

Shifting Frontiers in Global Resource Wealth:

The Role of Policies and Institutions

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Abstract

This paper explores the impact of increased market orientation and improved institutions on global resource wealth using a novel dataset of major hydrocarbon and mineral discoveries. Guided by the predictions of a two-region model, we employ an instrumental variable strategy to test whether increased market orientation boosts discoveries. Our results indicate that if Latin America and sub-Saharan Africa were to adopt the same quality of institutions as the United States, discoveries worldwide would increase by 25 percent. Our results support the primacy of institutions by calling into question the commonly held view that resource endowments are exogenous.

JEL Classification: E00, F3, F4.

Keywords: natural resources, discoveries, institutions, market orientation, liberalization, endogenous reserves

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I. INTRODUCTION

In the 15th century Portugal and Spain, the then most advanced maritime powers, conquered nations around the world to explore and secure control over the natural resources they would discover. Subsequent colonial empires included the French, English, Dutch and Japanese that imposed their rules on foreign territories. In turn, these empires discovered new resources and expanded their control over global resource wealth. A similar shift in (known) resource wealth occurred during the first half of the 19th century when the United States' expansion toward the Wild West sparked the so-called Gold Rush. The United States at the time of independence were thought of as a country of "an abundance of land but virtually no mining potential" (O'Toole, 1997). By 1913 the United States were the world's dominant producer of virtually every major industrial mineral and new deposits were continuously discovered. The US share of world mineral production in 1913 was far in excess of its share of world reserves (Davis and Wright, 1997). The successful resource-based development of the United States did not primarily depend on geological endowment, but was driven among other things by an open and accommodating legal environment with the government claiming no ultimate title to the nation's minerals (e.g., Wright and Czelusta, 2004). The US experience suggests that good institutions and an open market orientation can spur discoveries. Similarly, good institutions in the United Kingdom and Germany led to mining large coal and iron ore deposits which fed their industrial development during the late nineteenth century.¹

Today, more than another century later and with the colonial era well behind us, the shares of the United States and other advanced countries of global resource deposits have fallen dramatically, driven by discoveries in other parts of the world. We document that a major shift has taken place over the past decades. More specifically, we provide systematic evidence that changes in policies and institutions of – independent – countries, geared towards opening up their economies and improving institutions, have sparked a "North" to "South" shift in (known) global resource wealth. We thus investigate both analytically and empirically the hypothesis that exploration and discoveries of resources in certain countries is resulting from increased market orientation and

¹ Economic historians argue that natural resource may be under-produced due to lack of effective property rights (e.g. Anderson and Libecap, 2011) and private mineral rights become more explicit as mine values increased (Demsetz, 1967; Libecap, 1976). With increased competition for valuable resources, informal rules were insufficient to reduce risk and support long-term investment to develop the mines. Making property rights more formal boosted mining investment.

improved institutions over and above increased global demand for these resources or depletion forces in the North.

To illustrate the shift in global resource wealth, we present three key facts that further motivate our analysis. Specifically, we show that: (i) the stock of proven oil reserves has been continuously increasing over the past decades driven primarily by countries outside the OECD (Organization of Economic Co-operation and Development); (ii) the number of discoveries in developing countries has been increasing since the 1980s but decreasing in advanced economies; and (iii) the timing of the shift coincides with economic liberalization in developing countries. Inspired by these facts, we develop a simple two-region model of endogenous reserves based on Pindyck (1978) where multinational corporations are faced with a tax which is decreasing in market orientation and institutional quality. The model explores the interplay between that institutional channel with others such as the increase in the marginal cost of discoveries and (demand driven) natural resource price shocks. In turn, key model predictions of the model are then taken to the data.

For our empirical analysis we build a unique dataset of the universe of worldwide major natural resource discoveries since 1950. We then estimate a three-way panel model covering 128 countries, 33 types of natural resources and 40 years. Our main explanatory variable is a generic measure of market orientation. To account for the endogeneity of such a variable, we construct a measure of predicted market orientation that we use to instrument for actual market orientation. The measure of predicted market orientation follows an idea pioneered by Buera et al (2011) – a country's choice to liberalize its economy depends on the policies of neighbouring countries in general, but also on how successful other countries with liberalized and closed economies, respectively, performed. We include country, year and natural resource fixed effects in our panel estimates to control for global common shocks, technological progress, as well as countries' geographic location, geology and culture.

Consistent with the model's predictions, our empirical analysis shows that market orientation causes a statistically and economically significant increase in the likelihood of resource discoveries over and above the effect of changes in resource prices and depletion. In all specifications we find that countries discover more natural resources after they adopt market based institutions. We verify the mechanism through which this occurs by showing that

exploration spending also significantly increases following changes in market orientation. A country's proven resource endowment is thus in part determined by the quality of its institutions. To obtain a finer quantification than a dichotomous variable allows, we also use more disaggregated measures of institutional quality. The regression coefficients imply that if Latin America and sub-Saharan Africa were to adopt the same quality of institutions as the United States, the number of discoveries worldwide would increase by 25 percent, all else equal.

Separately, we also find that higher resource prices tend to increase discoveries. Additionally, our results show that there is a concave relationship between the stock of previous discoveries and new discoveries. At low levels, previous discoveries increase the number of additional discoveries as companies' capitalize on the information that a pool of reserves exists in a region or country. As the stock of previous discoveries increases, the impact on new discoveries becomes negative, indicating that the marginal cost of discoveries increases after the "low-hanging fruit" has been picked and reserves 'run out'. Our results are robust to a wide array of checks including using alternative estimators.

Our paper is closely related to the theoretical and empirical literature on exhaustible resource exploitation and exploration. Resource exploration and discovery has been investigated either as a deterministic or a stochastic process (e.g. Pindyck, 1978; Arrow and Chang, 1982; Devarajan and Fisher, 1982). The canonical model is the exploration model developed by Pindyck (1978) where a social planner maximizes the present value of the social net benefits from consumption of oil and the reserve base can be replenished through exploration and discovery of new fields. We extend Pindyck (1978) to a simple two-region model to explore the relationship between exploration investment and discoveries where multinational corporations are faced with explicit and implicit taxes on their investment in the South and but none in the North.

Investments in the resource sector involve sunk costs and are thus subject to the holdup problem and the risk of expropriation (Long, 1975). Empirical evidence suggest that a stable political environment, a low risk of expropriation, and a favourable investment climate boost investment in the resource sector (Bohn and Deacon, 2000; Stroebel and van Benthem, 2014). Using an identification strategy that exploits variations in institutions and oil deposits sitting on both sides of a border, there is evidence that institutions substantially affect oil and gas exploration (Cust and Harding, 2015). We explore the North to South shift in resource extraction and consider

variations across time and resources as well as across countries. This is crucial, since institutions and market orientation do change with time. We go beyond discoveries of major oil and gas fields to also include major mineral deposits. Our identification strategy relies on the fact that neighbours' past experiences influence policy choices in terms of economic liberalization as in Buera et al. (2011) and that neighbours' policy choices are not related to natural resource discoveries at home.

This paper contributes to the literature on institutions as deep determinants of economic development (Acemoglu, Johnson and Robinson, 2002; Easterly and Levine, 2002; Hall and Jones, 1999; Rodrik, Subramanian and Trebbi, 2002). We contribute to that literature by providing systematic evidence that policies geared toward economic liberalization and/or improvement in institutions instigated by independent countries lead to major natural resources discoveries that eventually push those countries toward extractive activities. In other words, changes in policies and institutions in developing countries in the post-colonial era have become a determinant of (known) resource wealth.

This paper is related to the literature on institutions and the resource curse (see Frankel 2012; Venables, 2016; Ross 2012; and van der Ploeg, 2011 for recent surveys). In particular, empirical evidence suggests that the curse in terms of the effect of natural resources on growth is less negative and can even turn positive if the quality of institutions is beyond a certain threshold (e.g., Mehlum, Moene and Torvik, 2006; Bosscini, Pettersson and Roine, 2007). While this literature has long focused on the direction of causality running from resource endowment and institutions to growth and conflicts, our results suggest that the other direction of causality running from policies and institutions to resource endowment is also important. It should be noted that our focus is “upstream” rather than “downstream”. As such we are concerned with “external” policies and institutions that are geared toward foreign investors who conduct exploration activities. Our results do not contradict the fact that subsequent to a discovery, countries with poor “internal” institutions (e.g. weak state capacity) may experience poor economic performance or civil strife.

Lastly, our paper also relates to the literature linking institutions and international capital flows, and the so-called “Lucas’ paradox” (Lucas, 1990). Countries with weak rule of law, high political or default risk, underdeveloped financial markets, or high transaction cost and

deficiencies in governance may attract only limited investment flows even if they offer high rates of return (Shleifer and Wolfenzon, 2002). In this respect, policies and institutional factors have been shown to play an important role in explaining the magnitude and nature of capital flows to developing and emerging economies (Alfaro, Kalemli-Ozcan and Volosovych, 2008). We contribute to this literature by providing evidence that economic liberalization and changes in institutions affect the structure of the economy through expansion of the resource sector. We verify that a key channel through which changes in market orientation affect discoveries is exploration expenditure. Since foreign firms play a lead role in conducting exploration activities in developing countries, exploration expenditures are a form of international capital flows.²

The remainder of the paper is organized as follows. Section II presents basic facts about resource wealth and economic liberalization used to motivate our analysis. Section III then develops a two-region model extending Pindyck (1978). Section IV lays out the data and empirical strategy. Section V presents the main results and key robustness checks. Section VI concludes.

II. FACTS

Here we use our data on major hydrocarbon and mineral discoveries as well as widely used data on prices, (proved) reserves and institutions to present basic but to the best of our knowledge, not well established facts about the global pattern of the evolution of (known) resource wealth.³

Fact 1: Global proved oil reserves have continuously increased, particularly driven by developing countries.

