Shifting Frontiers in Global Resource Wealth:

The Role of Policies and Institutions

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Abstract

This paper explores the effect of change in market orientation and improvements in institutions on resource wealth using worldwide major hydrocarbon and mineral discoveries. We first analyse the effects of a change in the level of market orientation or institutions captured by a tax on multinational corporations in a two-region model of endogenous reserves based on Pindyck (1978). We then estimate the effects of changes in market orientation on a large three-way panel─resource, country and year. Our empirical results are consistent with the predictions of the model. An increase in market-orientation cause a statistically and economically significant increase in the likelihood of resource discoveries over and above the effect of changes in resource prices and depletion. A thought experiment whereby Latin America and sub-Saharan Africa were to 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.

JEL Classification : E00, F3, F4.

Keywords: natural resources, discoveries, institutions, 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). Only one century later, after it had developed into a stable country, the US became the world's pre-eminent resource producer, overtaking Europe. Today, more than another century later and with the colonial era well behind us, the US' and other advanced countries' shares of global resource deposits have fallen dramatically, driven by discoveries in other parts of the world. In the present paper, we indeed document that a major shift has taken place over the past decades. More specifically, we provide systematic evidence that the key driver this time around are changes in policies and institutions of –independent – countries geared towards opening up their economies sparking a "North" to "South" shift in (known) global resource wealth.

This paper explores the effect of changes in market orientation and improvements in institutions on resource wealth using worldwide major hydrocarbon and mineral discoveries. To illustrate the shift in global resource wealth, we present three key facts that further help motivate the 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 while it has been decreasing in advanced economies; (iii) the timing of the shift coincides with economic liberalization in developing countries. We use these facts to develop a two-region model of endogenous reserves based on Pindyck (1978) where multinational corporations are faced with a tax. 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 are then taken to the data.

For our empirical analysis we build a unique dataset on the universe of worldwide major natural resource discoveries since 1950. We then estimate a three-way panel covering 128 countries, 33 types of natural resources and 40 years. Our main explanatory variable of interest 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 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 discovery 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. A country's proven resource endowment is thus in part determined by its institutions. In order to be able to obtain a finer quantification than a dichotomous variable allows, we 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. We verify that exploration spending increase following changes in market orientation.

We also find that changes in resource prices tend to increase discoveries, but the point estimates are not always significant. 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" have been picked. Our results are robust to a wide array of checks including using alternative estimators.

This 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 maximize 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. Investments in the resource sector also involve sunk costs and are thus subject to the holdup problem. Bohn and Deacon (2000), Long (1975) and Stroebel and van Benthem (2014) provide both theory and empirical evidence that a stable political environment, a low risk of expropriation, and a favourable investment climate are crucial for investment in the resource sector. Cust and Harding (2014) provide empirical evidence that institutions substantially affect oil and gas exploration. Their identification strategy relies on exploiting variations in institutions and oil deposits sitting on both sides of a border. We contribute to this literature by extending Pindyck (1978) to a two-region framework to explore the North to South shift in resource extraction. On the empirical front, we focus on discoveries of major oil and gas fields and also include novel data on discoveries of major mineral deposits. Indeed, the latter could be seen as more appropriable than oil extraction because mining output does not move through pipelines and takes place exclusively on land. 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 et al (2002), Easterly and Levine (2002), Hall and Jones (1999) and Rodrik, Subramanian, and Trebbi (2002) all find that institutions causes development. They provide evidence that institutions trump the effect of policies/trade and geography. Interestingly, to address the endogenous nature of institutions Acemoglu, Johnson, and Robinson (2001) use mortality rates of colonial settlers as instrument. The instrument relies on the predetermined nature of the mortality rates in the territories which Europeans settlers decided whether to colonize in large numbers or extract natural resources from. The former territories were given "good"

European institutions while the latter not.[1] This paper contributes 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 polcies and institutions in developing countries in the post-colonial era have become a determinant of (known) resource wealth.

This 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 et al. 2008). This paper contributes to this literature by providing evidence that economic liberalization and changes in institutions affect the structure of the economy through the expansion of the resource sector. We verify that a key channel through which changes in market orientation affect discoveries is exploration expenditure. Considering that foreign firms are playing a lead role in conducting exploration activities in developing countries exploration expenditures are a form of international capital flows.[2]

Lastly, 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). Mehlum, Moene and Torvik (2006) and Bosscini, Pettersson and Roine (2007) argue that the curse in terms of the effect of natural resources on growth is less negative or positive if the quality of institutions is beyond a certain threshold. Our contribution has important implication for that literature that is the so-called "resource curse" needs to be revisited in light of the endogeneity of resource wealth to policies and institutions.

