started from effectively the same baseline conditions and political participation.

Continuity outcomes

Having corroborated balance at baseline, we examined the changes in continuity outcomes for the incumbent parties, as outlined in equation 3. Table A-3 shows the results that compare the differences in continuity outcomes between 2019 and 2015. We found no significant changes in the likelihood of running for office or being reelected across the treatment groups, nor did we observe any differences in the level of support for the incumbent parties among those who chose to run. These findings effectively rule out the scenarios in our model where the incumbent party would win specifically in the areas where information was disclosed to local authorities and reductions in illegal mining occurred.

Because we do observe tangible reductions in illegal mining, the data effectively rules out the "pooling" scenario (Proposition 1), in which no enforcement occurs. Instead, the model's remaining separating equilibria indicate that even when incumbents choose to enforce, electoral benefits may fail to materialize if a sufficiently large pro-mining constituency punishes them for crackdowns (Proposition 3). Our null findings on incumbents' continuity suggest the latter mechanism may be at play: despite a real decline in illegal mining, local authorities did not translate enforcement into reelection success.

Building on this theoretical framework, we now turn to analyzing whether vote shares became more concentrated following the intervention.

Vote concentration

According to Propositions 2 and 3, separating equilibria can increase voter polarization around either the incumbent or a unified challenger, depending on the makeup of pro-mining versus anti-mining constituencies. In the sections that follow, we scrutinize these predictions by testing for shifts in the distribution of votes and exploring whether the reduction in illegal mining translated into a more concentrated electoral field.

We find an increase in vote concentration in the municipalities where the mayor was informed of the illegal mining detection technology. Table 1 presents the results of

Table 1: Changes in voter concentration: Municipality level

Dep. Variable	Difference in HHI	Difference in HHI standardized	Difference in parties	Difference in total votes	Difference in winner's vote share
	(1)	(2)	(3)	(4)	(5)
Local	0.0257**	0.0332**	-0.0034	48.7458	0.0299**
	(0.0120)	(0.0130)	(0.1878)	(217.9159)	(0.0132)
National	0.0074	0.0190	-0.0817	6.6699	0.0116
	(0.0127)	(0.0152)	(0.1817)	(192.0426)	(0.0136)
Both	0.0305**	0.0363**	-0.1665	283.0692	0.0316**
	(0.0125)	(0.0143)	(0.1836)	(261.3498)	(0.0138)
Observations	842	842	842	842	842
R-squared	0.0247	0.0478	0.0313	0.1249	0.0217
Mean dep var control	-0.0242	-0.00790	0.397	924.5	-0.0252

Notes: Results of estimating equation (3) at the municipality level for different dependent variables: Column (1) difference in the Herfindahl-Hirschman Index (HHI). Column (2) standardized HHI. Column (3) number of parties participating in the election. Column (4) difference in the total number of votes, and Column (5) difference in the vote share of the winning candidate. All reported differences are calculated between the 2019 and 2015 elections. Robust standard errors are provided in parentheses. Statistical significance is indicated as follows: *** p<0.01, ** p<0.05, * p<0.1.

estimating equation (3) at the municipality level for accountability measures. Column 1 and 2 show that there is an increase in the Herfindahl-Hirschman Index when the mayor was informed, regardless of whether he was the only one informed (first row, "Local" coefficient) or the National government was also informed (third row, "Both" coefficient). But when the National government was the only one informed, there are no changes in the HHI. This could be explained by the voters observing the National government acting alone against illegal mines, but as they did not observe the local government in the enforcement operation, they do not react in the local elections ballot box. Columns 3 and 4 show that these HHI changes cannot be attributed to changes in the number of parties or the total votes. Column 5 suggests the change in the HHI is partly driven by an increase in the vote share of the winning candidate (that not necessarily is the incumbent as we saw in the previous table).

Table 2 is analogous to Table 1, but is estimated at the poll station level. We confirm the increase in the HHI and the vote share of the winner when the mayor is informed. Column 1 suggests there is also an increase when only the National government is informed, but it is not robust when calculating the standardized HHI in column 2.

