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The impacts of profit-based royalties on early-stage mineral exploration

Emilio Castillo

Mining Engineering Department, Universidad de Chile, Beauchef 850, Santiago, Chile

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ABSTRACT

The impact of public policy on the mineral industries is difficult to measure due to little short-term responsiveness to policy changes by companies already investing in known fixed deposits. Nevertheless, early-stage (or grassroots) exploration has been suggested to provide early signals about the impact of a policy. Among mineral policies, taxation has received plenty of attention in theoretical analysis and simulation studies, but little empirical evaluation.

Profit-based royalties should affect early-stage exploration by decreasing the expected value of a discovered deposit. The empirical approach here uses a difference-in-difference strategy, analyzing the Chilean mining royalty changes of 2004 and 2010. The first tax change is argued to be exogenous as it happened due to the political cycle and in line with a major increase in commodity prices, and the later modification occurred as a result of a major earthquake. Results indicate a surprisingly small average impact on grassroots exploration. However, the effect is heterogeneous as larger companies increased their budget as opposed to junior companies. The absence of geographical spillovers not only supports these estimated effects but also suggests that neighboring countries do not need to engage in harmful tax competition.

1. Introduction

Proper management of nonrenewable resources requires coping with a wide set of political and economic challenges. These are widely known and include revenue volatility, crowding out other sectors in the economy (Dutch disease), rent-seeking behavior and lack of investment in non-depletable assets (Humphreys et al., 2007). Understanding the effects of mineral royalties on firm decisions takes a main role when analyzing the contribution of extractive industries to economic development. Economic rent lies at the heart of the discussion: if mining companies are receiving profits beyond those required to invest and produce (that is, rents), then excess revenue belongs to the resource owner, usually the nation (Hogan and Goldsworthy, 2010; Tilton and Guzman, 2016, ch. 5). In the case of Chile, Leiva (2020) suggests that mineral rents in the mining sector have been sub optimally assigned to the government and that the favorable investment climate supports a higher tax burden. However, mining taxation has also been suggested as an important variable that could hinder the future development of mineral deposits (Ali et al., 2017).

In terms of modeling the response of nonrenewable industries to taxation, Dasgupta and Heal (1979) analyze the effect of sales and profits taxes on the optimal extraction path, indicating that a constant profit-based tax does not distort the efficient extraction path as opposed to ad-valorem taxes. In the presence of high uncertainty and price volatility associated to resource projects, Garnaut and Ross (1975, 1979) indicate that only a highly specific Resource Rent Tax (RRT) can be strictly neutral. However, despite expected neutrality, RRT can reduce the discovery rate for high quality deposits and late-stage exploration (Campbell and Lindner, 1987; Fraser, 1998). For mining companies, theoretical impacts of royalties include ore selection (high grading), reduction in exploration and mine development, changes in the extraction profile and, in extreme cases, earlier mine closure (Krautkraemer, 1990; Slade, 1984; Otto et al., 2006, p. 8). The distortionary effect of mining taxation can be particularly challenging for exploration activities as taxation focuses on successful discoveries, discouraging risky exploration activity (Boadway and Keen, 2010; Davis and Smith, 2020). Nevertheless, as noticed by Lund (2009) in his review of rent taxation for nonrenewable resources, several studies focus on the effects on development and extraction decisions due to the inability to define production possibilities for the exploration phase.

An exception comes from Deacon (1993), who adapts Pindyck's model (Pindyck, 1978) in a simulation study, finding substantial distortions in oil production decisions and allocation of exploratory efforts as a result of taxation. In a regression analysis, Brown et al. (2018) show that drilling decisions are more sensitive to tax changes than price changes. Less favorable policies also affect market structure, resulting in the exit of smaller firms (Lange and Redlinger, 2019; Boomhower, 2019). An additional strategic concern may arise if changing taxes in a country diverts investment to its neighbors. Investment in the primary sector is expected to be relatively inelastic to marginal changes in

E-mail address: ecastillo@uchile.cl.

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taxation (Stöwhase, 2006). However, tax competition in nonrenewable resources can occur and will depend on the relative scarcity of financial and natural capital (Maniloff and Manning, 2018).

In practice, the full range of impacts arising from mineral taxation may require years or decades to be noticed by governments, not providing useful policy feedback. Nevertheless, changes in grassroots exploration expenditures should provide an early indicator for the impact of mining royalties (Otto et al., 2006, p. 26).

Despite known theoretical effects, little empirical evidence has been developed to understand how mineral exploration reacts to taxation. Investment during the exploration stage greatly depends on the geological potential of a jurisdiction and the investment climate or institutional framework where exploration takes place (Tilton, 1992; Otto et al., 2006, p. 216). Empirical research based on exploration expenditures has previously assessed national competitiveness into attracting investment based on these two main variables. Jara et al. (2008) suggest that changes in early-stage exploration (or grassroots) for specific metals should immediately reflect shifts in investment climate. Subsequent studies focus on the relative weights of investment climate and geological potential driving exploration decisions, indicating that both aspects and their interaction are relevant to the allocation of exploration expenditures (Jara, 2017; Khindanova, 2011, 2015). However, these studies have been limited due to data availability, only analyzing cross-sectional country level data. Besides, they do not focus on the ability of exploration expenditures to provide early signs on the effects of changes to specific mineral policies.

The purpose of this paper is to empirically analyze the effects of profit-based royalties on early-stage mineral exploration. This is done by first developing a two-stage theoretical model. In the first stage, investors define exploration funding or budget for a company based on their expected profits. In the second stage a firm decides where to allocate a fixed budget, where exploration effort is incentivized by the value of the potential discovered reserves and defined on a firm's specific knowledge in every location. The model suggests empirical estimates of the effect of mineral taxation on exploration, and more generally, for any policy affecting the value of discovered deposits. This paper overcomes previous limitations using firm-level data on exploration expenditures over a 22-year period. The empirical strategy relies on a differences-in-differences identification and a synthetic control method as a robustness check, based on the Chilean Mining Specific Tax of 2004 and its rate increase in 2010, a tax system which has been previously classified as neutral towards investment decisions (Davis and Smith, 2020). The exogeneity of the first tax change in 2004 is assumed as the tax resulted mostly from the political cycle and just when commodity prices started booming. The 2010 modification happened because of a major earthquake in the country, and therefore unpredictable. The exogeneity lies in the fact that had the earthquake not happened, it is unlikely the government would had changed the royalty regime.

The main results indicate a positive average impact, but not statistically different than zero for both tax changes. However, the average effect masks heterogeneous impacts. In the first tax change, smaller companies reduced their budgets around 2 percent while larger companies increased their budgets 32 percent. Additionally, smaller companies were 4–6 percentage points more likely to leave the country. The 2010 modification had no significant effect on budgets of larger and smaller companies. The synthetic control method confirms the sign of the average and heterogeneous effects but lacks the statistical significance and cannot closely represent average investment during the preintervention period. Counter intuitive positive effects in larger companies can be explained by stability agreements in the tax regime granted by the government to major companies, creating a sense of confidence in the rule of law and commitment from government policies, providing incentives for grassroots exploration. An additional explanation comes from a more positive view from major companies as the country could have become more attractive in the long-run after a reasonable debate. Overall, changes in early-stage exploration are highly sensitive to policy nuances and the general investment climate, even in the face of theoretically relevant policies like royalties. This is particularly relevant when major companies are involved, as they might be less sensitive to tax changes than junior companies. Additionally, the absence of geographical spillovers not only makes previous estimates more reliable but also suggests that neighboring countries do not need to engage in harmful tax competition.

2. Theoretical model

Exploration and production decisions in the mining industry are mostly done by individual firms. Small, highly specialized firms called junior companies take part in the riskier exploration stage, discovering new deposits and reducing technical and other uncertainties during pre-production stages. Major companies (larger companies), also take part in early-stage exploration, but they focus on development and production decisions. Within a single jurisdiction, the level of exploration depends on the value of the expected discoverable deposit. In the deterministic case, given an initial deposit R_0, its value ($V(R_0)$) comes from solving the dynamic problem first observed by (Hotelling, 1931).

$$\begin{aligned} V(R_t) = \max_{q_t} \quad & p_t q_t - c(q_t, R_t) + \delta V(R_{t+1}) \\ \text{subject to} \quad & R_{t+1} = R_t - q_t \end{aligned} \tag{1}$$

where δ indicates the discount factor, p_t the price of a unit of the commodity at time t, q_t the quantity extracted at time t and $c(q_t, R_t)$ the extraction cost as a function of the quantity extracted and the depletion of the resource stock. Given a functional form for the cost function, it is possible to obtain a solution for the stock value $V(R_0)$. Additionally, a maximum capacity investment decision could be included considering the maximum production level and an investment capacity cost function $k(q_{max})$. In the presence of a constant profit-based royalty τ, the firm solves (Dasgupta and Heal, 1979):

$$\begin{aligned} V(R_t) = \max_{q_t} \quad & (p_t q_t - c(q_t, R_t))(1-\tau) + \delta V(R_{t+1}) \\ \text{subject to} \quad & R_{t+1} = R_t - q_t \end{aligned} \tag{2}$$

In this slightly different problem, extraction decisions from already producing firms remain unchanged (Dasgupta and Heal, 1979), but the tax do affect investment decisions $k(q_{max})$ because of the decrease in the marginal value of the resource stock $\frac{dV(R_0)}{d\tau}$. The value of the discovered stock is also important for junior companies because they define the level of exploration activity accordingly. Nevertheless, as noticed by Eggert (1987, ch. 2), grassroots exploration is also an spatial allocation problem, where companies allocate their annual funds in J different regions or countries. Additionally, the discovery process should be considered in tandem with the ability to appropriate profits defined by political institutions at jurisdiction j. Formally, exploration companies maximize expected profits as depicted in Eq. (3).

$$\begin{aligned} \max_{e_j} \quad & \sum_{j=1}^{J} \left(\int_0^\infty \alpha_j V(R_j) \gamma_{i,j}(R_j, e_j) dR_j - c(e_j) \right) \\ \text{subject to} \quad & \sum_{j=1}^{J} c(e_j) \leq B \end{aligned} \tag{3}$$

where $\gamma_{i,j}(R_j, e_j)$ represents, for every jurisdiction j, the likelihood of discovering a deposit of size R_j by allocating e_j exploration effort at a cost $c(e_j)$. In addition, α_j reflects a company's ability to appropriate the value of a discovered deposit, depending on the investment climate in jurisdiction j. Finally, in a dynamic context, investors decide the budget for each firm (B) in order to maximize expected profits knowing that companies will invest according to their allocation of exploration effort.