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[1] One important consideration is that there need not be a strong correlation between the diseases that killed settlers and the diseases that afflict natives, and that both are independent of the countries' geographical suitability for trade.

[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 render difficult the empirical documentation that (aggregate) capital flows precede discoveries.

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

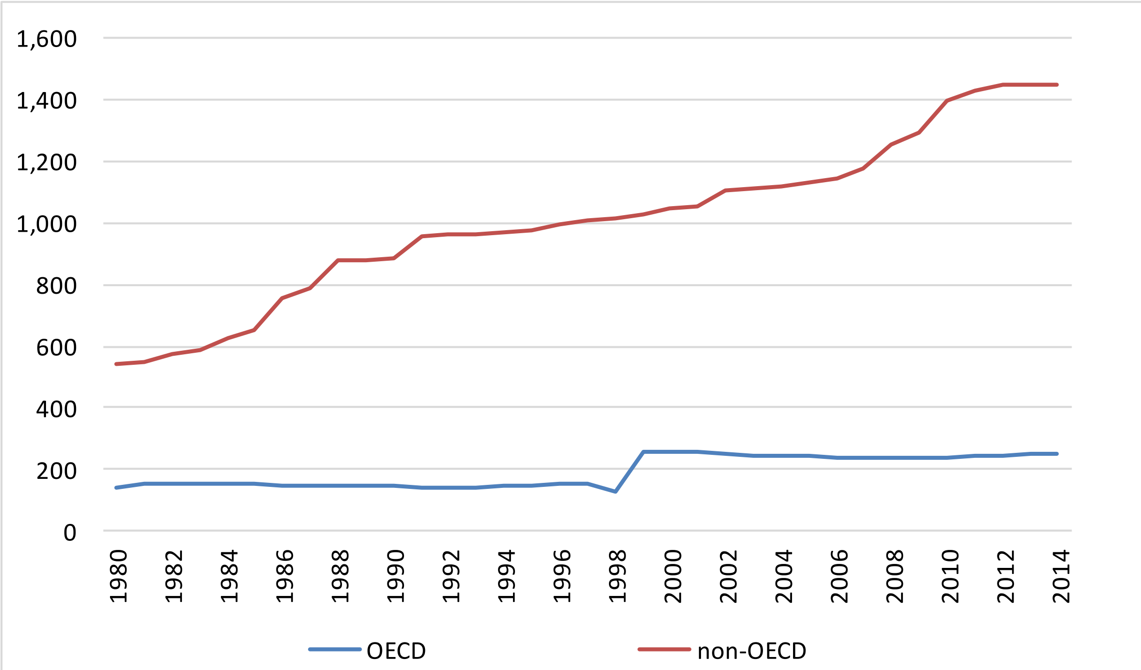
In this section we use our data on major hydrocarbon and mineral discoveries as well as widely used data on prices, reserves and institutions to present a few simple, but to the best of our knowledge, not well established facts about the global pattern of the evolution of resource wealth.[3]

Fact 1: Global proven oil reserves have been continuously increasing, 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 peak oil hypothesis, Figure 1 shows that proven 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 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.