Next we study heterogeneity of the HHI effects by characteristics of the poll station. We first estimate with generalized random forests the variables that are more important

Table 2: **Changes in voter concentration: Polling Station level**

Dep. Variable	Difference in HHI	Difference in HHI standardized	Difference in the municipality winner's vote share	Difference in the polling station winner's vote share	Difference in total votes
	(1)	(2)	(3)	(4)	(5)
Local	0.0297***	0.0305***	0.0307***	0.0282***	-1.4133
	(0.0052)	(0.0065)	(0.0074)	(0.0057)	(20.0549)
National	0.0130**	-0.0013	0.0151**	0.0122**	-4.8229
	(0.0051)	(0.0062)	(0.0074)	(0.0057)	(20.8671)
Both	0.0193***	0.0243***	0.0189***	0.0213***	11.5180
	(0.0050)	(0.0061)	(0.0071)	(0.0055)	(21.5121)
Observations	6,806	6,806	6,806	6,806	6,806
R-squared	0.0289	0.0205	0.0314	0.0234	0.0189
Mean dep var control	-0.0352	-0.00212	-0.104	-0.0334	98.20

Notes: Each observation corresponds to a polling station. All reported differences are calculated between the 2019 and 2015 elections. Column (1) presents the difference in the HHI; similarly, Column (2) reports the standardized differences in HHI. Column (3) reports the difference in the vote share of the winning candidate while Column (4) of the Polling station (most voted candidate). And lastly, Column (4) presents the difference in the total number of votes. Robust standard errors are provided in parentheses. Statistical significance is indicated as follows: *** p<0.01, ** p<0.05, * p<0.1.

for heterogeneous effects. We find that the vote share of the green party in 2015 and the distance from the polling station to the closest mine are the two most important (See Table A-4).

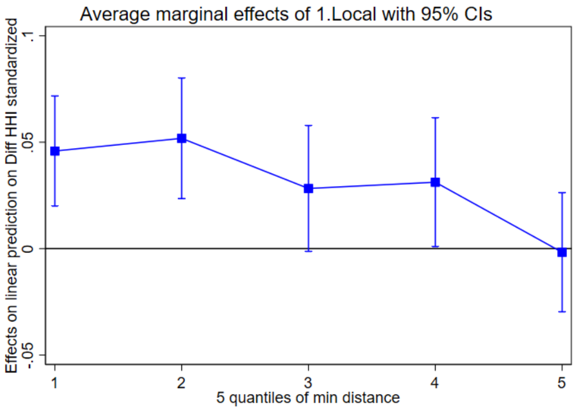
Then for the two most important variables we plot the effects of the intervention by quintiles of the variables (Figure 4b). We find the largest increases in the HHI in poll stations closest to the disclosed mines, and in poll stations where the green party candidate received no votes. These are places where environmental policies will have little support and the closure of illegal mines is not welcomed by the population. These results are in line with the theoretical predictions.

6 Conclusions

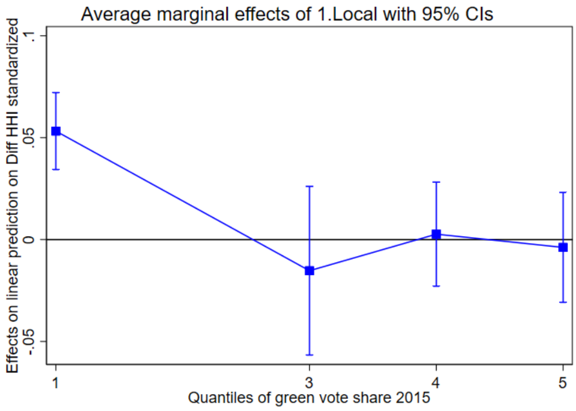
Our findings provide novel insights into the political economy of state capacity interventions aimed at curbing illegal activity. While the randomized provision of machine-learning-based detection technology significantly reduced illegal mining, we do not observe electoral rewards or punishments for incumbents at the municipality level. However, the intervention did lead to a re-composition of votes within municipalities where local authorities were informed, increasing vote concentration toward the winning party and facilitating electoral gains for environmentally oriented political groups. This result suggests that while voters may not directly reward enforcement against illegal mining, issue salience and political competition dynamics shift in response to interventions that enhance state capacity.