2.1. Simplified exploration allocation model

The model can be simplified considering J jurisdictions where to allocate exploration investment. Assuming constant prices and constant marginal extraction costs but increasing as the deposit is depleted ($c(q_t, R_t) = \frac{cq_t}{R_t}$), the dynamic extraction problem is linear in the extraction level and the company chooses to produce at maximum capacity as long it is profitable (Conrad, 2010). The assumption is based on how mine planning takes place, usually deciding a maximum capacity during development and maximizing its utilization rate (Newman et al., 2010; Abdel Sabour, 2002), and depicted by common empirical mining supply curves (Tilton and Guzman, 2016, ch. 3). In this case, the firm will extract q_{max} during $T = \frac{R_0 - c/p}{q_{max}} - 1$ periods. Maximum capacity is defined implicitly as a function of the discovered resource stock $R_{0,j}$ and the tax rate in each jurisdiction τ_j. This is illustrated in Eq. (4).

$$V(R_0) = \max_{q_{max}} \quad \left\{ \frac{1-\delta^{T+1}}{1-\delta}(p-c)(1-\tau_j)q_{max} - k(q_{max}) \right\} \tag{4}$$

In this case, the marginal effect of a change in the tax rate in the value function is:

$$\frac{dV}{d\tau} = -q_{max}(p-c)\frac{1-\delta^{T+1}}{1-\delta} < 0 \tag{5}$$

For the exploration firm, it is reasonable to assume that the distribution of deposits and the probability of discovery are independent. In this case, the probability to find a deposit has diminishing returns with respect to exploration effort but it is still idiosyncratic: firms may have specific knowledge, experience or abilities in a particular jurisdiction affecting the exploration success. This is represented by the term $A_{i,j}$. Let $V_j(R) = E(V(R_{0,j}))$ represent the expected value of a deposit discovered in the jurisdiction j and α_j the fraction that a firm can receive from the maximum value in the jurisdiction j. Suppose a logarithmic functional form for the discovery probability in the level of exploration effort ($\gamma_{i,j} = A_{i,j} ln(e_{i,j})$) and constant marginal exploration costs (w), then the exploration allocation problem for every firm i becomes:

$$\begin{aligned} \max_{e_{i,j}} \quad & \sum_{j=1}^{J} \left(\alpha_j V_j(R) A_{i,j} ln(e_{i,j}) - w e_{i,j} \right) \\ \text{subject to} \quad & \sum_{j=1}^{J} w e_{i,j} \leq B \\ & e_{i,j} \geq 0 \end{aligned} \tag{6}$$

The exploration effort allocated for each firm i in every jurisdiction j is given in Eq. (7).

$$e_{i,j} = \frac{B \alpha_j V_j(R) A_{i,j}}{w \sum_{k=1}^{J} \alpha_k V_k(R) A_{i,k}} \tag{7}$$

Applying logarithm to Eq. (7) allows to obtain the following expression for exploration expenditures:

$$\begin{aligned} ln(e_{i,j}) = {} & \ln(\alpha_j) + ln(B) - ln(w) + ln(V_j(R)) \\ & - ln\left(\sum_{k=1}^{J} \alpha_k V_k(R) A_{i,k} \right) + ln(A_{i,j}) \end{aligned} \tag{8}$$

Then, the marginal effect of a tax change is given by:

$$\frac{d ln(e_{i,j})}{d\tau} = \frac{dV_j(R)}{d\tau} \left(\frac{1}{V_j(R)} - \frac{\alpha_j A_{i,j}}{\sum_{k=1}^{J} \alpha_k V_k(R) A_{i,k}} \right) \leq 0 \tag{9}$$

The result is interesting in the sense that the effect of a tax change is attenuated by a firm's specialization level in the country and the political institutions that affect the ability to appropriate expected profits. The first term is negative (direct decrease in value), but the second one is positive (specialization effect). In the extreme case of an exploration firm highly specialized in a specific country j ($A_{i,k} \sim 0$ $\forall\ k \neq j$), then the marginal effect of the tax change in exploration expenditures is close to zero due to the firm's inability to reallocate budget in other countries.

Nevertheless, the previous model still needs to consider the dynamic nature of exploration budget, as investors can also change the budget constraint of firms in response to the tax change. In this stage, consider a highly specialized firm, exploring only in one country, and a diversified company exploring in two countries. Then, exploration effort as a function of the budget constraint is already defined in Eq. (7) and the maximization problem of investors is given by Eq. (10).

$$\max_{B_i} \quad \sum_{i=1}^{2} \sum_{j=1}^{2} \left(\alpha_j V_j(R) A_{i,j} ln(e_{i,j}(B_i)) - w e_{i,j}(B_i) \right) \tag{10}$$

With only two firms and two countries, the optimal budget for firm 1 is $B_1 = \alpha_1 V_1(R) A_{1,1}$ and for firm 2 is $B_2 = \alpha_1 V_1(R) A_{2,1} + \alpha_2 V_2(R) A_{2,2}$. Then, as firm 1 is more specialized in country 1 than firm 2 ($A_{1,1} > A_{2,1}$), the tax generates a larger negative effect in the budget of firm 1. Eq. (11) shows that specialized exploration firms will be more affected as a result of a mining tax. This is expected as the market would punish their inability to reallocate resources by decreasing their budget over time.

$$\frac{dB_1}{d\tau} = \alpha_1 A_{1,1} \frac{dV_1(R)}{d\tau} < \alpha_1 A_{2,1} \frac{dV_1(R)}{d\tau} = \frac{dB_2}{d\tau} \tag{11}$$

The previous model represents the impact of a profit-based royalty, but it could also be expanded to represent the effect on exploration expenditures from any policy change affecting the future value of extracting a discovered deposit.

3. Empirical approach

3.1. Identification strategy

Eq. (12) represents the differences-in-differences approach to be estimated.

$$y_{ijt} = \theta_j + \theta_t + \delta \tau_{post} CL + \boldsymbol{X_{ijt}} \boldsymbol{\beta} + \varepsilon_{ijt} \tag{12}$$

where y_{ijt} indicates the log of exploration expenditures of firm i in country j at year t. τ_{post} is a dummy variable taking the value of 1 for years after each tax change and zero otherwise. CL is a dummy variable indicating if the investment occurs in Chile. The model allows for a different intercept for each country (θ_j) and year fixed effects (θ_t). The tax effect is captured by δ, measuring the combined effect of decreasing future value of a deposit and the specialization effect as indicated in Eq. (9). Additionally, other control variables such as company type (e.g. junior, major or other), the corporate income tax rate and institutional quality measures are included.

The endogeneity of the tax change is an empirical concern. During the last dramatic increase in commodity prices, many resource-rich countries revised their mining tax regime (Fjeldstad et al., 2016; Global Legal Monitor, 2017; Santa-María, 2014; Williams, 2013). In Chile, the 2004 Mining tax change occurred mainly as a combination of political struggles during the electoral period, the early signs of increasing prices and lobbying from large mining companies, preferring a profit-based royalty over a value-based royalty (Letelier and Dávila, 2015; Napoli and Navia, 2012).

The Chilean mining tax was a profit-based royalty levying mining profits at a 5% rate for companies with sales above the equivalent value of 50,000 tonnes of copper. It also considered a progressive tax rate from 1% to 4.5% for miners with above 15,000 tonnes of equivalent copper sales and below 49,999 tonnes of equivalent copper sales. As part of the law discussion, a stability period was granted for large operators, offering 15 years without changing the mining tax regime (Hernández, 2012, p. 79–91). A stability agreement is expected to provide more confidence to mining investors as economic conditions change over time (UN, 2019, p. 433). Additionally a modification of the mining tax occurred in 2010 as a result of a major earthquake and the need for additional rebuilding funds (Hernández, 2012, p. 95–96). The government temporarily increased tax rates during three years

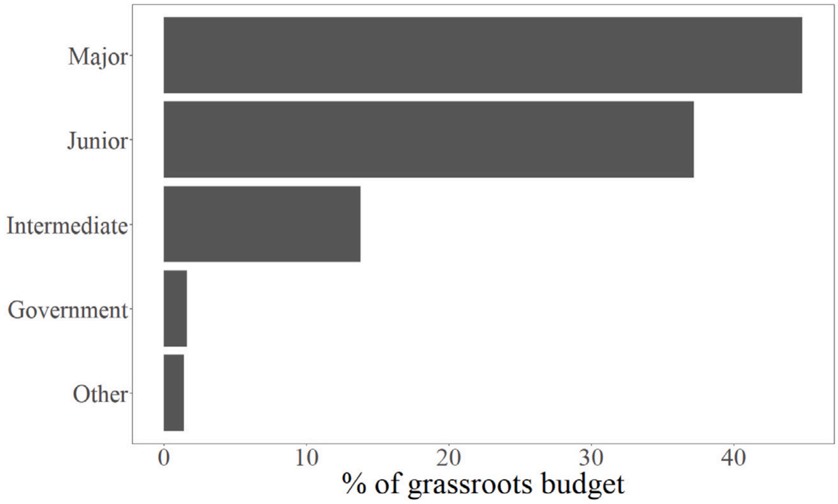

Fig. 1. Average investment by company type in grassroots exploration budgets, 1997–2018. Values indicate the mean of annual contribution in percentage points across the full sample.
Source: Corporate Exploration Strategies (S&P Global Market Intelligence, 2019).

for existing mining companies, but also increased the rate for new projects depending on their operating margins, ranging from 5% to 14% (Biblioteca del Congreso Nacional de Chile, 2010). Major companies already operating were offered six additional years in their stability agreements, and the government assured that no more modifications in the tax rate or the tax base will occur for the total period. Had the earthquake not occurred, it is unlikely the government would have changed the rate considering that only a few years had happened since the previous change and operating companies had tax invariability contracts. Therefore, the identification strategy relies mostly on the exogeneity of the 2004 Mining tax change in Chile and its effects until 2010. In a complementary way, the 2010 modification (in response to the 2010 earthquake) provides a way to analyze the impact of a marginal increase.