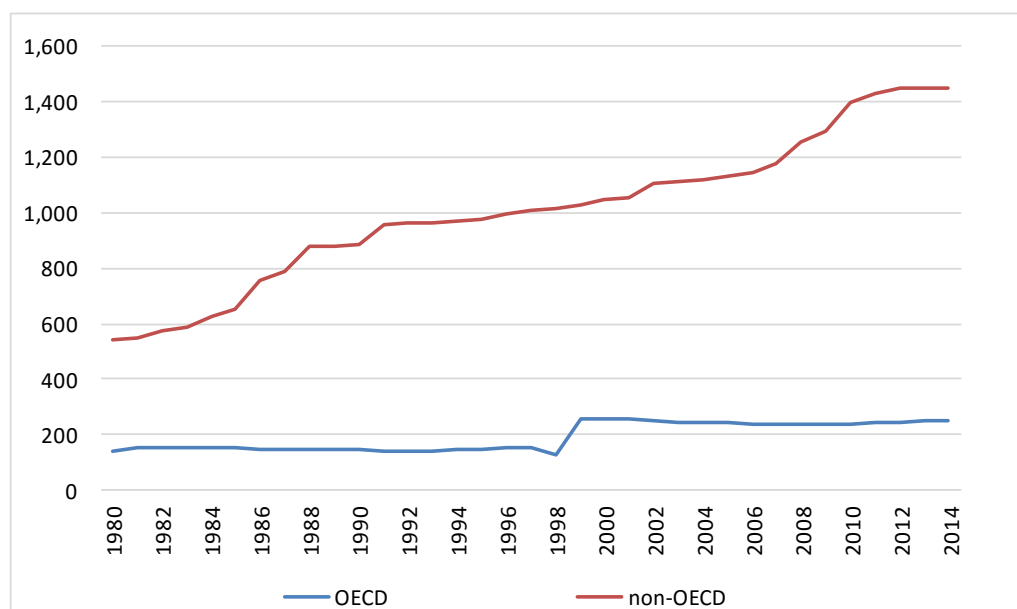
Discoveries of natural resources have shown no sign of decreasing over time. To the contrary, and notwithstanding the long-running debate about the so-called “peak oil hypothesis”, Figure 1 shows that proved oil reserves, for example, have steadily increased over the past three decades driven almost exclusively by non-OECD reserves. Furthermore, there is likely to be substantial potential for further discoveries in developing countries still. While there is an estimated \$130,000 of known subsoil assets beneath the average square kilometer of OECD countries, the

² While international capital flows during the exploration phase (prior to eventual discoveries), capital flows perhaps even more significantly after resource discoveries during the development phase. That renders the empirical documentation that (aggregate) capital flows precede discoveries difficult.

³ See section IV and Appendix B for a detailed description of the data used in this paper.

figure for Africa is only about \$25,000 (see Collier 2011 and McKinsey Global Institute 2013). That suggests that certain regions have been much less subject to exploration than others. That then raises the question of *why* these regions remain underexplored relative to other regions.

Figure 1: Proved oil reserves in OECD and non OECD countries

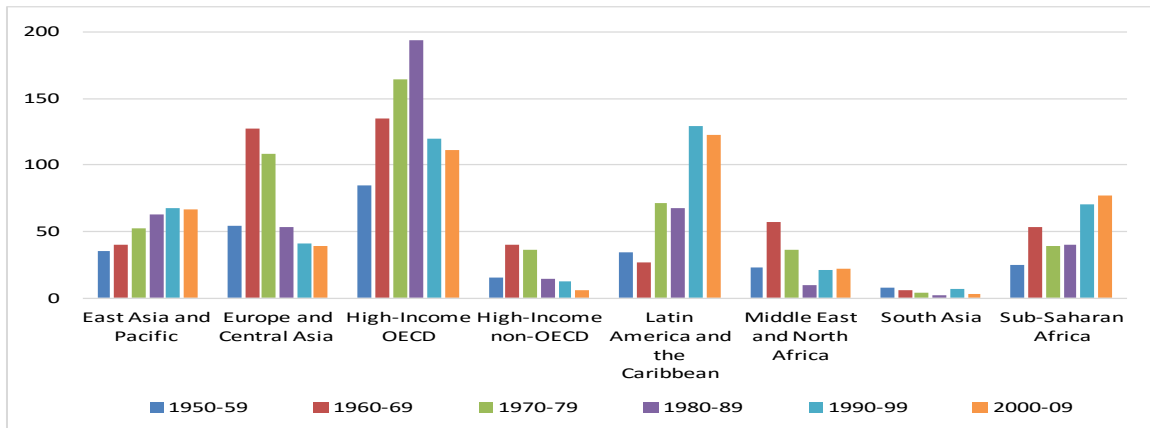


Note: Data are from BP. Units are thousand million barrels. Proved reserves are generally taken to be those quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known reservoirs under existing economic and operating conditions.

Fact 2: Major resource discoveries have shifted from advanced to developing countries.

A “North” to “South” shift in major resource discoveries has taken place over the past decades. Figure 1 already gave some indication of a shift in discoveries from developed to developing countries. Figure 2 shows a more comprehensive exercise where we plot the number of natural resource discoveries by decade and region for a set of large discoveries of minerals and hydrocarbons. While the total number of discoveries has remained fairly constant over the last decades, the regional composition has experienced a shift. While discoveries in OECD countries have been on a downward trajectory since the 1980s, discoveries in Latin America and the Caribbean, and Sub-Saharan Africa have been rising. High-income OECD countries accounted for 37 to 50 percent of all discoveries during 1950–89. That share has fallen to 26 percent in the past decade with sub-Saharan Africa and Latin America and the Caribbean doubling their shares. Latin America has experienced the most discoveries of natural resources in the past two decades.

Figure 2: Major Discoveries of Natural Resources by Region and Decade

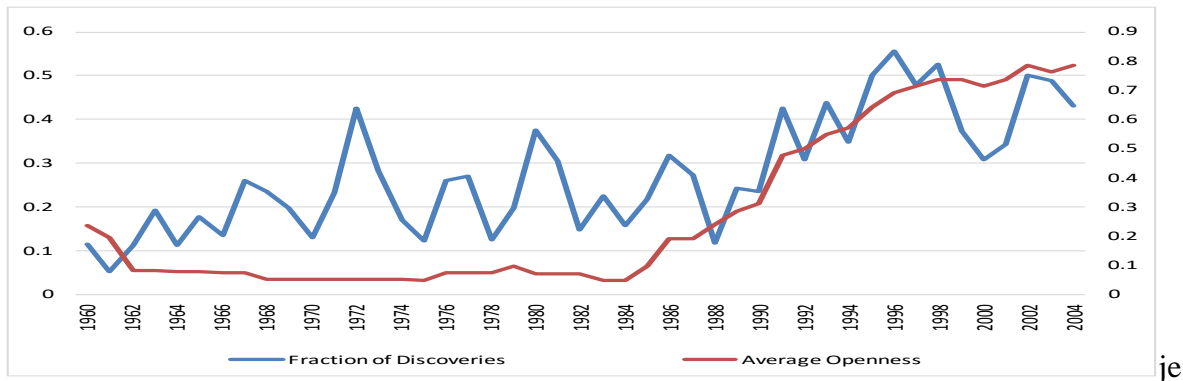


Note: Data from MinEX (2014) for mineral discoveries and Mike Horn for oil and gas combined with authors' calculations.

Fact 3: Countries that have liberalized their economies have substantially more discoveries after opening up than before liberalization.

The timing of the shift in discoveries from North to South coincides with economic opening in Latin America and Sub-Saharan Africa. Figure 3 uses data from Sachs and Warner (1995) and Wacziarg and Welch (2008) on economic liberalization (updated until 2004) to plot the average share of major discoveries in Latin America and Sub-Saharan Africa against the average openness in these countries. There is a strong positive correlation between the two variables. In fact, liberalization seems to precede the increase in the fraction of discoveries.

Figure 3: Natural Resource Discoveries and Economic Liberalization in Latin America and the Caribbean and Sub-Saharan Africa



Note: Data are from MinEX, Mike Horn for discoveries, Wacziarg and Welch (2008) for openness measure combined with authors' calculations

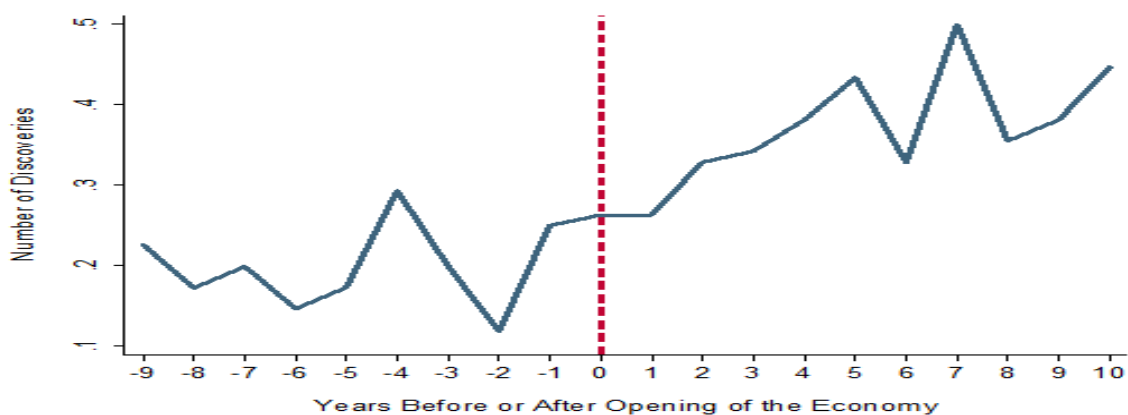
There is also ample anecdotal evidence of a link between better institutions and more discoveries across continents and types of natural resources (see Table 1). The increase in discoveries after countries open up appears quite stark. In Peru, for example, discoveries more than quadrupled. Discoveries tripled in Chile, and they doubled in Mexico. Interestingly, these discoveries not only occurred when commodity prices were high, but also when they were at historical lows. The pattern linking liberalization and discoveries seem to hold across geographical regions and time periods.