Figure 4: Heterogeneous Treatment Effects

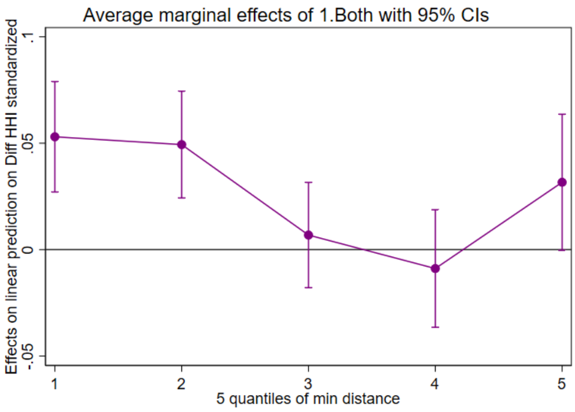
(a) Standardized HHI linear prediction effect from minimum mine disclosed quintile.



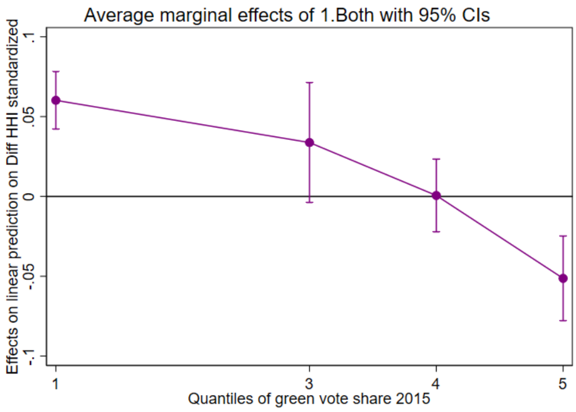
(b) Standardized HHI linear prediction effect from 2015 green vote share quintile.



(c) Standardized HHI linear prediction effect from minimum mine disclosed quintile.



(d) Standardized HHI linear prediction effect from 2015 green vote share quintile.



***Notes*:** All figures illustrate the effects on the linear prediction of the difference in the standardized HHI across different quintiles. Figures 4a and 4c depict the effects at various distance quintiles from the minimum disclosed mine distance. Figure 4a shows the effect when only local authorities were alerted about mining activities in the municipality, while Figure 4c present the effects at different quintiles of the 2015 green vote share. The minimum distance disclosed quintile cutoffs are as follows: 2.3 km, 4.4 km, 7.3 km, and 13.7 km. Figures 4b and 4d present the effects at different quintiles of the 2015 green vote share. Figure 4b corresponds to the scenario where only local authorities were alerted, while Figure 4d corresponds to the scenario where both national and local authorities were alerted about mining activities in the municipality. The 2015 green vote share quintile cutoffs are 0%, 0%, 0.2%, and 17.1%. All confidence intervals are provided at the 95% level.

Moreover, our results indicate that the observability of enforcement actions plays a critical role in shaping voter responses, with electoral effects concentrated in polling stations near disclosed mining sites.

These findings contribute to ongoing debates on the political feasibility of state-building efforts in contexts where illegal activities provide economic benefits to politically active constituencies. Our results underscore the importance of considering the distributional consequences of enforcement and the heterogeneous electoral effects that may arise from such interventions. By demonstrating how monitoring technology can both reduce illegal activities and reshape political landscapes, we highlight the difficulties for scalable policy solutions that balance state capacity-building with electoral incentives. Future research could further explore how variations in enforcement strategies and the broader political context influence the viability of these interventions, particularly in regions where illegal economic activities are deeply embedded in local livelihoods and governance structures.