In addition to the differences-in-differences estimation, a spillovers test and a synthetic control method are presented as robustness checks. The synthetic control method is used in comparative studies to generate a counterfactual from the data itself as a weighted average of non-treated units (Abadie et al., 2010). In this case, the variable of interest is the average grassroots exploration investment. Predictors are based on geological potential (e.g. mineral rents as a percentage of the GDP) and the institutional framework (e.g. World Governance Indicators).

3.2. Data

The main source of information is the S&P Global Corporate Exploration Strategies database. The data consist of firm-level non-ferrous mineral exploration budgets,[1] based on published sources, information from joint venture partners and conversations with company representatives (S&P Global Market Intelligence, 2019). A subset of this data has been used by previous studies, but using only aggregated country level and cross sectional information (Jara et al., 2008; Jara, 2017; Jara et al., 2020; Khindanova, 2011, 2015). Nominal values are adjusted to constant 2018 US$ using the annual average of the U.S. Producer Price Index. Table 1 presents the summary statistics from exploration budgets (in natural logarithm) by exploration stage of 4705 firms investing in more than 120 countries over the 1997–2018 period. Considering all observations across every exploration stage, 42% of the information is related to gold exploration, followed by copper with 20%.

Table 1
Descriptive statistics for exploration budgets, 1997–2018.

Stage	Commodity	N obs	Mean	St. Dev.	Min	Max
Grassroots	Gold	20,638	−0.622	1.232	−2.303	4.333
	Copper	10,176	−0.647	1.299	−2.303	3.789
	Others	18,265	−0.781	1.231	−2.303	4.290
Late stage	Gold	10,212	0.141	1.391	−2.303	4.722
	Copper	4432	0.005	1.466	−2.303	5.298
	Others	9467	−0.068	1.392	−2.303	4.977
Minesite	Gold	4650	0.719	1.427	−2.303	4.766
	Copper	2018	0.458	1.400	−2.303	4.787
	Others	4126	0.264	1.357	−2.303	4.477

Note: Every observation represents the log of the investment of a specific firm in a country for a given year.

The data distinguish three different exploration stages. Grassroots represents the earliest stage until the quantification of initial resources. Late-stage further defines a previously discovered orebody and minesite exploration includes activities around an existing mine (S&P Global Market Intelligence, 2019). Grassroots exploration is mostly driven by discovering deposits, therefore represented by the theoretical model described in Section 2. Late-stage and minesite exploration have different incentives, mostly related to decreasing geological uncertainty and expanding mine reserves (Fraser, 1998). Considering the differences in incentives, the analysis is focused on grassroots exploration, as their expected profits are different than risk-reducing exploration. Additionally, the database classifies investment in five type of organizations. Junior companies have revenues under US$50 million, intermediate companies between US$50 million and US$500 million and major companies more than US$500 million. Other organizations include governments or corporations earning non-mining revenue (S&P Global Market Intelligence, 2019).

Almost all of grassroots exploration is driven by major and junior companies. As indicated in Fig. 1, major companies have represented around 45 percent of grassroots annual budgets, followed by junior companies with 41 percent. The remaining share is mostly explained by intermediate-size companies, averaging a 10 percent from 1997 to 2018.

As depicted in Fig. 2, average expenditures by company type show a similar trend over the period. Data shows a significant decline in 2009 for non-major companies, resulting from a commodity price decline during the economic crisis. This situation exemplifies how exploration budgets are usually defined prior observing prices (six months to one

[1] Data excludes iron ore, coal, aluminum, oil, gas and industrial minerals. It contains information from gold, base metals, PGM, diamonds, uranium, silver, REE, phosphate and other metallic minerals.

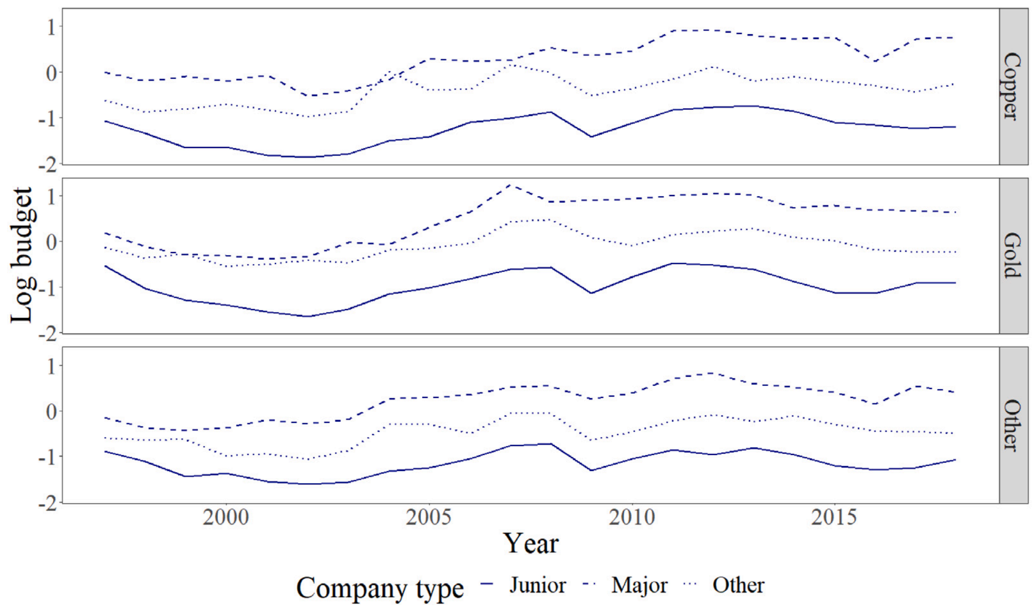

Fig. 2. Log of average grassroots budgets by commodity, 1997–2018. Every line represents the average of log budgets of every company type for a specific commodity.
Source: Corporate Exploration Strategies (S&P Global Market Intelligence, 2019).

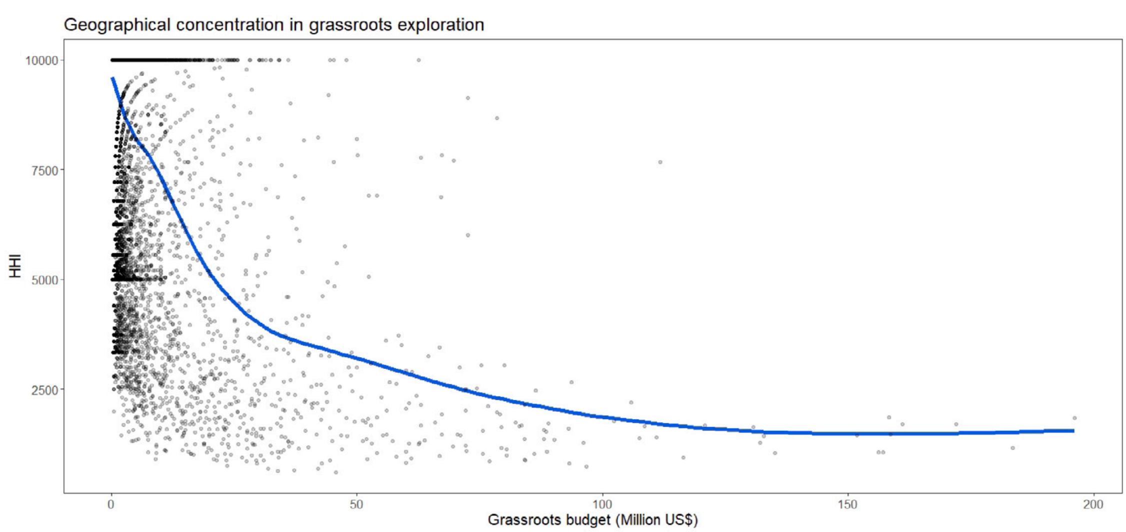

Fig. 3. HHI vs. Grassroots annual budget. Every point indicates the HHI (concentration) of the grassroots budget of a company each year. The blue line represents the local linear regression.
Source: Corporate Exploration Strategies (S&P Global Market Intelligence, 2019).

year) and how major's exploration is less sensitive to price changes due to availability of internal funds (Eggert, 1987).

In terms of geographical investment, smaller companies tend to allocate most of their budget in fewer countries, indicating a higher degree of specialization. This is illustrated in Fig. 3. The vertical axis shows the Herfindahl–Hirschman index (HHI),[2] taking a value of 10,000 if a company allocates its entire grassroots budget in just one country, and decreasing as the firm invest in more locations.

4. Results

This section presents the results from the differences-in-differences strategy previously outlined. Additionally, a spillover analysis and a synthetic control method are included to confirm the robustness of findings. Year-by-year coefficients from the differences-in-differences approach appear in the Appendix.

4.1. Differences-in-differences

As previously discussed, the main identification strategy relies on exogenous tax changes in Chile: a new profit-based tax in 2004 and the increase in its rate after the 2010 earthquake. Other Latin American countries[3] are included in the comparison group. It is assumed that their common regional geological properties and institutional frameworks provide support for the underlying and untestable parallel trends

[2] The HHI is a concentration measure, calculated by adding up the square of each market share.

[3] Including: Argentina, Bolivia, Brazil, Colombia, Costa Rica, Ecuador, Guatemala, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Uruguay and Venezuela.

Fig. 4. Budget trends in Latin American countries, 1997–2018. Every line represents the average of log grassroots budget in every country over time. Dotted vertical lines indicates years of the Chilean tax changes.

Table 2
Testing for parallel trends in preintervention period (1997–2004).