Table 1: Number of discoveries before and after opening – Country Examples

Country	Chile	Ghana	Peru	Indonesia	Mexico
Date of Opening	1976	1985	1991	1970	1986
Number of Discoveries 10 years before opening	5	0	5	3	12
Number of Discoveries 10 years after opening	15	6	23	15	21

To shed further light on that phenomenon we conduct an event-study style analysis where we calculate the average number of discoveries prior and after liberalization for all such episodes in the updated Wacziarg and Welch dataset.⁴ Figure 4 shows that the number of discoveries significantly increases after economic liberalization. The average number of discoveries per year and country rises from 0.2 prior to liberalization to 0.36 afterwards.

Figure 4: Average number of discoveries before and after liberalization



Note: Authors' estimations.

⁴ In practice, we regress the number of discoveries on a set of period fixed effects while controlling for event fixed effects. We then retrieve the coefficients of the period fixed effects and plot them.

The event analysis does not include any controls and does not address endogeneity issues or other statistical confounding influences. Nevertheless, it provides us with a window into what the data have to offer and motivates our main hypothesis that economic opening and improvements in institutions increase the number of natural resource discoveries and are thus a key driver of the observed shift in the frontier of discoveries.

III. A TWO-REGION MODEL OF RESOURCE DISCOVERIES

Inspired by the above facts, we present a simple two-region model of endogenous reserves and resource discoveries. The global economy has two resource-producing regions: the North with free access for international resource companies (IRCs) and the South which is less open for IRCs. We extend a three-period version of the canonical model of resource exploration and depletion put forward by Pindyck (1978) to two regions with a global competitive market for resources. IRCs decide *where* to explore reserves depending on local extraction costs including those due to bad institutions and lack of openness and availability of subsoil resources. They relocate activities until costs of resource exploration across the globe are equalized.

IRCs in the North decide on exploration investment in periods zero and one, I_0 and I_1 . This gives initial reserves, $S_1(I_0)$, and discovery of new reserves, $D(I_1) = A \ln(I_1)$. At the start of period two, reserves in the North are $S_2 = S_1(I_0) + D(I_1) - R_1$, where R_1 denotes current depletion. Future depletion cannot exceed remaining reserves. The resource is sold on the world market at prices p_1 and p_2 . This market is competitive, so IRCs take prices as given. The cost of extraction falls with remaining proven reserves: $G(S_t) = \gamma / S_t$ with $\gamma > 0$. IRCs can freely borrow at a given world interest rate r . Variables, cost and exploration functions for the South are denoted by an asterisk. North and South may differ in extraction costs and initial reserves. Another difference is that the South has institutional failures and access restrictions captured by taxes $T_0^* > 0$ and $T_1^* > 0$ on exploration investment. Global IRCs thus maximize their net worth:

$$(1) \quad \begin{aligned} & \text{Max}_{I_t, I_t^*, R_t, R_t^*} \sum_{t=1}^2 \left((1+r)^{-t} [p_t - G(S_t)] R_t - (1+r)^{t-1} I_{t-1} \right) + \\ & \sum_{t=1}^2 \left((1+r)^{-t} [p_t - G^*(S_t^*)] R_t - (1+r)^{t-1} (1+T_{t-1}^*) I_{t-1} \right), \end{aligned}$$

subject to $R_2 \leq S_2 = S_1(I_0) + D(I_1) - R_1$ and $R_2^* \leq S_2^* = S_1^*(I_0^*) + D^*(I_1^*) - R_1^*$. This gives the Hotelling rules governing the speeds at which the resource is extracted for the North and South:

$$(2) \quad p_1 - G(S_1) = \frac{1}{1+r} [p_2 - G(S_2) + G'(S_2)R_2] \quad \text{and} \quad p_1 - G^*(S_1^*) = \frac{1}{1+r} [p_2 - G^*(S_2^*) + G^{*'}(S_2^*)R_2^*].$$

Hence, future rents minus the marginal increase in future extraction cost from extracting an extra unit of resource today must equal current rents plus interest. Maximizing net worth also yields:

$$(3) \quad [p_1 - G(S_1(I_0))]D'(I_1) = 1 \quad \text{and} \quad [p_1 - G^*(S_1^*(I_0^*))]D^{*'}(I_1^*) = 1 + T_1^*.$$

The marginal rent from discovery investment must thus be cost including taxes. These yield discoveries: $D = A \ln((p_1 - \gamma / S_1)A)$ and $D^* = A^* \ln((p_1 - \gamma^* / S_1^*)A^* / (1 + T_1^*))$. Discoveries thus rise with the global resource price. The North has more discoveries if it has a higher or more easily accessible stock of reserves that depresses extraction costs ($\gamma < \gamma^*$ or $S_1 > S_1^*$), geological conditions are better ($A > A^*$), and there are less taxes, less institutional barriers and easier access for IRCs in the North ($T_1^* > 0$). Global IRCs relocate exploration across the global so that the total marginal cost of extracting and discovering a unit of resource is equalised across the globe as can be seen from the global arbitrage condition $p_1 = \frac{\gamma}{S_1} + \frac{I_1}{A} = \frac{\gamma^*}{S_1^*} + (1 + T_1^*) \frac{I_1^*}{A^*}$.

Maximizing net worth also gives the efficiency conditions that yield initial reserves and exploration in much the same way as discoveries (4) follow from (3) (see Appendix A). The main difference is that initial exploration investment benefits from making future extraction cheaper by ensuring higher proved reserves. We thus get the following comparative statics results for discoveries (and those for exploration investment and reserves are in Appendix A):

$$(4) \quad D = D(p_1^+, R_1^+, A^+, \gamma^-) \quad \text{and} \quad D^* = D^*(p_1^+, R_1^+, T_0^-, T_1^-, A^+, \gamma^*^-).$$

A gradual opening of the South to natural resource exploration as indicated by a fall in the future tax ($T_2^* < T_1^*$) shifts more effort to additional future discoveries rather than exploration today.

Resource discoveries in the South are thus held back by the lack of openness to IRCs.⁵

⁵ Furthermore, resource extraction in the South increases if it more attractive for IRCs to discover new reserves and is postponed if the market expects easier access for IRCs in the future.

Finally, to explain world resource prices one needs to introduce global resource demand. Due to tax shifting, equilibrium world resource prices increase with resource exploration taxes in the South. Resource producers are more successful in shifting the burden to consumers if demand for resources is relatively inelastic and supply of resources is not. Taxes and restrictive access in the South will thus lead to a shifting of exploration activities and discoveries from the South to the North once account is taken of the endogenous nature of world resource prices (see Appendix A). As the South liberalizes and gets more open to IRCs, exploration activities and discoveries shift from the North to the South. This is our hypothesis of the shifting frontier of natural resources for which the facts discussed in Section II seem to give support. Other (not mutually exclusive) forces include the rise in global resource demand (e.g., from China and India) that led to more exploration efforts and discoveries and increases in the marginal cost of exploration.

Our empirical analysis aims to test whether the “institutional channel” of resource discoveries is potent over and above others. We therefore allow discoveries to depend not only on institutions and ease of access for IRCs but also on global resource demand shocks and changes in marginal costs of discoveries due to depletion forces.

IV. DATA AND EMPIRICAL STRATEGY

Before we turn to the empirical strategy for testing our theoretical predictions, we present and discuss the various datasets that we use. We focus on the novel data on major hydrocarbon and mineral deposits and the data on market orientation and institutional quality (see Appendix B for a more comprehensive list of data and sources).

Discoveries

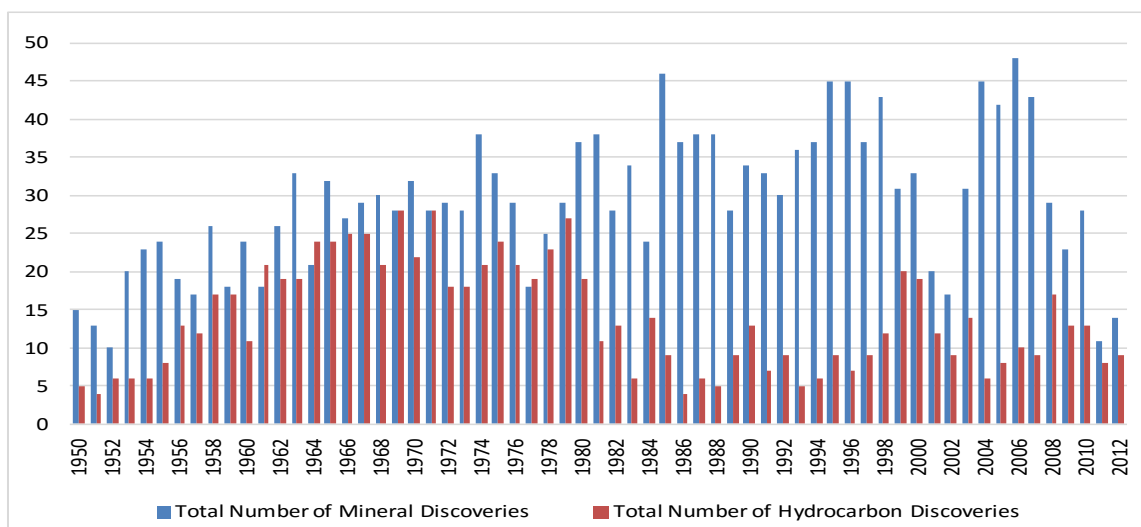
The oil and gas discovery dataset is from Horn (2014). It should be noted that Horn reports discoveries of giant oil (including condensate) and gas fields which we refer to as hydrocarbon or simply oil discoveries. A giant oil discovery is defined as a discovery of an oil and/or gas field that contains at least a total of 500 million barrels of ultimately recoverable oil equivalent. Ultimately recoverable reserves refer to the amount that is technically recoverable given existing technology. The data on mineral deposits discoveries is from MinEx. The list of minerals included in the dataset is comprehensive and includes precious metals and rare earth (see

appendix B). The dataset excludes iron ore and bauxite, which are more abundant than other metals and require proximity to port facilities for the former and substantial energy availability for the latter. A major mineral deposit has the capacity to generate annual revenue stream of at least USD 50 million after accounting for fluctuations in commodity price. Figure 5 plots the total number of worldwide discoveries (split between minerals and hydrocarbons) by year. Since the early 1980s the average number of discoveries has been fairly stable at the global level. In our empirical work we use discoveries disaggregated by 128 countries and 33 types of resources.