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

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

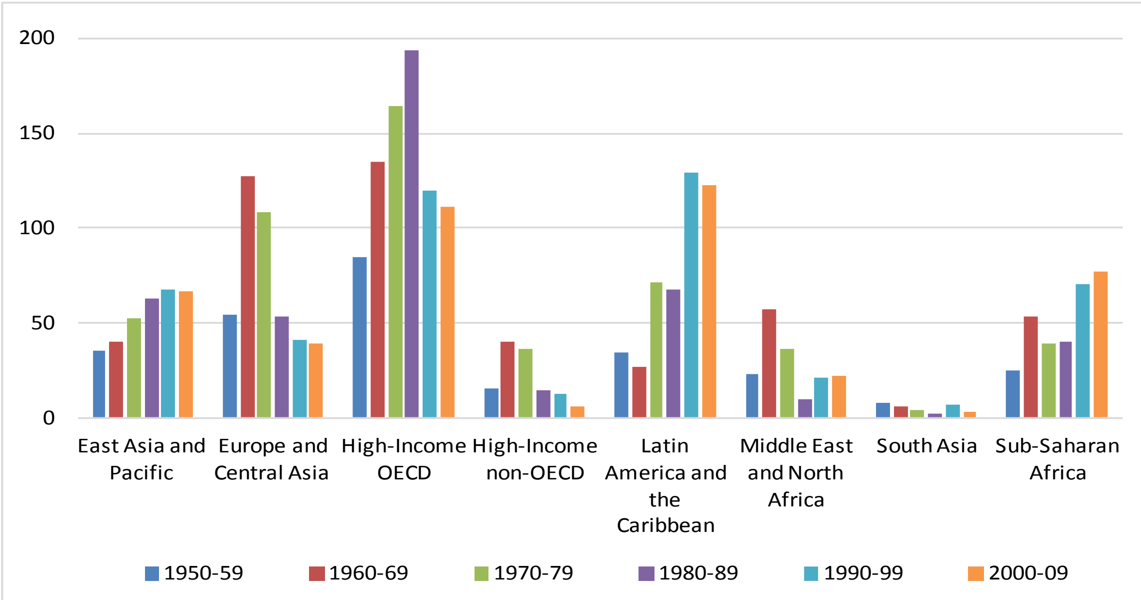


Note: Data are from BP. Units are thousand million barrels.

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 large set 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. That becomes particularly apparent by comparing the trends in discoveries for high-income OECD countries with these for Latin America and the Caribbean and Sub-Saharan Africa. 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 are 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 North to South shift coincides with economic opening in Latin America and Sub-Saharan Africa. We use data from the Sachs and Warner 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. Figure 3 shows a strong positive correlation between the two variables. In fact, liberalization seems to precede the increase in the fraction of discoveries.

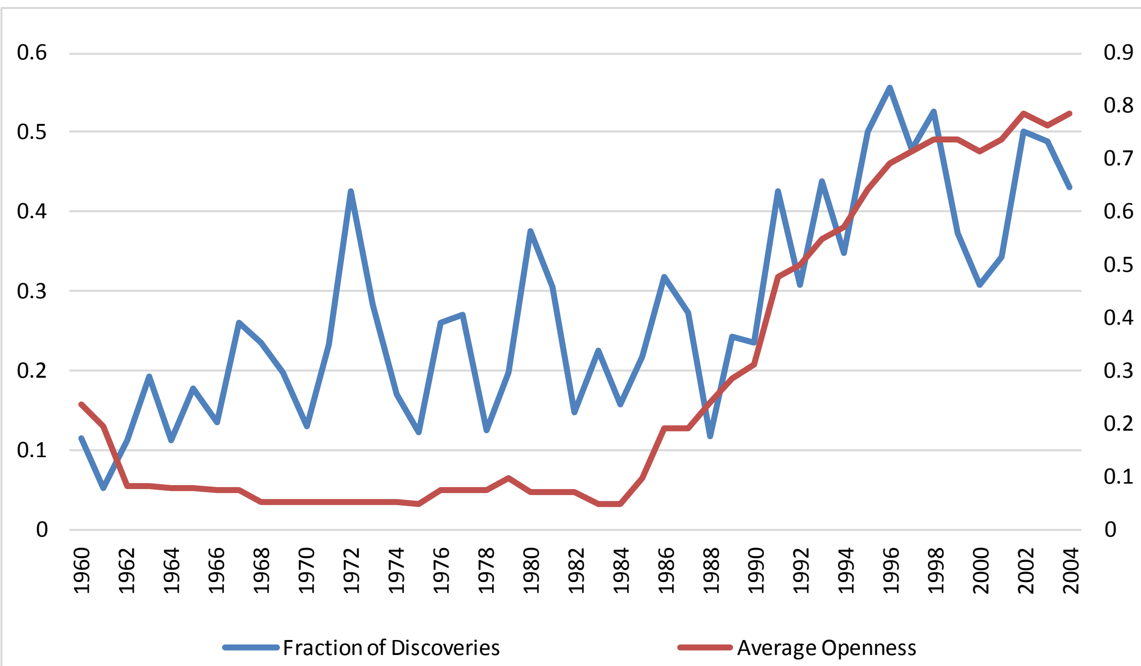
There is also ample anecdotal evidence of a link between better institutions and more discoveries across continents and types of natural resources (see Table 1). The increase in discoveries after countries open up appears quite stark. In Peru, for example, discoveries more than quadrupled, in Chile they tripled, and in Mexico they doubled. These discoveries not only occurred when commodity prices were high, but also when commodity prices 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 some 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 Wacziarg and Welch updated 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 3: Natural Resource Discoveries and Economic Liberalization in Latin America and the Caribbean and Sub-Saharan Africa