	Log real budget		
	All (1)	Junior (2)	Major (3)
CL	−61.632	−5.162	−32.596
	(41.331)	(38.955)	(90.362)
$CL \cdot Year$	0.030	0.002	0.015
	(0.020)	(0.019)	(0.346)
N obs	2635	1229	996
R^2	0.312	0.460	0.278
Country and year fixed effects	Y	Y	Y
Company type and mineral fixed effects	Y	Y	Y
Governance controls	Y	Y	Y

Note: Testing for differences in preintervention trends between Chile and other Latin American countries between on grassroots exploration budgets. Column (1) includes data for every company type, column (2) for junior companies and column (3) for major companies. Robust standard errors appear in parenthesis and clustered at the country level.
*p<0.1; **p<0.05; ***p<0.01.

assumption. Testing for trends before the policy change can be suggestive of counterfactual parallel trends despite not being necessary nor sufficient for the parallel trends assumption (Kahn-Lang and Lang, 2020). Pre-trends analysis for total grassroots investment, and junior and major companies appear in Table 2. Results indicate that differences in trends ($CL \cdot Year$ coefficient) are not statistically significant. Also, differences in levels (CL coefficient) are not statistically significant, therefore there is no evidence of pre-existing differences potentially affecting post treatment trends.

The sample is divided into three periods to evaluate the impact of each tax: 1997–2004, 2005–2010 and 2011–2018. Each effect is estimated using only the two adjacent periods. Then, the effect from the first tax change is estimated by comparing Chile against the Latin American countries in the control group before the tax change (1997–2004) and after (2005–2010). The second tax change analyzes the same units comparing the period 2005–2010 to 2011–2018, considering that the second tax was a marginal increase in the tax rate from the previously defined royalty. Fig. 4 shows average budget trends for five main destinations of exploration budget in Latin America, indicating tax changes as vertical lines.

Table 3 shows the impact of each mining tax change including different control variables. The first column is the basic differences-in-differences estimator, considering year[4] and country fixed effects. Country fixed effects like land area are an important measure for geological potential identified in previous studies (Khindanova, 2011, 2015; Jara, 2017). The second column includes mineral and company type fixed effects. The third column incorporates other governance controls: six Worldwide Governance Indicators (The World Bank, 2019) and the Corporate Income tax rate of the country in any given year (KPMG, 2019; University of Michigan, 2004; OECD, 2019). A first approach to Table 3 indicates a positive effect in the average exploration budget, a counterintuitive result. For the first change, as more controls are included, the effect becomes less significant reaching an average effect of a 2.9 percent increase in average grassroots exploration. According to the theoretical model, an effect that is close to zero suggests that grassroots exploration is not being penalized because of the tax. The second tax change is surprising, showing a higher and significant point estimate. However, the result is no longer statistically significant when additional governance controls are included, suggesting that other institutional variables may be driving the average increase.

Even though average effects do not show significant estimates, heterogeneous effects should be expected. Smaller companies are more specialized than bigger companies, therefore they should suffer more from a tax change than larger companies. Results in Table 4 confirms that differences across companies occur, but not as clear as expected.

Junior companies decreased their grassroots investment around 1.6 percent after the first tax change, while major companies increased their investment around 32 percent.[5] However, only the coefficient for

[4] It has been noticed that exploration expenditures are highly correlated with commodity prices (Jara et al., 2008). Year fixed effects provide a general way to control for time-changing variables. Additionally, using prices instead of year fixed effects does not change main results.

[5] The percentage change comes from the exact point estimate of the semi-elasticity of model (2) in Table 4 given by $e^{0.274} - 1 = 0.315$.

Table 3
Tax effect on grassroots exploration.

	Log real budget		
	(1)	(2)	(3)
First change (2004)			
$CL \cdot \tau_1$	0.053*	0.043	0.029
	(0.029)	(0.039)	(0.053)
N obs	5894	5894	5894
R^2	0.114	0.281	0.284
Second change (2010)			
$CL \cdot \tau_2$	0.099***	0.152***	0.105
	(0.033)	(0.034)	(0.102)
N obs	6749	6749	6749
R^2	0.083	0.287	0.288
Country and year fixed effects	Y	Y	Y
Company type and mineral fixed effects	N	Y	Y
Governance controls	N	N	Y

Note: Results indicate the effect of Chilean profit-based royalty changes on grassroots exploration budgets. The year of the tax change is indicated in parenthesis. Model (1) considers country and year fixed effects; model (2) additionally includes company type effects (major, junior, intermediate and other firms), and mineral target; model (3) adds Worldwide Governance Indicators and the Corporate Income tax level as additional controls. Robust standard errors appear in parenthesis and clustered at the country level.
*p<0.1; **p<0.05; ***p<0.01.

major companies is highly statistically significant. The 2010 change had a lesser effect on companies, not statistically different from zero at any common significance level. This suggests that the marginal increase from the previous tax was not a major deterrent for grassroots exploration.

The negative and close to zero effect on junior companies can be explained from their high geographical specialization, making re-allocation of exploration effort more difficult. On the other hand, the high and strong positive effect on major companies is unusual, as it could indicate that major companies were willing to increase their early exploration effort in response to the tax change. However, this differential effect can be explained as a strategic result from the stability agreements signed between the Chilean government and major companies. Stability agreements could reduce risk and increase confidence in the government, making major companies more likely to invest in grassroots exploration. As junior companies were not part of any stability agreement, they did not have more incentives to increase their exploration effort in the country but the overall improvement in the investment climate could have mitigated the impact of the tax. The boost in major grassroots exploration decreases after the rate increase in 2010, though this is not significant. Additionally, it can be argued that the way the country managed the debate improved the perception of major companies already investing in the country about potential future policy changes that could affect long-run investments.

Exploration firms can also react to the tax change by leaving the country as it becomes less profitable to invest. The dependent variable, exit, takes a value of one if a company invested in a country at a year $t-1$ and did not invest in year t. If a company moves from grassroots to late-stage exploration, then it is not considered as exiting, as the company maintains their presence in the country. Table 5 indicates that tax changes increased the likelihood of leaving the country between three to five percentage points, but the result is not statistically significant after including governance controls. Nevertheless, the second change shows the opposite as companies were more likely to arrive to invest in the country compared to other jurisdictions after the marginal rate increase. As with the increase on average investment previously described, the marginal tax change does not seem to have a negative effect on exploration decisions.

Exit decisions by company type appear in Table 6. Junior companies were 4 to 6 percentage points more likely to leave the country after the first tax change. The impact, however, is not statistically significant. The effect is reversed for the second tax change, when more junior companies arrived to invest in the country, driving the increase in the average effect presented in Table 5. On the other hand, major companies appeared more likely to stay in the country after the first tax change as the effect in their exit decisions is negative but not different than zero as more controls are included. Stability agreements with larger companies could have created incentives for major companies

Table 4
Tax effect on grassroots exploration by company type.

	Log real budget	
	(1)	(2)
First change (2004)		
$CL \cdot \tau_1 \cdot Junior$	−0.001	−0.016
	(0.053)	(0.059)
$CL \cdot \tau_1 \cdot Major$	0.285***	0.274***
	(0.085)	(0.081)
$CL \cdot \tau_1 \cdot Other$	0.178**	0.144*
	(0.069)	(0.080)
N obs	5894	5894
R^2	0.300	0.308
Second change (2010)		
$CL \cdot \tau_2 \cdot Junior$	0.198***	0.141
	(0.067)	(0.090)
$CL \cdot \tau_2 \cdot Major$	−0.162*	−0.216
	(0.065)	(0.151)
$CL \cdot \tau_2 \cdot Other$	0.220***	0.164
	(0.069)	(0.112)
N obs	6749	6749
R^2	0.303	0.307
Country and year fixed effects	Y	Y
Company type and mineral fixed effects	Y	Y
Governance controls	N	Y

Note: Results indicate the effect of Chilean profit-based royalty change on grassroots exploration budgets by company type. The year of the tax change is indicated in parenthesis. For every company type, model (1) considers company type effects, (major, junior, intermediate and other firms), and mineral target; model (2) additionally uses Worldwide Governance Indicators and the Corporate Income tax level as additional controls. Robust standard errors appear in parenthesis and clustered at the country level.
*p<0.1; **p<0.05; ***p<0.01.

Table 5
Tax effect on exit decisions.

	Exit		
	(1)	(2)	(3)
First change (2004)			
$CL \cdot \tau_1$	0.027*	0.028*	0.045
	(0.013)	(0.013)	(0.034)
N obs	5342	5342	5342
R^2	0.313	0.331	0.331
Second change (2010)			
$CL \cdot \tau_2$	−0.030*	−0.034**	−0.072***
	(0.016)	(0.016)	(0.024)
N obs	6749	6749	6749
R^2	0.292	0.315	0.316
Country and year fixed effects	Y	Y	Y
Company type and mineral fixed effects	N	Y	Y
Governance controls	N	N	Y

Note: Results indicate the effect of Chilean profit-based royalty changes on exit decisions. The exit variable is one the year a company stop investing in grassroots exploration in the country without moving to another exploration stage. The year of the tax change is indicated in parenthesis. Model (1) considers country and year fixed effects; model (2) additionally includes company type effects (major, junior, intermediate and other firms), and mineral target; model (3) adds Worldwide Governance Indicators and the Corporate Income tax level as additional controls. Robust standard errors appear in parenthesis and clustered at the country level.
*p<0.1; **p<0.05; ***p<0.01.

Table 6
Tax effect on exit decision by company type.