Exploration

To measure exploration effort, we use disaggregated data on exploration expenditures from Rystad for oil and gas and from SNL Metals and Mining for selected minerals including copper, nickel, zinc, diamond, uranium, and platinum.⁶ The SNL Metals and Mining dataset only starts in 1994 and thus limits the sample period for this part of our empirical analysis. Similarly to the data on discoveries, data on exploration spending are broken down by country, type of natural resource and year and allow us to conduct detailed three-way panel regression analysis.

Figure 5: Number of Natural Resource Discoveries by Year



Note: Discoveries data are from MinEX for mineral and Mike Horn for oil combined with authors' calculations.

Market orientation

To measure market orientation or openness, we use data from a panel of dates of economic liberalization for a large number of countries (133 countries) and years (1950 to 2004) originally

⁶ According to Rystad, exploration expenditures in the oil and gas sector worldwide amounts to about a fifth of total capital expenditures.

constructed by Sachs and Warner (1995) (SW thereafter) and revised and extended by Wacziarg and Welch (2008). Following SW, the following criteria are used to classify a country as open: (i) the average tariff rate on imports is below 40%; (ii) non-tariff barriers cover less than 40% of imports; (iii) the country is not a socialist economy (according to the definition of Kornai (1992)); (iv) the state does not hold a monopoly of the major exports; and (v) the black market premium is below 20%. The resulting indicator is a dichotomous variable. If in a given year a country satisfies all of these above criteria, SW call it open and set the indicator to 1. Otherwise, the indicator takes the value of 0.

While this indicator was originally designed to capture openness to trade, we follow Rodriguez and Rodrik (2001) and Buera et al. (2011) by viewing the SW indicator as proxy for much broader policy and institutional differences. Trade liberalisation is usually just one part of a government's overall reform plan for integrating an economy with the world system. Other aspects of such a program almost always include price liberalization, budget restructuring, privatization, deregulation, and the installation of a social safety net (Sachs and Warner, 1995). For the purpose of the present study, it is thus useful in our view to capture as broad as measure of market orientation which policy implications often reverberate on the "openness" of the resource sector. Indeed, investment in exploration is often worthwhile only if there are prospects for further extractive activities. Such a generic market orientation does allow us to capture a combination of factors such as favourable business climate including fiscal terms, political risks and access to relevant equipments and financing.⁷ We thus use the indicator as proxy for country's degree of market-orientation. If the SW indicator is equal to 1, the country is deemed market oriented. If the indicator is equal to 0, the country is not.

Political risk and Quality of Institutions

To complement the data by SW (considering also that the SW data is only available up to 2004) and to allow for more disaggregated measures of institutions, we use data from International Country Risk Guide's (ICRG's) Political Risk Index which allow us to capture investor's perception of risk. Institutions are likely to affect discoveries through a variety of channels

⁷ We prefer this to resource-specific measure of market orientation, because generic measures typically capture de facto conditions and/or multilateral commitments (e.g., to the World Trade Organization) which are more difficult to reverse and thus more credible than say sectoral regulations that govern rather narrower aspects of a bilateral relationship between firms and national authorities.

besides the perception of risk on the part of the potential foreign investors. For instance, improved institutions could make transfer of capital and technology easier and in turn affect discoveries. We do not attempt to separate those channels. The aim of the political risk rating is to provide a means of assessing political stability of the countries covered by ICRG on a comparable basis. This is done by assigning risk points to a pre-set group of factors, termed political risk components. The minimum number of points that can be assigned to each component is zero, while the maximum number of points depends on the fixed weight that a component is given in the overall political risk assessment. In every case the lower the total of risk points, the higher the risk; and the higher the risk point total, the lower the risk. Those ratings are available from 1985 onwards and thus allow us to include the period of high prices in the early 2000. In supplementary analysis we use the disaggregated ICRG indicators on property rights, rule of law, etc. separately to shed additional light on the institutional and political channels which influence resource discoveries.⁸

Empirical strategy

To capture the causal impact of liberalizations on natural resource discoveries we estimate the following three-way panel:

$$(I) \quad y_{itk} = \gamma OPEN_{i,t-1} + \delta PRICE_{t-1,k} + \rho STOCK_{i,t-1,k} + \beta Z_{i,t-1} + \alpha_i + \theta_t + \sigma_k + \varepsilon_{i,t,k},$$

where y_{itk} is the number of major discoveries for country i at time t and for natural resource k , $OPEN_{i,t-1}$ is an indicator for whether country i is liberalized at time $t-1$, $PRICE_{t-1,k}$ is the five year moving average of the log change of the international market price for natural resource k , $STOCK_{i,t-1,k}$ is the sum of the number of discoveries of natural resource k in country i at time $t-1$, $Z_{i,t-1}$ is a vector of other country specific controls and α_i , θ_t and σ_k are country, year and resource fixed effects. The fixed effects control for time-invariant country-specific characteristics such as geographic location, global technological progress and business cycles as well as abundance and other features of individual resources. We also use a specification where we replace the vectors of country and natural resource fixed effects by a vector of country-

⁸ Unfortunately, other indicators of institutional quality (e.g., from the World Bank and the Heritage Foundation) are not available for a sufficient period of time, with some indicator starting in the early 2000s at best.

natural resource fixed effects. This controls for features such as the country-specific (difficult to measure) geological abundance of *individual* natural resources.

The average log change in prices over the past five years captures that with higher prices, the marginal profitable exploration project increases. The stock of lagged discoveries and in many specifications also the square of lagged discoveries is included to account for the clustering of discoveries and depletion of geological reserves. Additionally, the Polity2 score obtained from the Polity IV database (Marshall and Jaggers, 2009) is included in some specifications.⁹

As discussed in the literature, the quality of institutions may be endogenous to discoveries. For instance, discoveries may trigger conflicts over resources and erode political institutions (Ross 2001, 2012). As a first step to avoiding reverse causality, all explanatory variables are included with a lag. This is unlikely to resolve most of the underlying issues, however. We thus construct an instrument for openness based on the idea that neighbours' institutions, and in particular the relative success of neighbours who choose different institutions, are a strong predictor for the choice of own institutions. We closely follow the reduced-form specification in Buera et al. (2011) for this exercise.¹⁰ Specifically, we consider the following linear probability model:

$$(II) \quad E[OPEN_{i,t} | ..] = \phi_1 \overline{OPEN}_{i,t-1} + \phi_2 \hat{E}_{i,t-1} [z | OPEN = 0] + \phi_3 \hat{E}_{i,t-1} [z | OPEN = 1].$$

Here, the liberalization decision of country i in period t ($OPEN_{i,t}$) depends on a distance-weighted measure of other countries policies ($\overline{OPEN}_{i,t-1}$) and the distance-weighted average growth rate over the previous 3 years of other countries under the two policy regimes ($\hat{E}_{i,t-1} [z | OPEN = 0]$) and ($\hat{E}_{i,t-1} [z | OPEN = 1]$).¹¹ We also control for country and time fixed effects. We use the results from these regressions to predict openness for each country-year pair. Predicted openness $\hat{OPEN}_{i,t-1}$ is then used to instrument for $OPEN_{i,t-1}$ to estimate (I). To gauge the direction of a possible bias, we also report ordinary least square (OLS) results alongside the two-stage least square (2SLS) results.

⁹ The Polity2 score ranges from -10 to +10, with higher values indicating more democratic institutions and we include it to capture the effects (if any) of the domestic political system

¹⁰ Buera et al. (2011) also include the lagged SW index in their reduced form specification. Their aim is not to construct an instrument, but to motivate a structural estimation.

¹¹ The weights are based on distance data obtained from the CEPII: http://www.cepii.fr/CEPII/fr/bdd_modele/presentation.asp?id=6

Since the presence of a large number of zeros and heteroscedasticity of errors can lead to bias and inconsistency of least squares estimates, we separately also use a Zero-Inflated Poisson

estimator (ZIP). Let $\text{prob}(y_{itk}) = \frac{e^{-\lambda_{jtk}} \lambda_{jtk}^{y_{itk}}}{y_{itk}!}$, where y_{itk} denotes the number of natural resource

discoveries in country i at time t and for a specific resource k . (Silva and Tenreyro, 2006). y_{itk} is assumed to follow a Poisson distribution as follows. Specifying λ_{jtk} as a linear function of explanatory variables X_{jtk} , gives the expectation of y_{itk} conditional on X_{jtk} :

$L_{jtk} \equiv E[y_{itk} | X_{jtk}] = e^{X_{jtk} \cdot B_{jk}}$, where X_{jtk} is the row vector of explanatory variables. Taking logs gives the model to be estimated: $\log E[y_{itk} | X_{itk}] = B_{jk} X_{itk}$.

We cluster standard errors at the country-natural resource level but significance of our results is unchanged if we cluster at the country level (see Supplementary Appendix).¹²

V. MAIN EMPIRICAL RESULTS

We now turn to our benchmark results. Table 2 shows the first-stage of the 2SLS estimates. The high F-Statistics (well above 10) indicate that we do not have weak instruments. Table 3 shows the second stage of the baseline 2SLS estimates. Table 4 presents the OLS estimates for comparison. Column 1 of Tables 3 and 4 only include fixed effects and our basic variables of interest – openness and the average price change over the past 5 years. In columns 2, 3 and 4 we add additional controls, importantly the stock of past discoveries as well as its square. The time period for which data for all relevant variables is available is 1964-2004, mainly limited due to the SW indicator which finished in 2004 and price data which is available from the 1960s.¹³

Across all specifications, regression results consistently show that the coefficient on our measure of market orientation (economic liberalization) is positive and statistically significantly associated with more discoveries. More open countries are thus more likely to discover new resources. More open institutions allow for easier transfer of capital and technology and thus

¹² With clustering at the country level no F-Test of joint significance of all regressors is possible as in our case we have less regressors than cluster dummies (Cameron and Miller, 2015).