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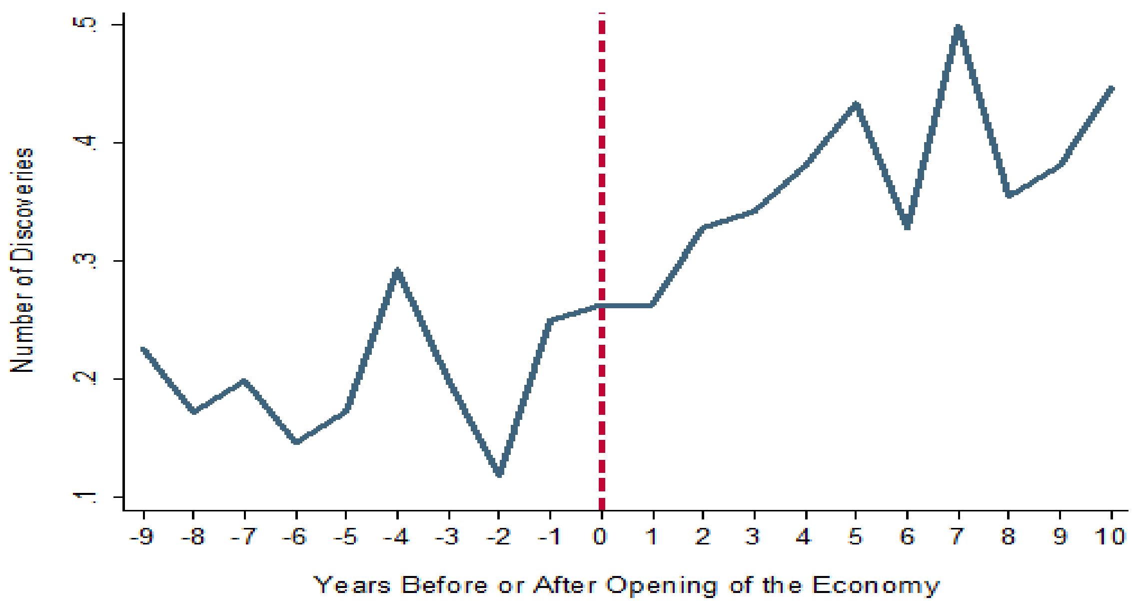
Note: Data is from MinEX, Mike Horn for discoveries, Wacziarg and Welch (2008) for openness measure combined with authors' calculations

[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 confounders. 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.

Figure 4: Average number of discoveries before and after liberalization



Note: Authors' estimations.

III. A Simple Two-Region Model of Endogenous Reserves

Building on the above facts, we present a two-region model of endogenous reserves. Consider a global economy with two resource-producing regions. The North has free access for international resource companies (IRCs), but the South is less open for resource exploration and production. To highlight the idea of a shift in the frontier of resource wealth, we extend a three-period version of the canonical contribution on resource exploration and depletion by Pindyck (1978) to two regions with a global competitive market for resources. IRCs decide where to explore reserves depending on differences in extraction costs and the easy availability of subsoil natural resources stemming from institutional failures and other hindrances to resource exploration activities. They thus relocate their activities until costs of resource exploration across the globe are equalised.

IRCs in the North decide levels of resource exploration investment in periods zero and one, I_0 and I_1. This gives initial reserves at the start of period one, $S_1(I_0),$ and discovery of reserves at the end of period one, $D(I_1) = A\ln(I_1).$ These activities thus face decreasing returns to scale. 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 the resource depletion rate in period one. The future depletion rate cannot exceed remaining reserves. The resource is sold on the international resource market at prices p_1 and p_2. This market is competitive, so IRCs take prices as given. The cost of extracting one barrel of resource falls with the stock of remaining proven reserves: $G(S_t) = \gamma / S_t$ with $\gamma > 0,$ so it is never optimal to let reserves go to zero. IRCs have access to international capital markets at a given world interest rate *r*. Variables, cost and exploration functions for the South are denoted by an asterisk. Apart from differences in extraction costs and initial reserves, the key difference is that resource exploration in the South is hampered by institutional failures and other access restrictions. We capture these with taxes $T_0^* > 0$ and $T_1^* > 0$ on resource exploration investment in the South.