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Online Appendix

Figures in the Appendix

Tables in the Appendix

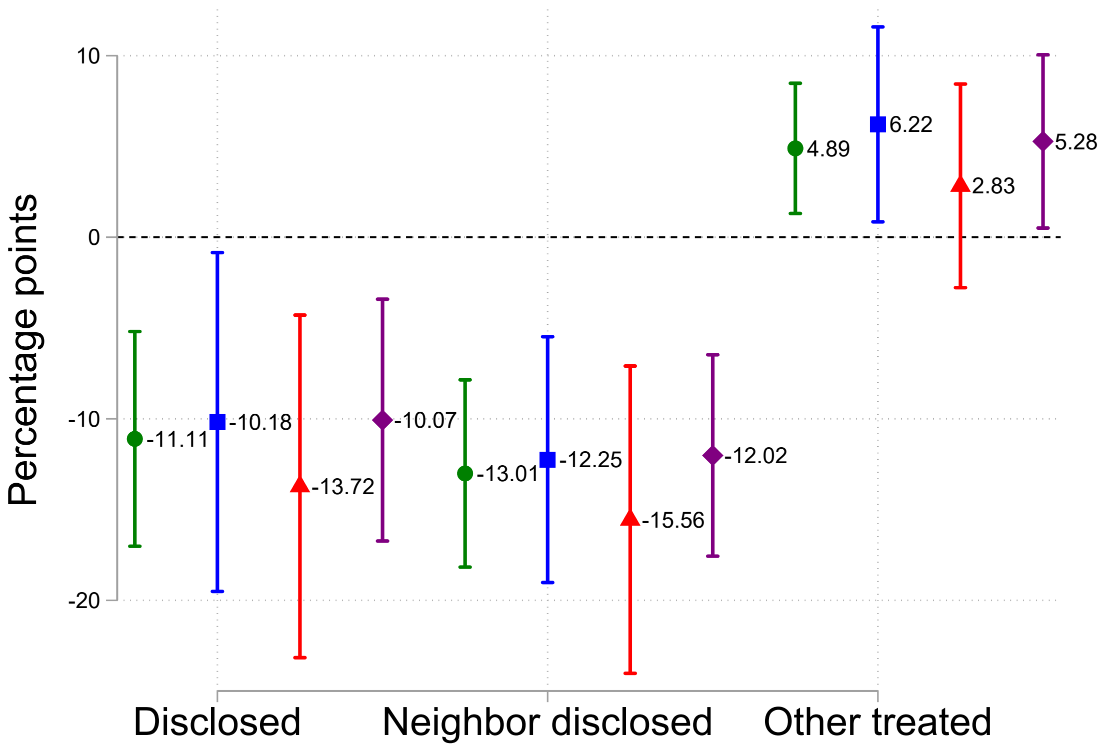
A Appendix

Table A-1: Summary statistics.

Variable	Mean	Std. Dev.	Min.	Max.	N
Vote share 2015	0.55	0.14	0.20	1.00	6806
Vote share 2019	0.46	0.18	0.00	1.00	6806
Total votes 2015	1306.77	2009.55	1.00	27989.00	6806
Total votes 2019	1411.19	2191.86	3.00	25704.00	6806
2015 HHI	0.44	0.13	0.14	1.00	6806
2019 HHI	0.43	0.13	0.15	1.00	6806
2015 HHI standarized	0.24	0.16	0.00	1.00	6806
2019 HHI standarized	0.25	0.16	-0.01	1.00	6806
Parties running in 2015	4.51	1.88	1.00	11.00	6806
Parties running in 2019	5.17	2.11	1.00	12.00	6806
# Green parties 2015	0.65	0.75	0.00	3.00	6806
# Green parties 2019	0.51	0.66	0.00	3.00	6806
2015 green parties vote share	0.10	0.18	0.00	1.00	6806
2019 green parties vote share	0.06	0.14	0.00	0.91	6806
Incumbent Reelected	0.14	0.34	0.00	1.00	6806
Incumbent Reelected by coalition	0.04	0.20	0.00	1.00	6806
Incumbent running in 2019	0.18	0.39	0.00	1.00	6806
Incumbent running in coalition	0.03	0.18	0.00	1.00	6806

Notes: Each observation corresponds to the polling points station level. The table presents the electoral variables along with its mean, standard deviation, minimum and maximum values, and the total number of observations, respectively. Each observation corresponds to the polling station level. Electoral variables are reported for both 2015 and 2019 electoral polls.

Figure A-1: Effects on the percentage of illegally gold mined area



Note: This figure presents a graphical representation of the estimated coefficients of equation (1) in (Saavedra, 2024). The dependent variable is the percentage of gold mined area mined illegally. The first four coefficients are estimates of the effect of including a location in the treatment letter (β_D). The middle coefficients are estimates of the effect on neighboring grids (β_S). The last four coefficients are the estimates in other grids in treatment municipalities (β_T). In each group, the green circle coefficient is the effect in any treatment municipality, the blue square coefficient is the effect in municipalities where only local authorities where informed. The red triangle coefficient is the estimate for municipalities where only the Air Force was informed. The purple diamond coefficient on the right of each group is the effect in municipalities where both the local authorities and the Air Force were informed.