¹³ For some resources, price data have limited time series information. Appendix B provides detailed information on available price data by natural resource.

exploration is more attractive in those regions, as predicted by the model in section III. Comparing the magnitude of the IV and OLS coefficients shows that the IV estimates are larger by a magnitude of about 4.

Table 2: The Impact of Liberalization on Resource Discoveries (First stage of 2SLS)

VARIABLES	(1) SW/Wacziarg Openness	(2) SW/Wacziarg Openness	(3) SW/Wacziarg Openness	(4) SW/Wacziarg Openness
Predicted SW/Wacziarg Openness	0.809*** (0.0414)	0.809*** (0.0414)	0.808*** (0.0414)	0.729*** (0.0544)
Average Price Change Past 5 Years	0 (0.0222)	-0.000649 (0.0222)	-0.000975 (0.0222)	-0.000580 (0.0231)
Stock of Discoveries		-0.00114** (0.000468)	0.00250** (0.00100)	0.00158 (0.00104)
Stock of Discoveries Squared			-7.24e-05*** (1.45e-05)	-4.81e-05** (1.87e-05)
Polity 2 Score				0.0108*** (0.00120)
Constant	0.437*** (0.0727)	0.445*** (0.0723)	0.440*** (0.0722)	0.379*** (0.0922)
Year FE	YES	YES	YES	YES
Country FE	YES	YES	YES	YES
Natural Resource FE	YES	YES	YES	YES
Observations	49,738	49,738	49,738	46,796
F Value	1699.27	1690.97	1632.1	1621.86
R-squared	0.698	0.698	0.699	0.700

Note: The table reports the estimation results of regression with the number of discoveries as dependent. *** denotes significance at the 1% level, ** at the 5% level, and * at the 10% level.

The OLS estimates are biased downwards as one would expect thinking back to the general reverse causality story where resource discoveries lead to rent seeking and potentially even conflict. Looking at the 2SLS point estimates indicates that liberalization increases discoveries per country-year-natural resource by roughly 0.05. We will discuss that quantification in more detail below, but it translates into an economically highly significant impact at the aggregate level.

Table 3: The Impact of Liberalization on Resource Discoveries (2SLS)

VARIABLES	(1) Number of Discoveries	(2) Number of Discoveries	(3) Number of Discoveries	(4) Number of Discoveries
SW/Wacziarg Openness, lagged	0.0516*** (0.0161)	0.0560*** (0.0162)	0.0541*** (0.0158)	0.0542*** (0.0192)
Average Price Change Past 5 Years	0.0140 (0.0127)	0.0267 (0.0164)	0.0255* (0.0154)	0.0273* (0.0163)
Stock of Discoveries, lagged		0.0224*** (0.00282)	0.0358*** (0.00453)	0.0344*** (0.00487)
Stock of Discoveries Squared, lagged			-0.000266*** (7.61e-05)	-0.000233*** (6.90e-05)
Polity 2 Score, lagged				-0.000103 (0.000424)
Year FE	YES	YES	YES	YES
Country FE	YES	YES	YES	YES
Natural Resource FE	YES	YES	YES	YES
Estimation	2SLS	2SLS	2SLS	2SLS
Observations	49,738	49,738	49,738	46,796

Note: The table reports the estimation results of regression with the number of discoveries as dependent. *** denotes significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table 4: The Impact of Liberalization on Resource Discoveries (OLS)

VARIABLES	(1) Number of Discoveries	(2) Number of Discoveries	(3) Number of Discoveries	(4) Number of Discoveries
SW/Wacziarg Openness, lagged	0.0173*** (0.00528)	0.0220*** (0.00611)	0.0194*** (0.00540)	0.0156*** (0.00531)
Average Price Change Past 5 Years	0.0140 (0.0127)	0.0267 (0.0164)	0.0255* (0.0154)	0.0273* (0.0163)
Stock of Discoveries, lagged		0.0224*** (0.00282)	0.0359*** (0.00454)	0.0345*** (0.00489)
Stock of Discoveries Squared, lagged			-0.000268*** (7.65e-05)	-0.000235*** (6.91e-05)
Polity 2 Score, lagged				0.000368 (0.000368)
Year FE	YES	YES	YES	YES
Country FE	YES	YES	YES	YES
Natural Resource FE	YES	YES	YES	YES
Estimation	OLS	OLS	OLS	OLS
Observations	49,738	49,738	49,738	46,796

As analytically illustrated in section III, better institutions, higher prices and the stock of previous discoveries all impact the number of new discoveries. Empirically we find that increases in prices are associated with more discoveries, although the coefficient is not always significant. The result is intuitive, since higher prices make additional exploration activity

profitable. Roughly, we find that doubling prices over the past five years increases the number of discoveries by 0.03 per country, year and type of resource. The coefficient associated with the stock of discoveries is positive and statistically significant. That result suggests that in locations where discoveries have occurred in the past, more discoveries are more likely. The coefficient associated with the square term in the stock of cumulative discoveries is negative suggesting that the effect is non-linear. In other words, bigger stocks of cumulative discoveries eventually turn out to be associated with a lower likelihood of discovery as the easiest available deposits have been depleted.¹⁴ We interpret this as a trade-off between the initially reduced costs of exploring close to a known deposit with the eventually increased cost due to geological depletion.¹⁵

Table 5 reports results when we instead employ the Zero-Augmented Poisson estimator. Recall, that our dependent variable is count data with a very large fraction of zeros. The results in table 5 model this feature of the data explicitly. Previous results are confirmed, but significance levels tend to be higher than when using least squares, potentially indicating an improved model fit.

Table 5: The Impact of Liberalization on Natural Resource Discoveries (ZIP)

VARIABLES	(1) Number of Discoveries	(2) Number of Discoveries	(3) Number of Discoveries	(4) Number of Discoveries
SW/Wacziarg Openness, lagged	0.352** (0.157)	0.554*** (0.178)	0.453*** (0.167)	0.366** (0.169)
Average Price Change Past 5 Years	1.435*** (0.547)	1.763*** (0.587)	1.559*** (0.566)	1.819*** (0.576)
Stock of Discoveries, lagged		0.0180*** (0.00442)	0.0660*** (0.0122)	0.0629*** (0.0125)
Stock of Discoveries Squared, lagged			-0.000625*** (0.000154)	-0.000596*** (0.000157)
Polity 2 Score, lagged				0.00112 (0.0117)
Year FE	YES	YES	YES	YES
Country FE	YES	YES	YES	YES
Natural Resource FE	YES	YES	YES	YES
Estimation	ZIP	ZIP	ZIP	ZIP
Observations	49,738	49,738	49,738	46,796

Note: The table reports the estimation results of regression with the number of discoveries as dependent. *** denotes significance at the 1% level, ** at the 5% level, and * at the 10% level.

¹⁴ The coefficient associated with the Polity2 score are not statistically significant and changes sign across specification. That result suggests that the structure of the political system has no significant association with the likelihood of discoveries over and above the degree of openness.

¹⁵ Indeed, on the former, Cavalcanti et al (2016), show using well level data on oil drilling for Brazil, that after a first wild-cat discovery, follow-up exploration activity and thus additional discoveries increase significantly in the following years.

Verifying the Mechanism: Exploration Efforts

So far, we have focused on the relationship between market orientation and major discoveries. To examine the underlying mechanism, we explore whether exploration efforts rise following changes in market orientation. Our hypothesis is that more market-oriented or open economies are able to attract more exploration investment and thus have more resource discoveries.

Oil and gas exploration, as well as mineral exploration, are capital intensive and thus costly. Nowadays, over a hundred billion dollars are spent on resource exploration annually according to Rystad and SNL Metals and Mining. And while exploration is an extremely risky activity¹⁶, in which “luck is obviously a major factor” (Harbaugh, Davis, and Wendebourg, 1995), exploration efforts ought to be a key determinant of discoveries. To verify that proposition for our data we first estimate the following equation

$$(III) \quad y_{itk} = B(L)s_{itk} + \alpha_i + \theta_t + \sigma_k + \varepsilon_{itk},$$

where y_{itk} and s_{itk} are the number of discoveries and the logarithm of exploration spending in millions of constant (2010) U.S. dollars¹⁷, respectively, of resource k in country i at time t and α_i, θ_t and σ_k are country, year and resource fixed effects. $B(L)$ is a p -th order lag operator. We estimate the equation for $p \in \{1, 2, 3\}$ using both OLS and ZIP and then test whether $H_0 : \sum_0^p b_h = 0$. Table 6 reports the results of this exercise. We can always strongly reject the null hypothesis of no impact of exploration spending on discoveries.

Having established that exploration spending increases the likelihood of discoveries we now test whether openness increases exploration spending to complete the causal chain. To do so we estimate a regression analogous to equation (I), except that we use exploration spending and not

¹⁶ An oil exploration well (wildcat well – a well drilled a mile or more from an area of existing oil production) can have a probability as low as 10% of yielding viable oil, while a rank wildcat (a well drilled in an area where there is no existing production) has an even smaller chance of finding oil. Elf was drilling in 1971 for offshore oil in Norway and found nothing. Recently it found a huge new field just 3 metres away from the original drilling. This example shows how highly uncertain drilling outcomes are.

¹⁷ The exploration expenditures data are deflated using the U.S. GDP deflator. Using alternative deflators leads to similar results.