	Exit	
	(1)	(2)
First change (2004)		
$CL \cdot \tau_1 \cdot Junior$	0.035	0.056
	(0.034)	(0.036)
$CL \cdot \tau_1 \cdot Major$	−0.077***	−0.055
	(0.026)	(0.048)
$CL \cdot \tau_1 \cdot Other$	0.053***	0.086***
	(0.014)	(0.028)
N obs	5342	5342
R^2	0.342	0.344
Second change (2010)		
$CL \cdot \tau_2 \cdot Junior$	−0.077***	−0.114***
	(0.019)	(0.029)
$CL \cdot \tau_2 \cdot Major$	0.051**	0.005
	(0.021)	(0.030)
$CL \cdot \tau_2 \cdot Other$	−0.034	−0.068
	(0.037)	(0.039)
N obs	6749	6749
R^2	0.321	0.322
Country and year fixed effects	Y	Y
Company type and mineral fixed effects	Y	Y
Governance controls	N	Y

Note: Results indicate the effect of Chilean profit-based royalty changes on exit decision by company type. The exit variable is one the year a company stop investing in grassroots exploration in the country without moving to a next exploration stage. The year of the tax change is indicated in parenthesis. For every company type, model (1) considers company type effects (major, junior, intermediate and other firms), and mineral target; model (2) additionally uses Worldwide Governance Indicators and the Corporate Income tax level as additional controls. Robust standard errors appear in parenthesis and clustered at the country level.
*p<0.1; **p<0.05; ***p<0.01.

Table 7
Geographical spillovers of tax changes.

	Log real budget	
	(1)	(2)
First change (2004)		
$CL \cdot \tau_1$	0.028	0.022
	(0.056)	(0.070)
$Neighbor \cdot \tau_1$		−0.059
		(0.079)
$Region \cdot \tau_1$		−0.016
		(0.089)
N obs	29,986	29,986
R^2	0.362	0.362
F_{test}		0.404
Second change (2010)		
$CL \cdot \tau_2$	0.215***	0.229***
	(0.032)	(0.032)
$Neighbor \cdot \tau_2$		0.052
		(0.040)
$Region \cdot \tau_2$		0.114
		(0.075)
N obs	37,217	37,217
R^2	0.353	0.353
F_{test}		1.430
Country and year fixed effects	Y	Y
Company type and mineral fixed effects	Y	Y

Note: Results indicate geographical spillovers of Chilean profit-based royalty changes. The year of the tax change is indicated in parenthesis. Every model considers country, year, company type (major, junior, intermediate and other firms) and mineral target fixed effects. Model (2) additionally includes geographical spillover terms, distinguishing neighboring countries and countries in the same continent. F_{test} indicates the joint significance of both spillover coefficients. Robust standard errors appear in parenthesis and clustered at the country level.
*p<0.1; **p<0.05; ***p<0.01.

to stay for more time in the country, but no incentives to attract new larger companies. Exploration decisions of major companies, after controlling for governance quality indicators were not affected by the second tax change.

Average results do not show a clear negative impact on early-stage mineral exploration. This suggests that focusing only on average or total grassroots changes cannot provide a reliable way to the effect of specific policies on investment climate as hypothesized by Otto et al. (2006, p. 26) and Jara et al. (2008).

In the Chilean case, the apparent non-distortionary effect can be misleading after analyzing the impact by company size. On one hand, smaller companies appear slightly more affected by the first tax change, decreasing around 2 percent their grassroots investment. On the other hand, larger companies reacted in an opposite direction, increasing their grassroots budgets around 32 percent. This unusual positive behavior can be explained by the fact that these companies value stability and rule of law. In this sense, the stability agreements signed with the government and the respect to the rule of law after the royalty bill discussion were more important than the tax itself.

4.2. Robustness of findings

4.2.1. Geographical spillovers

Investment in the primary sector is expected to be relatively inelastic to marginal changes in taxation (Stöwhase, 2006). Nevertheless, if spillovers occur in exploration after a tax change, then the differences-in-differences coefficient will underestimate the true effect of the policy, as it will be including the positive effect to other countries. The existence of spillovers can promote strategic behavior between countries, leading to tax competition (OECD, 1998)

As suggested by Clarke (2017), it is possible to test for spillovers within a differences-in-differences framework if the spillover effect is monotonically decreasing in terms of distance from the treatment unit and at least some units are not affected by spillovers. Using this approach, four different regions were defined, as illustrated by Fig. 5. First, Chile as the treated unit where the tax change took place. Second, a set of neighbor countries with similar geological units and political institutions. Third, countries in the same continent that could have some similarities but not as clear as neighbor countries. Finally, other countries outside the American continent. A shortcoming of this approach is that untestable spillovers can still occur between Chile and countries outside the American continent.

The identification in this case includes two binary regional variables: one for neighboring countries and one for other countries in the American continent. $Neighbor$ takes a value of one if the investment is made in Argentina, Peru, or Bolivia and zero otherwise. Similarly, $Region$ takes the value of one for countries in the American continent (excepting Chile and its neighbors) and zero otherwise. In this case, the full sample is used, not restricting the control units to Latin American countries. Coefficients ρ_1 and ρ_2 in Eq. (13) indicate geographical spillovers. If spillovers occur, then at least one of the coefficients should be positive and significant.

$$y_{ijt} = \theta_j + \theta_t + \delta\tau_{post}CL + \rho_1\tau_{post}Neighbor + \rho_2\tau_{post}Region + \boldsymbol{X}_{ijt}\boldsymbol{\beta} + \varepsilon_{ijt} \tag{13}$$

Results from regressing Eq. (13) appear in Table 7. Spillover coefficients are neither individually significant nor jointly significant at usual significance levels for both tax changes. These results suggest that spillovers are not a significant concern affecting differences-in-differences estimates. Additionally, results indicate that neighboring countries do not need to engage in marginal tax competition to attract exploration investment.

4.2.2. Synthetic control

The synthetic control method provides a systematic way to define a control group in comparative studies. The approach evaluates the effect

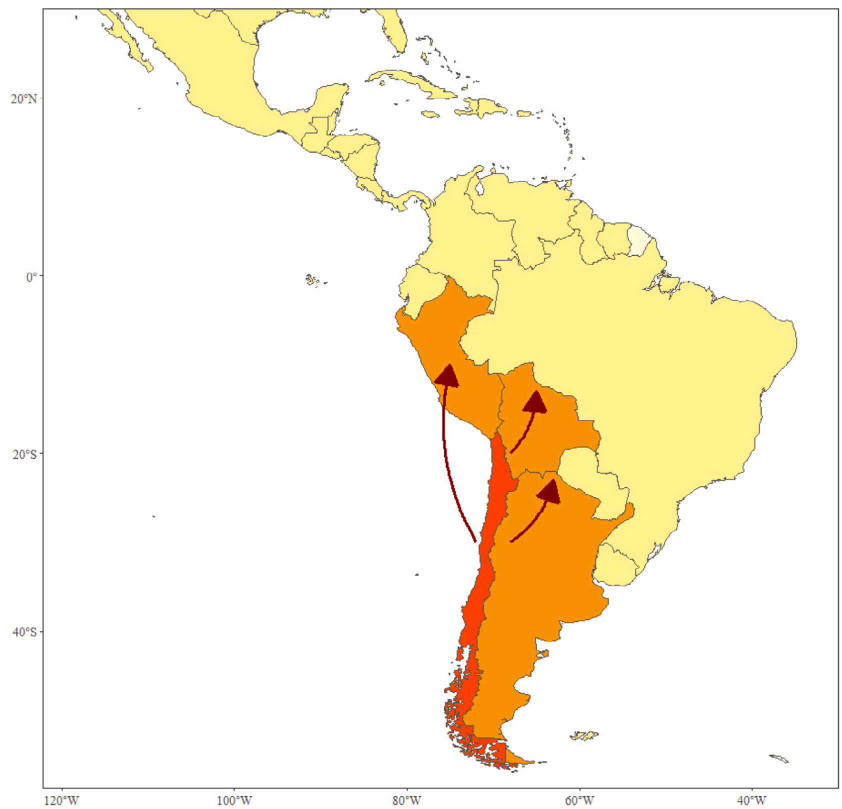

Fig. 5. An illustration of geographical spillovers from a Chilean royalty change. Potential spillovers are expected to flow from Chile to its neighbors and then to the rest of the region as indicated by the arrows.

of a policy change on one treated unit by developing a counterfactual assigning different weights to units in the control pool, matching pretreatment covariates and pretreatment outcomes (Abadie et al., 2010). The method relies on the no interference assumption between treatment and control units and in the goodness-of-fit of pretreatment variables to generate consistent estimates (Wan et al., 2018). However, it has been noticed that correlation between treatment and unobserved characteristics can also result in biased estimates (Ferman and Pinto, 2016).

In this analysis, there are fourteen countries in the donor pool for the synthetic Chile.[6] The matching process considered sixteen predictors for the preintervention period (1997–2004), representing both geological potential and institutional framework.

- Six Worldwide Governance Indicators (The World Bank, 2019): Voice and Accountability, Political Stability, Government Effectiveness, Regulatory Quality, Rule of Law and Control of Corruption.
- Seven exploration structure indicators: percentage of junior companies in total and grassroots exploration, percentage of grassroots investment, percentage of copper and gold investment, average total and grassroots exploration investment.
- Three other mining and economic indicators: percentage of mineral rents, percentage of mining exports and GDP per capita.

Estimated weights to define the synthetic Chile appear in Table 8. In this methodology, Peru (51.4 percent) and Brazil (48.6 percent) are selected as countries to generate the synthetic Chile. This results supports the use of a combination of Latin American countries as control in the previous differences-in-differences section.

Table 8
Country weights of average grassroots exploration for the synthetic Chile.

Country	Weights
Argentina	0
Australia	0
Botswana	0
Brazil	0.486
Canada	0
China	0
Finland	0
Iran	0
Mexico	0
Peru	0.514
Papua New Guinea	0
Sweden	0
USA	0
Zimbabwe	0

Note: Weights are estimated minimizing the mean square prediction error (MSPE) when the real average grassroots investment is the dependent variable.

Nevertheless, the synthetic control is not able to precisely follow the behavior of Chilean grassroots exploration during the pre-tax period (1997–2004). This is illustrated in Fig. 6. Fig. 6 represents the differences between the average grassroots budget in Chile and the synthetic Chile. For example, a positive (negative) value indicates that the treated unit was above (below) the synthetic control, suggesting a positive (negative) impact of the treatment. Differences between Chile and the synthetic control are overall positive but small. This indicates that average grassroots budgets slightly increased after the tax change compared to the synthetic control. There is a rather positive effect after the 2004 tax change and a transitory decline after the 2010 modification, but still positive as shown in Fig. 6. The synthetic approach confirms the average positive and small estimate from the differences-in-differences section.