Globally operating IRCs thus maximise their net worth as follows:

$$\text{(1)}\quad \underset{I_0,I_0^*,I_1,I_1^*,R_1,R_1^*,R_2,R_2^*}{\text{Max}} \frac{1}{1+r}\left[p_1 - G\left(S_1(I_0)\right)\right]R_1 + \frac{1}{(1+r)^2}\left[p_2 - G(S_2)\right]R_2 - I_0 - \frac{1}{1+r}I_1$$
$$\frac{1}{1+r}\left[p_1 - G^*\left(S_1^*(I_0^*)\right)\right]R_1^* + \frac{1}{(1+r)^2}\left[p_2 - G^*(S_2^*)\right]R_2^* - (1+T_0^*)I_0^* - \frac{1+T_1^*}{1+r}I_1^*,$$

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

$$\text{(2)}\quad p_1 - G(S_1) = \frac{1}{1+r}\left[p_2 - G(S_2) + G'(S_2)R_2\right],$$

$$\text{(3)}\quad p_1 - G^*(S_1^*) = \frac{1}{1+r}\left[p_2 - G^*(S_2^*) + G^{*\prime}(S_2^*)R_2^*\right].$$

These state that future resource rents minus the marginal increase in future extraction cost from extracting an extra unit of resource today must equal current resource rents plus interest. Maximising net worth also yields the efficiency conditions:

$$\text{(4)}\quad \left[p_2 - G(S_2) + G'(S_2)R_2\right]D'(I_1) = 1+r \ \text{ or } \ \left[p_1 - G\left(S_1(I_0)\right)\right]D'(I_1) = 1,$$

$$\text{(5)}\quad \left[p_1 - G^*\left(S_1^*(I_0^*)\right)\right]D^{*\prime}(I_1^*) = 1+T_1^*,$$

which state that the marginal rent from discovery investment must equal its cost including any taxes. These efficiency conditions give the optimal level of discoveries in the North and South:

$$\text{(6)}\quad D = A\ln\left((p_1 - \gamma/S_1)A\right) \ \text{ and } \ D^* = A^*\ln\left((p_1 - \gamma^*/S_1^*)A^*/(1+T_1^*)\right).$$

Discoveries thus rise with the world price of resource. They are higher in the North than the South if the North has a higher or more easily accessible stock of reserves that depresses extraction costs ($\gamma < \gamma^*$ or $S_1 > S_1^*$), geological conditions make discoveries more likely in the North ($A > A^*$), and there are less taxes, less institutional barriers and easier access for IRCs in the North ($T_1^* > 0$). The global arbitrage condition $p_1 = \frac{\gamma}{S_1} + \frac{I_1}{A} = \frac{\gamma^*}{S_1^*} + (1+T_1^*)\frac{I_1^*}{A^*}$ states that the total marginal cost of extracting and discovering a unit of resource must be equalised across the globe and confirms these insights.

Finally, IRCs maximising net worth also requires the efficiency conditions:

$$(7) \qquad \left[p_1 - G\left(S_1(I_0)\right) - G'\left(S_1(I_0)\right) R_1 \right] S_1'(I_0) = 1 + r,$$

$$(8) \qquad \left[p_1 - G^*\left(S_1^*(I_0^*)\right) - G'\left(S_1^*(I_0^*)\right) R_1^* \right] S_1^{*}{}'(I_0^*) = (1+r)(1+T_0^*).$$

These conditions yield initial reserves and exploration in much the same way as discoveries (6) follow from (4) and (5). The main difference is that initial exploration investment benefits from making future extraction cheaper by ensuring a higher level of proven reserves. We thus obtain:

$$(9) \qquad I_0 = I_0(\overset{+}{p}_1, \overset{+}{R}_1), \quad S_1 = S_1(\overset{+}{p}_1, \overset{+}{R}_1), \quad I_0^* = I_0^*(\overset{+}{p}_1, \overset{+}{R}{}_1^*, \overset{-}{T}{}_0^*) \text{ and } S_1^* = S_1^*(\overset{+}{p}_1, \overset{+}{R}{}_1^*, \overset{-}{T}{}_0^*).$$