Table 6: The Impact of Exploration Spending on Natural Resource Discoveries

P Value of Wald Test (H0: Effect is 0)				
Dependent variable	Method	1 Lag	2 Lags	3 Lags
Number of Discoveries	OLS	0	0	0
	ZIP	0	0	0

Point Estimate (Sum of coefficients)				
Dependent variable	Method	1 Lag	2 Lags	3 Lags
Number of Discoveries	OLS	0.013	0.013	0.013
	ZIP	0.394	0.374	0.382

Given that we have confirmed that exploration spending is an important determinant of discoveries, column 1 of Table 7 now gives the basic 2SLS estimates of the drivers of exploration spending where we instrument openness with its predicted value. We find a strong positive impact of openness on exploration spending. The period of analysis when using exploration spending is relatively short due to data constraints. But to the best of our knowledge it is the best available data. Exploration spending data is available since 1994 while the openness variable is only available until 2004. The point estimates suggest an increase in exploration spending of over 100% after opening.

Table 7: The Impact of Liberalization on Exploration Spending (2SLS)

VARIABLES	(1) In Exploration Spending	(2) In Exploration Spending	(3) In Exploration Spending	(4) In Exploration Spending
SW/Wacziarg Openness, lagged	0.981** (0.458)	1.130** (0.453)	1.203*** (0.449)	2.168* (1.299)
Average Price Change Past 5 Years	2.211*** (0.553)	2.180*** (0.547)	2.297*** (0.541)	2.441*** (0.610)
Stock of Discoveries, lagged		0.0657*** (0.0127)	0.220*** (0.0230)	0.216*** (0.0231)
Stock of Discoveries Squared, lagged			-0.00231*** (0.000336)	-0.00226*** (0.000335)
Polity 2 Score, lagged				0.00693 (0.0229)
Constant	1.992*** (0.722)	0.918 (0.871)	-0.0334 (0.705)	0.00495 (1.323)
Observations	3,497	3,497	3,497	3,334
R-squared	0.697	0.728	0.763	0.754

Opening up the economy thus leads to a large and significant increase in exploration spending that in turn results in additional discoveries of new reserves according to Table 6. The remaining columns of Table 7 indicate that the effect of prices on exploration spending is statistically

significant as one would expect. Furthermore, the stock of cumulative discoveries first has a positive ‘probing’ effect and eventually a negative ‘running out of reserves’ effect.

Quantification

We now turn to quantifying the impact of institutions on discoveries. To be able to obtain a finer quantification than a binary variable allows, we use the ICRG political risk rating (which goes from 0 to 100) in this section instead of the SW openness indicator.¹⁸ First we verify that the ICRG index, reflecting property rights and political stability among others, does indeed affect discoveries as well. The political risk rating, is found to be statistically and economically highly significant as a determinant of resource discoveries (see Table 8).¹⁹

Table 8: The Impact of Political Risk on Natural Resource Discoveries

VARIABLES	(1) Number of Discoveries	(2) Number of Discoveries	(3) Number of Discoveries	(4) Number of Discoveries
Political Risk Rating, lagged	0.000514** (0.000217)	0.000545** (0.000220)	0.0245*** (0.00727)	0.0219*** (0.00721)
Average Price Change Past 5 Years	-0.00154 (0.00637)	-0.00302 (0.00659)	0.780 (0.756)	0.512 (0.722)
Stock of Discoveries, lagged	0.0160*** (0.00229)	0.0216*** (0.00408)	0.0170*** (0.00559)	0.0520*** (0.0177)
Stock of Discoveries Squared, lagged		-9.97e-05 (7.58e-05)		-0.000400* (0.000222)
Polity 2 Score, lagged		-5.12e-05 (0.000602)		-0.00440 (0.0200)
Year FE	YES	YES	YES	YES
Country FE	YES	YES	YES	YES
Natural Resource FE	YES	YES	YES	YES
Estimation	OLS	OLS	ZIP	ZIP
Observations	51,767	49,341	51,767	49,341

Note: The table reports the estimation results of regression with the number of discoveries as dependent. *** denotes significance at the 1% level, ** at the 5% level, and * at the 10% level.

Using the point estimates from the ZIP regressions indicates that a 1 standard deviation improvement in the political risk rating (which corresponds to a move from, for example, Mali to South Africa, South Africa to Chile, or Chile to Canada) would lead to 20% more natural

¹⁸ We report results for the ZIP estimator and OLS rather than 2SLS in this subsection, because we do not have an instrument for the ICRG index.

¹⁹ Due to data availability the time period when using ICRG is quite different from the one using the updated SW variable, namely 1985-2011 instead of 1964-2004. While the overlap between the two is thus only 19 years, the Supplementary Appendix shows that restricting the sample to this overlap period does not materially change the results.

resource discoveries in those countries. To provide a further sense of the relevant magnitude, a thought experiment is conducted in which Latin America's and sub-Saharan Africa's median property rights suddenly jump to the levels of the most advanced economies in each of these regions, which are, respectively, Chile and Botswana. This experiment yields a 15 percent increase in the number of deposits discovered worldwide, all else equal. The figure increases to 25 percent if instead Latin America and sub-Saharan Africa were to suddenly adopt the same level of property rights as in the United States, again all else equal.²⁰ Notwithstanding the dramatic increase in institutions implied by this thought experiment, the magnitudes unveiled suggest that institutions play an important role in driving exploration for and ultimately discoveries of natural resources.

Robustness

We now discuss results from an extensive battery of robustness checks. The checks include the use of alternative specifications (different fixed effects, clustering, price variables, time period), exploring the relevance of interactive effects between the main variables of interest as well as exploring the relevance of specific institutional features as measured by ICRG sub-indices. Additionally, we collapse our data to a two-way country-year panel to obtain easy to interpret results and split the sample between hydrocarbon and mineral discoveries.

Results are both quantitatively and qualitatively materially unaffected in the various robustness exercises presented in Tables S1-S4. Table S1 in the Supplementary Appendix highlights that the results are virtually unchanged if we employ country-resource fixed effects (to allow for specific geological conditions) rather than country and resource fixed effects, separately. Table S2 clusters standard errors at the country level, thereby reducing the number of clusters from nearly 2000 to 102 and again results are unchanged. To allow for richer price dynamics we include five lags of annual price changes in the regressions in Table S3. We find that yearly changes in prices are significant only with a number of lags as could be expected given that it takes time and

²⁰ The difference between the median political risk ratings is Latin America and the US in 2012 was 17 points. Therefore, if Latin America was suddenly like the US, discoveries should increase by a factor of $e^{17 \times 0.0219} = 1.45$. For SSA, the difference is 25.5 points, and therefore discoveries should increase by a factor of 1.75. If we then take the number of discoveries for Latin America and SSA in the decade 2000-2009 (123 and 77, respectively) and apply this factor, we get that Latin America and SSA would discover another 55 and 57 deposits, respectively, per decade. Given that the total number of deposits discovered over 2000-2009 was 448, this would be an increase in world-wide discoveries of roughly 25%.

sustained exploration effort (as well as luck) for discoveries to materialize. The coefficient on openness is of a slightly smaller magnitude than in alternative specifications but remains highly significant. Table S4 shows that restricting the period of analysis to the overlap of the ICRG and SW variables does not materially change our main results.

We then collapse our three-way panel to a two-way panel (country-year) since the obtained regression coefficients are particularly easy to interpret and can be immediately compared to the preliminary event-study analysis conducted in section II. Column 1 of Table S5 shows that opening of the economy increases discoveries by 0.31 per year and country. Recall that a cursory look at the data as shown in Figure 4 suggested an increase of 0.16, underestimating the positive impact. Columns 2 and 3 of Table S5 then split the analysis between hydrocarbon and mineral deposits. One could argue that there are important differences in the role market orientation plays in fostering mineral versus hydrocarbon discoveries. In particular, minerals might be seen as more appropriable than hydrocarbons because mining output does not move through pipelines and takes place exclusively onshore. Instead our results suggest that in fact the effect of market orientation is driven as much by hydrocarbon as by mineral discoveries.²¹ Both of these types of resources are estimated to increase by roughly 0.17 per year on average as a consequence of economic opening. Lastly, to conduct a somewhat more granular analysis of which aspects of institutions further discoveries, we use disaggregated ICRG indices. Table S8 shows that in particular changes in the investment profile sub-index and government stability are associated with higher numbers of resource discoveries. Property rights and an attractive investment environment are thus important in attracting exploration investment and discoveries. We also further investigate the relevance of interactive effects between the main variables but do not find statistically significant non-linearities (Table S7). Finally, we show that the timing of the rise in Asian demand does not correspond with the North to South shift in discoveries (see Figure S1).

VII. CONCLUSION

This paper has explored the effect of changes in market orientation and improvements in institutions on global resource wealth using major hydrocarbon and mineral discoveries. We first

²¹ We lose some power when splitting the sample, hence the reduced significance levels.

analysed the effects of a change in the level of market orientation or institutions captured by a change in a tax on multinational corporations in a two-region model of endogenous reserves and discoveries based on Pindyck (1978). We then estimated the effects of changes in market orientation on a large three-way panel by type of resource, country and year. Our empirical results confirm the predictions of our model that increases in market orientation cause a statistically and economically significant increase in the likelihood of resource discoveries over and above the effects of changes in resource prices and depletion forces. A thought experiment whereby Latin America and sub-Saharan Africa suddenly adopt the same quality of institutions as the United States yields an increase of 25 percent in the number of discoveries worldwide.

Our results provide novel evidence in support of the primacy of institutions by calling into question the view that resource endowments are an exogenous feature of an economy. Although we have established empirically that quality of institutions and outward orientation are together with prices and the stock of cumulative discoveries important drivers of exploration spending and discoveries, resulting resource boom may lead to aggressive rent seeking and conflicts, potentially worsening welfare for citizens. Our results thus suggest that the relationship between resource endowments and institutions is complex. Further research should attempt to “unbundle institutions” and revisit some of the key empirical findings including in the resource curse literature on the mediating role of institutions for resource endowments.