Table A-2: **Balance at baseline in aggregated electoral outcomes.**

Dep. Variable	**2015 Blank** (1)	**2015 Turnout** (2)	**2015 Invalid** (3)	**2015 Census** (4)
Local	0.0007	0.0109	-0.0012	-3.9680
	(0.0022)	(0.0072)	(0.0008)	(2.5078)
National	0.0013	0.0000	-0.0008	-1.3270
	(0.0016)	(0.0062)	(0.0008)	(2.6636)
Both	0.0005	0.0102	-0.0011	1.0251
	(0.0011)	(0.0063)	(0.0009)	(3.3836)
Observations	842	842	842	842
R-squared	0.0422	0.4008	0.3390	0.0906
Mean dep. variable Control	0.00857	0.675	0.0221	19.84

Notes: Each observation corresponds to the municipal level. Columns (1 to 3) report the balance of Blank, Turnout, and Invalid votes as a proportion of the total census, respectively, for any type of treatment. Column (4) presents the Census balance measured in thousands of people. Robust standard errors are provided in parentheses. Statistical significance is denoted as follows: *** p<0.01, ** p<0.05, * p<0.1.

Table A-3: Changes in continuity outcomes.

Dep. Variable	**Incumbent Run in 2019**	**Incumbent Coalition 2019**	**Incumbent Reelected 2019**	**Difference Incumbent Vote Share**
	(1)	(2)	(3)	(4)
Local	-0.0130	-0.0130	0.0211	0.0328
	(0.0462)	(0.0462)	(0.0439)	(0.0228)
National	-0.0543	-0.0543	-0.0086	-0.0020
	(0.0467)	(0.0467)	(0.0435)	(0.0245)
Both	-0.0262	-0.0262	0.0152	0.0377
	(0.0467)	(0.0467)	(0.0439)	(0.0233)
Observations	842	842	842	414
R-squared	0.0619	0.0619	0.0242	0.0639
Mean dep var control	0.574	0.574	0.289	-0.144

Notes: Each observation corresponds to the municipal level. Column (1) reports how many incumbents in average ran in 2019. Similarly, Column (2) presents how many incumbents in average ran in 2019 with coalition. Both Columns (1) and (2) display identical results, as all incumbents participated within a coalition in the 2019 election. Column (3) shows how many incumbents in average ran in 2019 and got reelected. Lastly, Column (4) presents the difference in the incumbent's vote share between the 2019 and 2015 elections for all types of treatments. Robust standard errors are provided in parentheses. Statistical significance is indicated as follows: *** p<0.01, ** p<0.05, * p<0.1.

Table A-4: RATE Estimates for different variables.

Variable	RATE estimate	Confidence Interval
2015 green vote share	-0.036	[-0.045, -0.027]
Min distance to any mine	0.019	[0.004, 0.034]
2015 winner is in a coalition	-0.019	[-0.027, -0.011]
Area of nearby illegal mining activity (UNODC)	-0.014	[-0.021, -0.008]
2015 station winner is in a green party	-0.014	[-0.02, -0.008]
2015 mun. winner allied with an indigeneous party	-0.011	[-0.019, -0.003]
Area of nearby legal mining activity (COMIMO)	-0.009	[-0.014, -0.004]
# Green parties in 2015 ticket	-0.008	[-0.015, -0.001]
2015 mun. winner is in a indigeneous party	-0.007	[-0.015, 0]
2015 station winner is in a green party	-0.007	[-0.012, -0.002]
2015 station winner is in a left party	-0.007	[-0.012, -0.003]
Min distance to predicted mine location	0.006	[-0.005, 0.016]
Mean distance to disclosed mine location	0.005	[-0.004, 0.015]
Max distance to predicted mine location	0.004	[-0.007, 0.015]
2015 HHI	-0.003	[-0.016, 0.011]
Vote share 2015	-0.001	[-0.013, 0.012]
2015 station winner allied with a left party	0.001	[-0.003, 0.006]
Min distance to any mine outside of the municipality	0.000	[-0.009, 0.009]
Area of nearby illegal mining activity (COMIMO)	0.000	[-0.009, 0.009]

Notes: RATE Estimates for Different Variables. Ordered by absolute magnitude of the RATE estimate. IC at the 95% confidence level.