Substitution of (9) into (6) gives discoveries in the North and the South:

$$(10) \qquad D = D(\overset{+}{p}_1, \overset{+}{R}_1, \overset{+}{A}, \overset{-}{\gamma}) \text{ and } D^* = D^*(\overset{+}{p}_1, \overset{+}{R}{}_1^*, \overset{-}{T}{}_0^*, \overset{-}{T}{}_1^*, \overset{+}{A}{}^*, \overset{-}{\gamma}{}^*).$$

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. Resource extraction rates in the North and South depend on world prices and geological conditions and extraction costs. Furthermore, extraction rates in the South also depend on the degree of openness to IRCs (see Appendix A). Resource extraction in the South will increase if it more attractive for IRCs to discover new reserves. Resource extraction 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 resource prices increase with resource exploration taxes in the South. Resource producers are more successful in shifting the burden to consumers if demand for resource is relatively inelastic and supply of resource is not. To the extent that this happens, taxes and restrictive access in the South will lead to a shifting of exploration activities and discoveries from the South to the North (see Appendix A). A corollary of this result is that, as the South liberalises and becomes 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 increase 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

We turn now to our empirical analysis testing for some of the theoretical predictions from our simple model. Before we turn to the empirical strategy, we present the various datasets used.

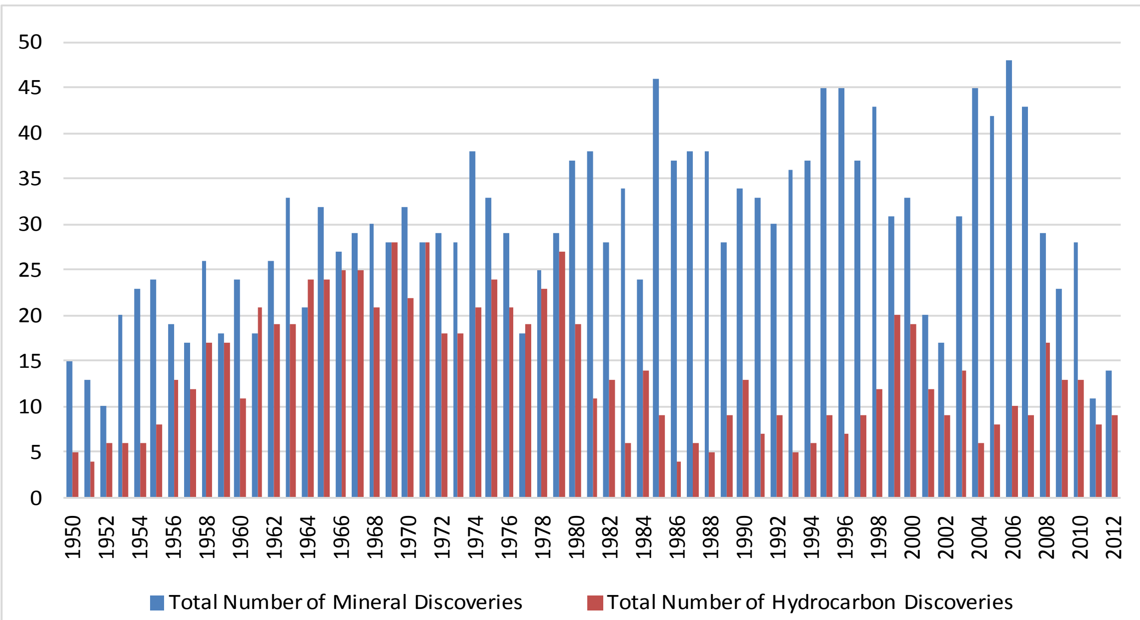
Data

Our dataset consists in measures of natural resource discoveries as well as institutional and macroeconomic variables for a large set of countries and a long time series. We also use data on exploration effort. Appendix B presents a more comprehensive description of the data. Here we focus on the novel data on major hydrocarbon and mineral deposits and the data on market orientation and institutional quality.