[6] Argentina, Australia, Botswana, Brazil, Canada, China, Finland, Iran, Mexico, Peru, Papua New Guinea, Sweden, USA and Zimbabwe.

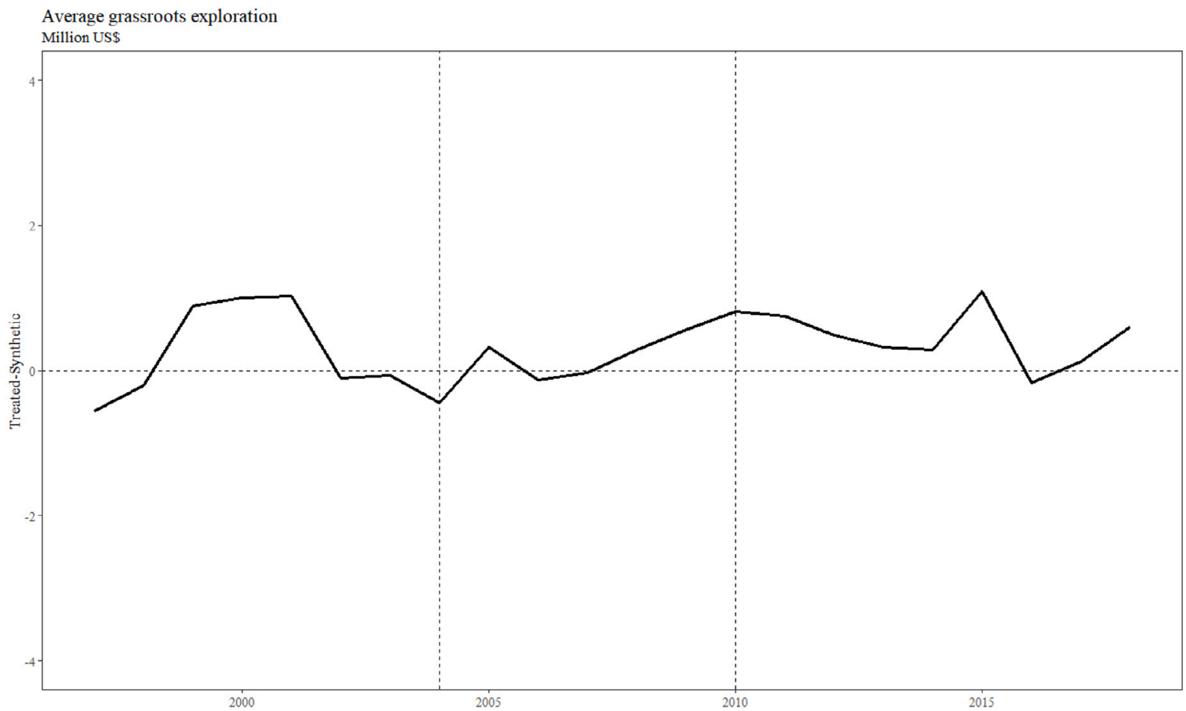

Fig. 6. Differences in average grassroots budgets between Chile (treated unit) and synthetic control. Positive (negative) values indicate that the treated unit is above (below) from what is expected from the synthetic control.

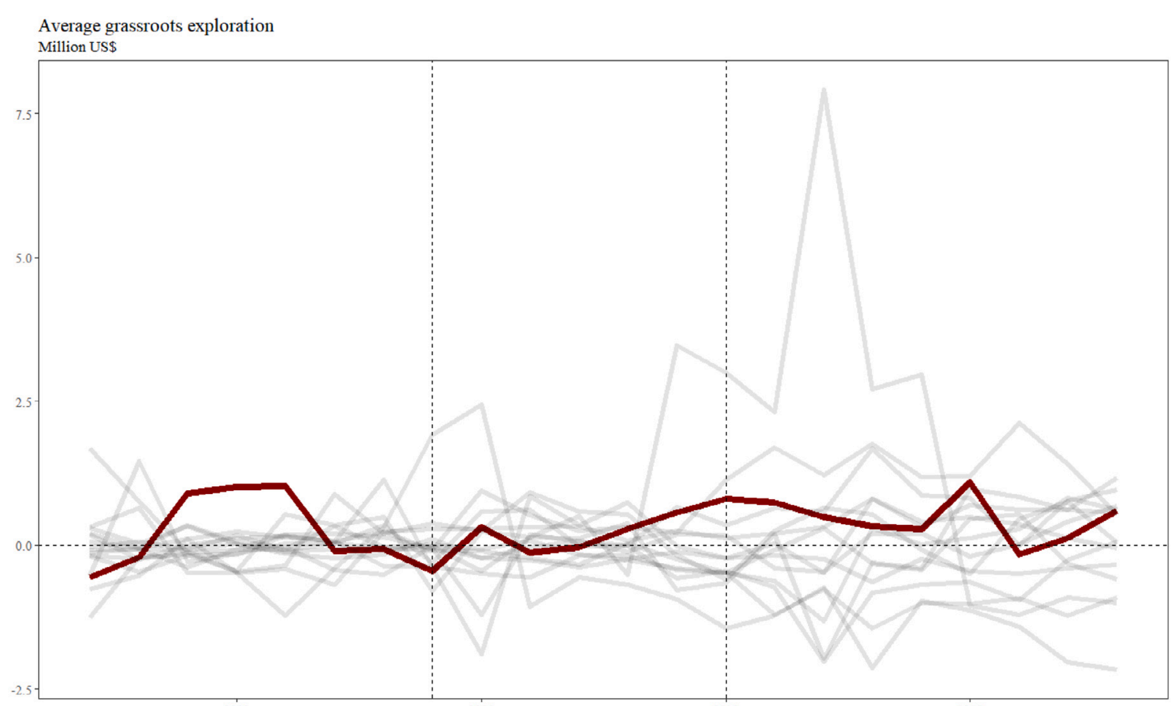

Fig. 7. Million US$ differences on average grassroots exploration budgets between treated and placebo units and their synthetic counterpart. The bold line represents the difference between Chile and the synthetic Chile.

Inference in synthetic control studies is based on placebo tests, comparing if the effect is significant relative to a randomly chosen country from the donor pool (Abadie et al., 2010). Fig. 7 illustrates that the effect is not unusual among other countries in the control group. The average impact on grassroots exploration after the first tax change is around 0.11 million US$ and 0.13 million US$ for the second change. However, in both cases the Chilean difference is larger than in only two other countries. This can be compared to a significance (p-value) of approximate 0.87, suggesting that the estimate is not different than zero at usual significance levels.

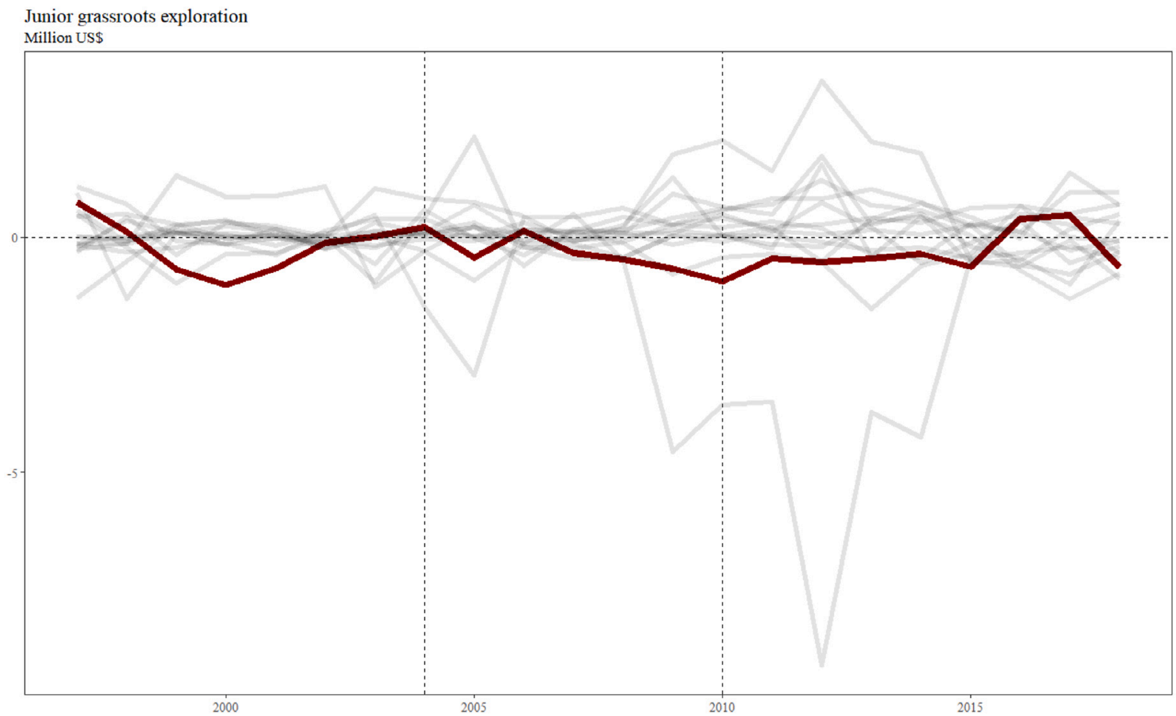

Fig. 8. Million US$ differences on junior grassroots exploration budgets between treated and placebo units and their synthetic counterpart. The bold line represents the difference between Chile and the synthetic Chile.