Our results on oil and gas discoveries also have important implications for the debate on global warming. To keep mean global surface temperature below 2 degrees Celsius, only 300 to 400 Giga tonnes of carbon can still be burnt but reserves of private oil and gas majors only are at least three times as high. To abide by international commitments to limit global warming a third of oil, half of gas, and 80 percent of coal reserves should be kept in the ground forever (e.g., McGlade and Ekins, 2015). This should be contrasted with the relentless stream of new discoveries of fossil fuel reserves. The assumption of completely inelastic supply of reserves is often used in climate economics. For example, the acceleration of global warming caused by postponing carbon taxes (the expectations-driven Green Paradox) assumes a given stock of reserves to be depleted. Much of this adverse effect disappears however once one allows for the fact that reserves depend on prices, quality of institutions and what is left in the ground.

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APPENDIX A: EQUILIBRIUM DISCOVERIES

Maximizing net worth also gives the efficiency conditions that yield initial reserves and exploration in much the same way as discoveries (4) follow from (3):

$$(3') \quad \begin{aligned} & \left[p_1 - G(S_1(I_0)) - G'(S_1(I_0))R_1 \right] S_1'(I_0) = 1+r \quad \text{and} \\ & \left[p_1 - G^*(S_1^*(I_0^*)) - G'(S_1^*(I_0^*))R_1^* \right] S_1^{*'}(I_0^*) = (1+r)(1+T_0^*). \end{aligned}$$

This is used together with (3) to obtain the comparative statics properties (4) and

$$(A1) \quad I_0 = I_0^+(p_1, R_1), \quad S_1 = S_1^+(p_1, R_1), \quad I_0^* = I_0^+(p_1, R_1^*, T_0^*), \quad S_1^* = S_1^+(p_1, R_1^*, T_0^*).$$

We now discuss how to derive equilibrium discoveries in the North and South once account is taken of global resource demand. Let world demand for oil in period t be iso-elastic and given by $\Gamma_t p_t^{-\varepsilon}$, $t=1,2$, where $\varepsilon > 0$ is the price elasticity of demand and $\Gamma_t > 0$ an exogenous shift to oil demand in period t . Market equilibrium on the world oil markets requires

$$(A2) \quad R_1 + R_1^* = \Gamma_1 p_1^{-\varepsilon} \quad \text{and} \quad R_2 + R_2^* = \Gamma_2 p_2^{-\varepsilon}.$$

Using initial exploration and discoveries as given in (4), the depletion equations become

$$(A3) \quad \begin{aligned} & R_1 + R_2 = S_1(p_1, R_1) + D(p_1, R_1, A, \gamma) \quad \text{and} \\ & R_1^* + R_2^* = S_1^*(p_1, R_1^*, T_0^*) + D^*(p_1, R_1^*, T_0^*, T_1^*, A^*, \gamma^*). \end{aligned}$$

The extraction rates follow from the Hotelling rules (2) or

$$(A4) \quad \begin{aligned} & p_1 - G(S_1(p_1, R_1)) = \frac{1}{1+r} [p_2 - G(R_2) + G'(R_2)R_2] \quad \text{and} \\ & p_1 - G^*(S_1^*) = \frac{1}{1+r} [p_2 - G^*(R_2^*) + G^{*'}(R_2^*)R_2^*]. \end{aligned}$$

Equations (A2)-(A4) can be solved for extraction rate and prices $\{R_1, R_1^*, R_2, R_2^*, p_1, p_2\}$ and thus also for initial and future oil discoveries $\{S_1, S_1^*, D, D^*\}$ in terms of the ease of access for IOCs in the South $\{T_0^*, T_1^*\}$, the extraction cost parameters and geological conditions in the North and the South $\{\gamma, \gamma^*\}$ and $\{A, A^*\}$, and the global oil demand shocks $\{\Gamma_1, \Gamma_2\}$. One could also extend the analysis to allow for discoveries to depend on how much has been explored initially and thereby on geological conditions. One can capture this by making A a function of I_0 and A^* a function of I_0^* , but our main conclusions regarding the shifting frontier of natural resources will not be materially affected.

APPENDIX B: DATA DESCRIPTION

Table B.I describes the macroeconomic variables and Table B.III presents summary statistics.

Table B.II: Data Definition and Sources

Variable	Source
Number of natural resource discoveries per year and natural resource	Horn (2014), MinEx (2014)
Sachs and Warner Openness Indicator	Sachs and Warner (1995), Wacziarg and Welch (2008)
Exploration spending	Rystad (2014) and SNL Metals and Minerals (2014)
Political Risk Rating	International Country Risk Guide (2015)
Polity 2 Score	Marshall and Jaggers (2009)
Commodities prices [We use the longest available series, taken either from UNCTAD, Datastream, Bloomberg or the IMF, depending on the natural resource. UNCTAD is used for Manganese, Tungsten and Phosphate.]	IMF, Primary Commodity Price System; Thomson Reuters Datastream, Bloomberg, L.P.; and UNCTADstat.
Population	Summers and Heston
GDP growth	Summers and Heston
Distance	CEPII

Table B.III. Summary statistics of macro variables (1950-2012)

Variable	Years	Obs	Min	Median	Max
Number of natural resource discoveries per year, country and natural resource	1950-2012	280704	0	0	10
Sachs and Warner Openness Indicator	1950-2004	161160	0	0	1
Political Risk Rating	1984-2012	109276	9	64	97
Polity 2 Score	1950-2012	219538	-10	2	10
Average log price change last 5 years	1960-2012	89526	-.33	0.038	0.46
GDP Growth (%)	1951-2012	167858	-.66	.04	.58
Distance	1950-2012		7.8	6636	19951

Natural resources - The following resources are in our sample (numbers in bracket indicate first year for which we have price data if that year is later than 1960): Antimony (2005), Boron (2004), Chromium (1990), Copper, Diamonds (2005), Fluorite (no price data), Natural Gas (1985), Gold, Graphite (no price data), Lead, Lithium (1997), Magnesium (2003), Manganese, Mineral sands (no price data), Molybdenum (2012), Nickel, Niobium (2013), Oil, Palladium (1992), PGE (no price data), Phosphate, Platinum (1992), Potash (no price data), Rare earths (no price data), Silver (1968), Soda ash (2007), Tantalum (2009), Tellurium (2013), Tin, Tungsten, Uranium (1980), Vanadium (1987), Zinc, Zircon (1997).

Discoveries of Gold, Oil, Natural Gas, Copper, Nickel, Uranium, Zinc and Silver account for over 90 percent of all discoveries (followed by Diamonds and Molybdenum which account for 1-2 percent each).

Countries - The following countries are included in our sample: Afghanistan, Albania, Algeria, Angola, Argentina, Armenia, Australia, Austria, Azerbaijan, Bahrain, Bangladesh, Bolivia, Botswana, Brazil, Brunei Darussalam, Bulgaria, Burkina Faso, Burundi, Cyprus, Cambodia, Cameroon, Canada, Central African Republic, Chile, China, Colombia, Republic of Congo, Democratic Republic of the Congo, Costa Rica, Czech Republic, Denmark, Dominican Republic, Ecuador, Egypt, El Salvador, Equatorial Guinea, Eritrea, Ethiopia, Fiji, Finland, France, Gabon, Germany, Ghana, Greece, Guatemala, Guinea, Guyana, Honduras, Hungary, Israel, India, Indonesia, Iran, Iraq, Ireland, Italy, Côte d'Ivoire, Japan, Jordan, Kazakhstan, Korea (South), Kuwait, Kyrgyz Republic, Lao P.D.R., Lesotho, Liberia, Libya, FYR Macedonia, Madagascar, Malaysia, Mali, Mauritania, Mexico, Mongolia, Morocco, Mozambique, Myanmar, Namibia, Netherlands, New Zealand, Nicaragua, Niger, Nigeria, Norway, Oman, Pakistan, Panama, Papua New Guinea, Peru, Philippines, Poland, Portugal, Qatar, Romania, Russia, Saudi Arabia, Senegal, Serbia, Sierra Leone, Slovak Republic, Solomon Islands, South Africa, Spain, Sri Lanka, Sudan, Suriname, Sweden, Syria, Tajikistan, Tanzania, Thailand, Togo, Tonga, Trinidad and Tobago, Tunisia, Turkey, Turkmenistan, United Arab Emirates, Ukraine, United Kingdom, United States, Uruguay, Uzbekistan, Venezuela, Vietnam, Yemen, Zambia, Zimbabwe.

SUPPLEMENTARY APPENDIX

Table S1: Using Country-Natural Resource FEs instead of separately country and natural resource FE (2SLS)

VARIABLES	(1) Number of Discoveries	(2) Number of Discoveries	(3) Number of Discoveries	(4) Number of Discoveries
SW/Wacziarg Openness, lagged	0.0601*** (0.0179)	0.0597*** (0.0182)	0.0569*** (0.0171)	0.0621*** (0.0216)
Average Price Change Past 5 Years	0.0122 (0.0123)	0.00948 (0.0123)	0.00977 (0.0117)	0.0123 (0.0121)
Stock of Discoveries, lagged		-0.00482 (0.00464)	0.0269* (0.0151)	0.0273* (0.0157)
Stock of Discoveries Squared, lagged			-0.000507** (0.000198)	-0.000468** (0.000209)
Polity 2 Score, lagged				-0.000471 (0.000362)
Year FE	YES	YES	YES	YES
Country FE	NO	NO	NO	NO
Natural Resource FE	NO	NO	NO	NO
Country-Natural Resource FE	YES	YES	YES	YES
Estimation	2SLS	2SLS	2SLS	2SLS
Observations	49,738	49,738	49,738	46,794

Note: The table reports the estimation results of regression with the number of discoveries as dependent. *** denotes significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table S2: Clustering at the country level instead of at the country-natural resource level (2SLS)