Discoveries

The data on major oil and mineral deposits discoveries combine two main datasets. 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.[5] The dataset excludes iron ore and bauxite, which are typically relatively more abundant than other metals and require for their exploitation proximity to port facilities in the case of 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 gives an overview of the total number of discoveries (split between minerals and hydrocarbons) by year. Since the early 1980s the average number has been fairly stable at the global level.

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.

Exploration

To measure exploration effort, we use 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. The SNL Metals and Mining dataset only starts in 1994 and thus limits the sample period for our empirical analysis. The data on exploration spending can be broken down by country, types of natural resources and year and thus allow us to conduct a three-way panel regression analysis.

[5] See data appendix for a full list of minerals included.

Market orientation

To measure market orientation or openness, we use data from a panel of dates of economic liberalisation for a large number of countries (133 countries) and years (1950 to 2004) originally 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 liberalisation, budget restructuring, privatisation, 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. 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), 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 besides the perception of risk on the part of the potential foreign investors. For instance, improved institutions could make easier the transfer of capital and technology and in turn affect the number of discoveries. The analysis here does not attempt to separate those channels. The aim of the political risk rating is to provide a means of assessing the 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 also use the disaggregated ICRG indicators on property rights, rule of law, etc. to shed some additional light on the channels which influence natural resource discoveries.[6]

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 natural 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 natural resources. We also use a specification where

[6] Unfortunately, other indicators of institutional quality such as those from the World Bank and Heritage Foundation are not available for a sufficient period of time, with some indicator starting in the early 2000s at best.

we replace the vectors of country and natural resource fixed effects by a vector of country-natural resource fixed effects. This way we control 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 are included, to account for the clustering of discoveries and depletion of geological reserves. Country-specific controls include population and the Polity2 score obtained from the Polity IV database (Marshall and Jaggers, 2009).[7]

As discussed in the literature, the quality of institutions may be endogenous to discoveries. For instance, discoveries might 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. Clearly, 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.[8]

Specifically, we consider the following linear probability model:

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

Here, the liberalization decision of country i in period t ($OPEN_{i,t}$) is a function of 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 ($\hat{E}_{i,t-1}\left[z\,|OPEN=0\right]$) and ($\hat{E}_{i,t-1}\left[z\,|OPEN=1\right]$).[9] We also control for country and time fixed effects. We use the results from these regressions to predict openness for each country-year pair.

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[7] The Polity2 score ranges from –10 to +10, with higher values indicating more democratic institutions.
[8] 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.
[9] The weights are based on distance data obtained from the CEPII: http://www.cepii.fr/CEPII/fr/bdd_modele/presentation.asp?id=6

Predicted openness $\widehat{OPEN_{i,t-1}}$ is then used to instrument for $OPEN_{i,t-1}$ in estimating equation (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. It turns out that the two sets of results are qualitatively similar.

Since the presence of a large number of zeros and heteroscedasticity of errors can lead to bias and inconsistency of the OLS estimates, we separately use a Zero-Inflated Poisson estimator (ZIP). Our use of the Poisson pseudo-Maximum-Likelihood estimator follows the suggestion in Silva and Tenreyro (2006), i.e., $\text{prob}(y_{itk}) = \frac{e^{-\lambda_{jtk}} \lambda_{jtk}{}^{N_{itk}}}{y_{itk} j!}$, where y_{itk} denotes the number of natural resource discoveries in country *i* at time *t* and for a specific resource *k*. 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_{jtk} conditional on X_{jtk}. Denoting the conditional expectation by L_{jtk}, we obtain:

$$L_{jtk} = E\left[y_{jtk} \middle| X_{jtk} \right] = e^{X_{jtk} . B_{jk}},$$

where X_j is the row vector of explanatory variables. Taking logs gives the model to be estimated:

$$\log E\left[y_{itk} \middle| X_{itk} \right] = B_{jk} X_{itk}.$$

The use of three different estimators (2SLS, OLS, ZIP) and we obtain qualitatively similar results from all three pointy to the validity of our results.

In all baseline regressions we cluster standard errors at the country-natural resource level but significance of the key results is unchanged when we cluster instead at the country level.[10].

[10] Results are reported in the supplementary appendix. Clustering at the country level might be preferable in general but has the disadvantage that no F-Test of the joint significance of all regressors is possible since in our case the number of regressors per cluster is smaller than the number of cluster dummies (see Cameron and Miller, 2015).