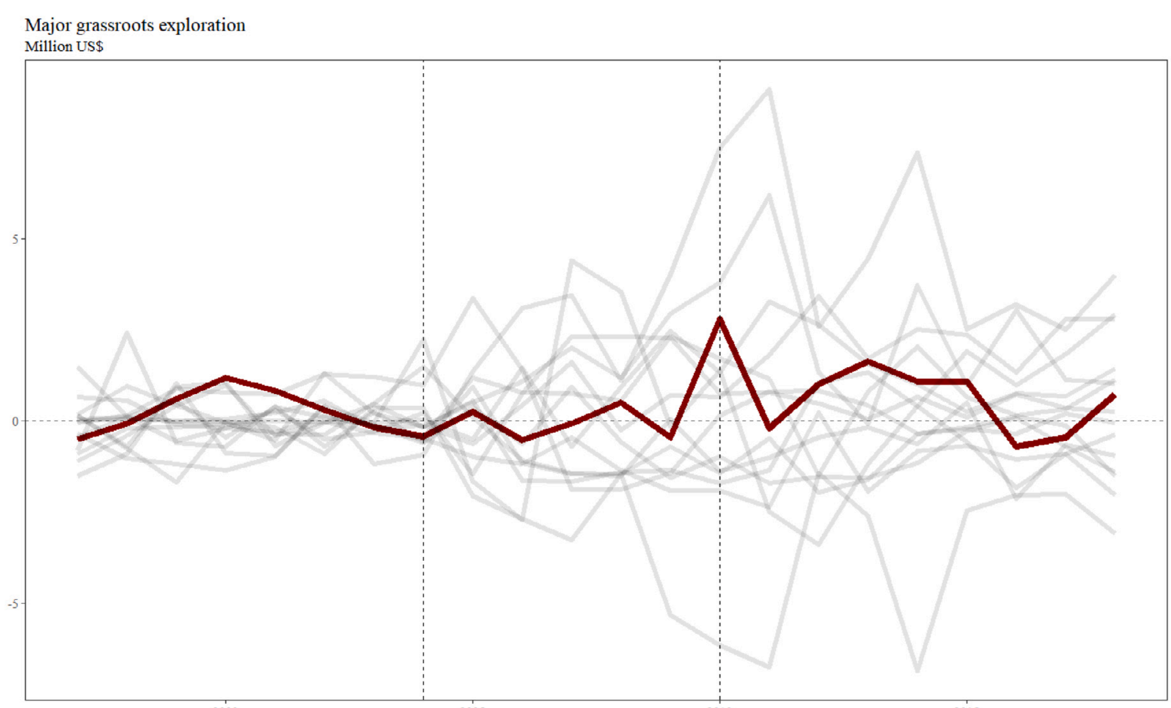

Fig. 9. Million US$ differences on major grassroots exploration budgets between treated and placebo units and their synthetic counterpart. The bold line represents the difference between Chile and the synthetic Chile.

In a similar way, it is possible to use the synthetic control method to analyze the policy effect on grassroots investment by company type. This difference is comparable to the differences-in-differences estimate by company type from Section 4.1. Country weights for the effect on junior and major companies are indicated in Table 9. Latin American countries still maintain an important position, but other countries are needed to better represent the nuances of investment by different companies.

For junior companies, the synthetic control closely follows investment decisions during the pretreatment period (Fig. 8). The difference

Table 9
Country weights of grassroots exploration by company type for the synthetic Chile.

Country	Weights (Junior)	Weights (Major)
Argentina	0	0
Australia	0.496	0.344
Botswana	0	0
Brazil	0.161	0.420
Canada	0	0
China	0	0
Finland	0	0
Iran	0	0
Mexico	0	0
Peru	0.280	0.236
Papua New Guinea	0	0
Sweden	0.063	0
USA	0	0
Zimbabwe	0	0

Note: Weights are estimated minimizing the mean square prediction error (MSPE) when the different between real average grassroots investment and the average by company type is the dependent variable.

between Chile and the synthetic control is close to zero after the first tax change and slightly positive for the second one. This result supports the differences-in-differences estimate. The placebo analysis indicates that the effect is not significantly different from zero compared to other countries. For major companies, Fig. 9 shows a slightly positive effect after both changes. As opposed to what occurs with junior investment, the synthetic control does not fit well during the pretreatment period. This occurs because Chile received the highest average investment from the countries in the sample between 1999 to 2001, then is not possible to find appropriate weights. Additionally, the placebo test indicates that the difference is not different than zero at usual significance levels. Given the differences between country weights for average, junior and major effects, the synthetic control method seems less appropriate than the differences-in-differences estimate to estimate heterogeneous effects by company type. Nevertheless, the method supports, in broad terms, the use of Latin American countries in the control group and the sign of the effects from the difference-in-differences strategy.

A main shortcoming from the synthetic control method in this application is the relative short sample for the preintervention period. Reliable estimates from the method usually requires longer pretreatment series to define weights for covariates and outcomes (Botosaru and Ferman, 2019). This can also affect the analysis in the presence of anticipation effects because it will require to redefine the treatment period to a year that when it was possibly to react to the expected policy. This reduces the number of preintervention periods to estimate weights for the synthetic unit. Particularly, the synthetic Chile is not able to accurately follow exploration investment decisions in the preintervention period and characteristics of the treated unit are not sufficiently matched. In this sense, the synthetic control method confirms the sign of the effect, but it is less reliable for the size of the effect.

5. Conclusions

Mining royalties are one of the most relevant policies related to the extractive industries. Despite clear theoretical prediction on the effects of royalties on firm decisions, little empirical evidence has been developed in this area. A main limitation for empirical studies is the lack of effects that can be measured in the short run. However, changes in early-stage exploration expenditures (or grassroots), have been suggested as a dynamic variable that should rapidly reflect the impact of changes in mining policies.

In the theoretical model, grassroots exploration is motivated by the expected value of discovering a deposit, which can be decreased (or increased) by changes in tax or other policies. This occurs as highly specialized firms cannot easily adapt their knowledge and experience to other countries. The model is tested using a differences-in-differences strategy, based on two tax changes implemented in Chile in 2004 and 2010, considering other Latin American countries in the comparison group. The first tax change is assumed exogenous as it occurred before a major increase in commodity prices and mostly because of the political cycle in the country. In 2010, a major earthquake motivated an increase in the tax rate to support the rebuilding process. In both cases, the government had previously signed stability agreements with major companies operating in the country, limiting future changes in the tax base and rate to protect investment.

Results indicate that average grassroots budgets did not decrease as a result of tax changes, as the estimate is positive but not different than zero. However, the average result masks significant heterogeneous effects by company type. Junior companies largely decreased their budgets while major companies increased their budgets for grassroots exploration. Exit decisions are also more likely for junior companies than for major companies. The significant increase in major budgets and their decision to stay in the country can be explained by the stability agreements signed with the government, as these agreements did not include junior companies. Nevertheless, it cannot be rejected that the process of the tax change itself improved the perception of major companies already investing in the country about future policy changes affecting their assets. Results are supported by the synthetic control method, indicating a consistent direction in the average royalty effect and by company type. Additionally, the absence of geographical spillovers to neighboring countries not only makes previous estimates more reliable but also suggest that neighboring countries do not need to engage in harmful tax competition.

In a policy context, these results are interesting as they highlight that major companies may not be as sensitive to changes in mining taxation as junior companies. Countries could take advantage of other instruments to generate an attractive investment climate to maintain the flow of discoveries and projects. However, the analysis also exemplifies how the impact on less visible junior companies can be neglected by policymakers.

Lastly, the non-negative effect of the Chilean profit-based royalty provides some guidelines to improve the contribution of mining while maintaining its competitiveness. In this sense, the process made in respect to rule of law, the neutrality of the tax mechanism and the overall tax burden can be balanced when improving the mining tax system.

CRediT authorship contribution statement

Emilio Castillo: Conceptualization, Investigation, Methodology, Software, Data curation, Formal analysis, Validation, Writing - original draft, Writing - review & editing, Visualization.

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Appendix

The Figs. A.1–A.3 show year-by-year estimates for the impact of Chilean profit-based royalties on early-stage exploration (average, major and junior) not included in the main text.