VARIABLES	(1) Number of Discoveries	(2) Number of Discoveries	(3) Number of Discoveries	(4) Number of Discoveries
SW/Wacziarg Openness, lagged	0.0560*** (0.0215)	0.0542** (0.0239)	0.0597** (0.0235)	0.0621** (0.0284)
Average Price Change Past 5 Years	0.0267* (0.0160)	0.0273* (0.0160)	0.00948 (0.0117)	0.0123 (0.0116)
Stock of Discoveries, lagged	0.0224*** (0.00362)	0.0344*** (0.00448)	-0.00482 (0.00500)	0.0273* (0.0145)
Stock of Discoveries Squared, lagged		-0.000233*** (8.40e-05)		-0.000468** (0.000213)
Polity 2 Score, lagged		-0.000103 (0.000573)		-0.000471 (0.000456)
Year FE	YES	YES	YES	YES
Country FE	YES	YES	NO	NO
Natural Resource FE	YES	YES	NO	NO
Country-Natural Resource FE	NO	NO	YES	YES
Estimation	2SLS	2SLS	2SLS	2SLS
Observations	49,738	46,796	49,738	46,794

Note: The table reports the estimation results of regression with the number of discoveries as dependent. *** denotes significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table S3: Using Annual Price Changes instead of a 5 year moving average

VARIABLES	(1) Number of Discoveries	(2) Number of Discoveries	(3) Number of Discoveries	(4) Number of Discoveries
SW/Wacziarg Openness, lagged	0.0326** (0.0133)	0.0366*** (0.0141)	0.0418*** (0.0156)	0.0461*** (0.0167)
Change in Prices	0.00234 (0.00263)	0.00224 (0.00268)	0.00322 (0.00286)	0.00290 (0.00294)
Change in Prices, lagged		-0.00199 (0.00369)	-0.00263 (0.00382)	-0.00241 (0.00419)
Change in Prices, lagged 2			0.00830** (0.00342)	0.00797** (0.00348)
Change in Prices, lagged 3				0.00669* (0.00369)
Stock of Discoveries, lagged	0.0345*** (0.00474)	0.0345*** (0.00477)	0.0346*** (0.00481)	0.0346*** (0.00483)
Stock of Discoveries Squared, lagged	-0.000237*** (6.70e-05)	-0.000236*** (6.74e-05)	-0.000236*** (6.78e-05)	-0.000237*** (6.79e-05)
Polity 2 Score, lagged	0.000179 (0.000358)	0.000133 (0.000367)	5.21e-05 (0.000379)	1.51e-05 (0.000395)
Year FE	YES	YES	YES	YES
Country FE	YES	YES	YES	YES
Natural Resource FE	YES	YES	YES	YES
Estimation	2SLS	2SLS	2SLS	2SLS
Observations	54,622	52,989	51,432	49,953

Note: The table reports the estimation results of regression with the number of discoveries as dependent. *** denotes significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table S4: Limiting the sample to the overlap of Wacziarg and ICRG (2SLS)

VARIABLES	(1) Number of Discoveries	(2) Number of Discoveries	(3) Number of Discoveries	(4) Number of Discoveries
SW/Wacziarg Openness, lagged	0.0601*** (0.0211)	0.0618*** (0.0211)	0.0610*** (0.0210)	0.0568*** (0.0198)
Average Price Change Past 5 Years	0.0159 (0.0141)	0.0195 (0.0151)	0.0188 (0.0148)	0.0148 (0.0153)
Stock of Discoveries, lagged		0.0205*** (0.00308)	0.0302*** (0.00524)	0.0300*** (0.00546)
Stock of Discoveries Squared, lagged			-0.000180** (8.29e-05)	-0.000166** (8.23e-05)
Polity 2 Score, lagged				-0.000475 (0.000738)
Year FE	YES	YES	YES	YES
Country FE	YES	YES	YES	YES
Natural Resource FE	YES	YES	YES	YES
Estimation	2SLS	2SLS	2SLS	2SLS
Observations	30,758	30,758	30,758	29,080

Note: The table reports the estimation results of regression with the number of discoveries as dependent. *** denotes significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table S5: Mineral Discoveries vs Hydrocarbon Discoveries (2SLS)

VARIABLES	(1) Number of Natural Resource Discoveries	(2) Number of Oil and Gas Discoveries	(3) Number of Mineral Discoveries
SW/Wacziarg Openness, lagged	0.315** (0.147)	0.171* (0.0931)	0.182* (0.110)
Stock of Discoveries, lagged	0.0428*** (0.0112)		
Stock of Discoveries Squared, lagged	-0.000210*** (4.92e-05)		
Stock of Hydrocarbon Discoveries, lagged		0.0201 (0.0224)	
Stock of Hydrocarbon Discoveries Squared, lagged		-0.000294** (0.000137)	
Stock of Mineral Discoveries, lagged			0.0381*** (0.0134)
Stock of Mineral Discoveries Squared, lagged			-0.000208*** (6.21e-05)
Country FE	YES	YES	YES
Year FE	YES	YES	YES
Estimation	2SLS	2SLS	2SLS
Panel Type	Two-Way	Two-Way	Two-Way
Observations	4,626	4,626	4,626

Note: The table reports the estimation results of regression with the number of discoveries as dependent. *** denotes significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table S6: Mineral Discoveries vs Hydrocarbon Discoveries (ZIP)

VARIABLES	(1) Number of Natural Resource Discoveries	(2) Number of Oil and Gas Discoveries	(3) Number of Mineral Discoveries
SW/Wacziarg Openness, lagged	0.415*** (0.150)	0.604* (0.314)	0.401** (0.196)
Stock of Discoveries, lagged	0.0161*** (0.00434)		
Stock of Discoveries Squared, lagged	-6.93e-05*** (1.65e-05)		
Stock of Hydrocarbon Discoveries, lagged		0.00285 (0.0162)	
Stock of Hydrocarbon Discoveries Squared, lagged		-7.30e-05 (9.52e-05)	
Stock of Mineral Discoveries, lagged			0.0111 (0.00760)
Stock of Mineral Discoveries Squared, lagged			-6.75e-05** (3.35e-05)
Country FE	YES	YES	YES
Year FE	YES	YES	YES
Estimation	ZIP	ZIP	ZIP
Panel Type	Two-Way	Two-Way	Two-Way
Observations	4,740	4,740	4,740

Note: The table reports the estimation results of regression with the number of discoveries as dependent. *** denotes significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table S7: Interactions between openness, prices and stock of discoveries (ZIP)

VARIABLES	(1) Number of Discoveries	(2) Number of Discoveries	(3) Number of Discoveries
SW/Wacziarg Openness, lagged	0.372** (0.166)	0.327* (0.188)	0.494*** (0.177)
Average Price Change Past 5 Years	1.894** (0.829)	1.821*** (0.576)	1.904* (1.013)
Stock of Discoveries, lagged	0.0629*** (0.0124)	0.0585*** (0.0128)	0.0235*** (0.00701)
Stock of Discoveries Squared, lagged	-0.000597*** (0.000155)	-0.000554*** (0.000195)	
Openness x Stock of Discoveries, lagged		0.00583 (0.0150)	-0.00667 (0.00695)
Openness x Average Price Change Past 5 Years	-0.135 (0.814)		-0.917 (1.015)
Openness x Stock of Discoveries Squared, lagged		-6.02e-05 (0.000248)	
Stock of Discoveries x Average Price Change Past 5 Years			0.0113 (0.0597)
Openness x Stock of Discoveries x Average Price Change Past 5 Years			0.0664 (0.0624)
Polity 2 Score, lagged	0.00123 (0.0118)	0.000800 (0.0118)	0.00988 (0.0121)
Year FE	YES	YES	YES
Country FE	YES	YES	YES
Natural Resource FE	YES	YES	YES
Estimation	ZIP	ZIP	ZIP
Observations	46,796	46,796	46,796

Note: The table reports the estimation results of regression with the number of discoveries as dependent. *** denotes significance at the 1% level, ** at the 5% level, and * at the 10% level.

Table S8: Using ICRG Sub-Indices (ZIP)

VARIABLES	(1) Number of Discoveries	(2) Number of Discoveries	(3) Number of Discoveries	(4) Number of Discoveries	(5) Number of Discoveries	(6) Number of Discoveries
ICRG Investment Profile, lagged	0.0672** (0.0299)					
ICRG Corruption Index, lagged		-0.0779 (0.0577)				
ICRG Law and Order, lagged			0.0807 (0.0739)			
ICRG Government Stability, lagged				0.0798*** (0.0280)		
ICRG Internal Conflict, lagged					0.0311 (0.0313)	
ICRG Bureaucratic Quality, lagged						-0.0799 (0.0945)
Average Price Change Past 5 Years	0.543 (0.716)	0.493 (0.717)	0.484 (0.719)	0.544 (0.720)	0.506 (0.720)	0.490 (0.716)
Stock of Discoveries, lagged	0.0545*** (0.0183)	0.0528*** (0.0188)	0.0524*** (0.0185)	0.0525*** (0.0187)	0.0522*** (0.0185)	0.0535*** (0.0191)
Stock of Discoveries Squared, lagged	-0.000435* (0.000227)	-0.000412* (0.000230)	-0.000405* (0.000229)	-0.000405* (0.000233)	-0.000403* (0.000227)	-0.000420* (0.000235)
Polity 2 Score, lagged	0.00404 (0.0197)	0.00966 (0.0214)	0.00498 (0.0204)	0.00669 (0.0201)	0.00267 (0.0207)	0.00938 (0.0201)
Year FE	YES	YES	YES	YES	YES	YES
Country FE	YES	YES	YES	YES	YES	YES
Natural Resource FE	YES	YES	YES	YES	YES	YES
Estimation	ZIP	ZIP	ZIP	ZIP	ZIP	ZIP
Observations	49,407	49,407	49,407	49,407	49,407	49,407

Note: The table reports the estimation results of regression with the number of discoveries as dependent. *** denotes significance at the 1% level, ** at the 5% level, and * at the 10% level.

Figure S1: The commodities price boom does not coincide with the North to South shift