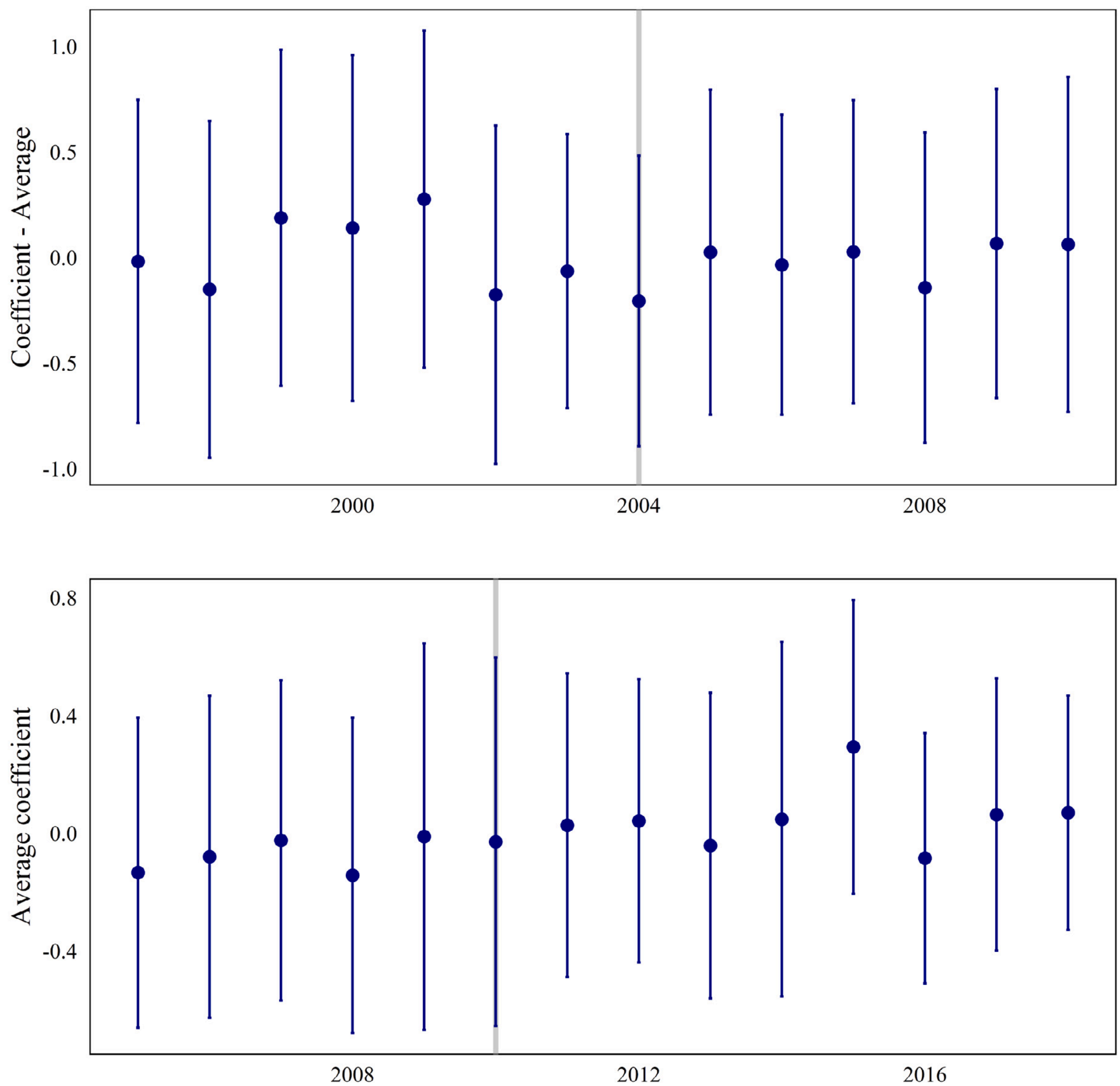

Fig. A.1. Year-by-year coefficients for the differences-in-differences approach for the first tax change in 2004 (top) and the second in 2010 (bottom). Coefficients comes from model including country, year, company type and mineral fixed effects, and governance controls. The year of each tax change is highlighted as a vertical line. Robust standard errors appear as vertical bars and are clustered at the country level.

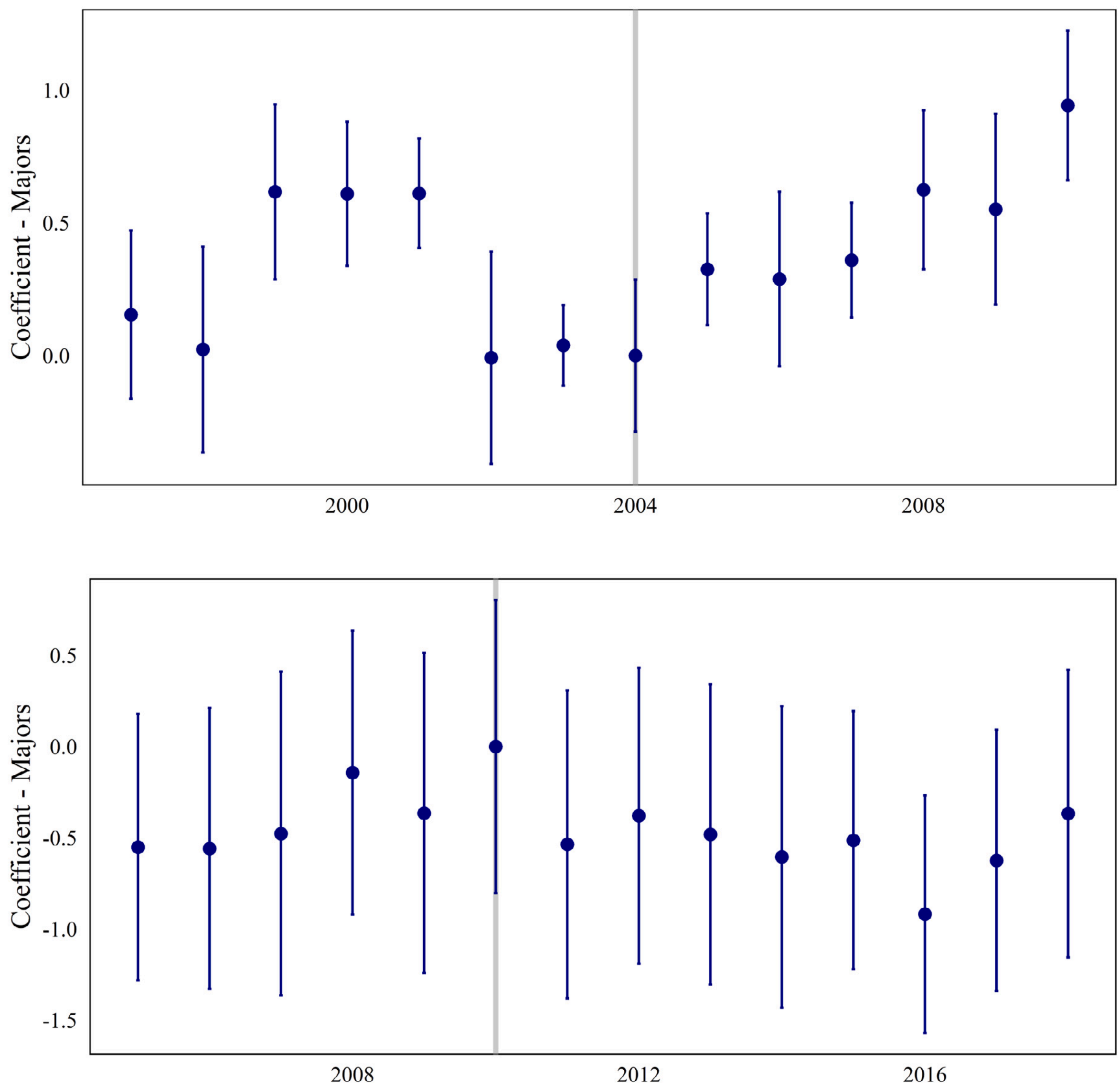

Fig. A.2. Year-by-year coefficients for the differences-in-differences approach from major companies for the first tax change in 2004 (top) and the second in 2010 (bottom). Coefficients comes from model including country, year and mineral fixed effects, and governance controls. The year of each tax change is highlighted as a vertical line. Robust standard errors appear as vertical bars and are clustered at the country level.

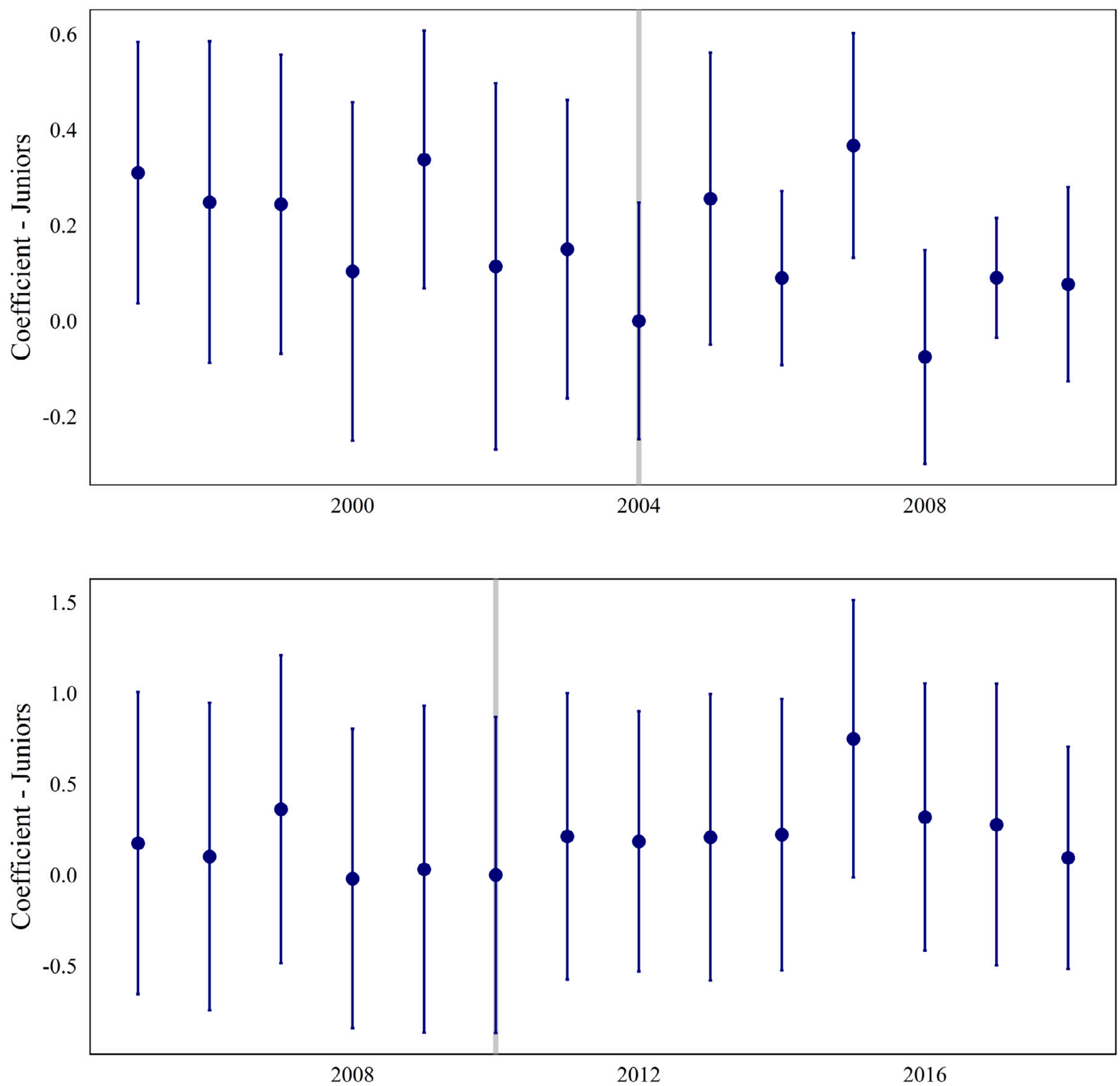

Fig. A.3. Year-by-year coefficients for the differences-in-differences approach from junior companies for the first tax change in 2004 (top) and the second in 2010 (bottom). Coefficients comes from model including country, year and mineral fixed effects, and governance controls. The year of each tax change is highlighted as a vertical line. Robust standard errors appear as vertical bars and are clustered at the country level.

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