III. MAIN RESULTS

We now turn to our benchmark results. Table 2 shows the first-stage of the 2SLS estimation. The high F-Statistics (well above 10) indicate that we do not have a weak instrument problem.

Table 3 shows the second stage of the baseline 2SLS estimation.[11] Table 4 then presents the OLS results as a comparison. Column 1 of Tables 3 and 4 only include fixed effects and our basic variables of interest – openness, stock of previous discoveries and average price change over the past 5 years. In columns 2-4 we add additional controls, importantly also the square of the stock of past discoveries. 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.

Table 2: The Impact of Liberalisation 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***	0.809***	0.808***	0.729***
	(0.0414)	(0.0414)	(0.0414)	(0.0544)
Average Price Change Past 5 Years	0	-0.000649	-0.000975	-0.000580
	(0.0222)	(0.0222)	(0.0222)	(0.0231)
Stock of Discoveries		-0.00114**	0.00250**	0.00158
		(0.000468)	(0.00100)	(0.00104)
Stock of Discoveries Squared			-7.24e-05***	-4.81e-05**
			(1.45e-05)	(1.87e-05)
Polity 2 Score				0.0108***
				(0.00120)
Constant	0.437***	0.445***	0.440***	0.379***
	(0.0727)	(0.0723)	(0.0722)	(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.

Across all specifications regression results consistently show that the coefficient on our measure of market orientation (economic liberalisation) is positive and statistically significantly associated with a higher number of discoveries. More open countries, which we view as a proxy for countries with stronger institutions, are thus more likely to discover new natural resources. More open institutions allow for easier transfer of capital and technology and thus 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. The OLS estimates thus seem to be 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 estimate indicates that liberalisation increases discoveries per country-year-natural resource by roughly 0.05 discoveries per year. We will discuss that quantification in more detail below, but that translates into an economically highly significant impact at the aggregate level.

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 natural 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 discovery is negative suggesting that the effect is non-linear. In other words, bigger stocks of discoveries eventually turn out to be associated with a lower likelihood of discovery as the easiest available deposits have been depleted.[12] We thus interpret the non-linearity 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.[13]

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

[13] Indeed, on the former, Cavalcanti et al (2014), show using well level oil drilling data, that after a first wild-cat discovery, follow-up exploration activity and thus additional discoveries increase significantly in the following years.

As analytically illustrated in section III, better institutions, higher prices and the stock of previous discoveries all impact the number of new discoveries. However, thinking back to our facts, institutions are likely account for the cross-country rather than the time-series dimensions. Prices affect all countries (even though there might be some interactions which we explore in the robustness section) and the concavity in the stock of discoveries is not strong enough (as estimated) to actually reduce discoveries in well explored regions, rather the rate of growth is slowed.

Table 3: The Impact of Liberalisation 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***	0.0560***	0.0541***	0.0542***
	(0.0161)	(0.0162)	(0.0158)	(0.0192)
Average Price Change Past 5 Years	0.0140	0.0267	0.0255*	0.0273*
	(0.0127)	(0.0164)	(0.0154)	(0.0163)
Stock of Discoveries, lagged		0.0224***	0.0358***	0.0344***
		(0.00282)	(0.00453)	(0.00487)
Stock of Discoveries Squared, lagged			-0.000266***	-0.000233***
			(7.61e-05)	(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 Liberalisation 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***	0.0220***	0.0194***	0.0156***
	(0.00528)	(0.00611)	(0.00540)	(0.00531)
Average Price Change Past 5 Years	0.0140	0.0267	0.0255*	0.0273*
	(0.0127)	(0.0164)	(0.0154)	(0.0163)
Stock of Discoveries, lagged		0.0224***	0.0359***	0.0345***
		(0.00282)	(0.00454)	(0.00489)
Stock of Discoveries Squared, lagged			-0.000268***	-0.000235***
			(7.65e-05)	(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

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 Liberalisation 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**	0.554***	0.453***	0.366**
	(0.157)	(0.178)	(0.167)	(0.169)
Average Price Change Past 5 Years	1.435***	1.763***	1.559***	1.819***
	(0.547)	(0.587)	(0.566)	(0.576)
Stock of Discoveries, lagged		0.0180***	0.0660***	0.0629***
		(0.00442)	(0.0122)	(0.0125)
Stock of Discoveries Squared, lagged			-0.000625***	-0.000596***
			(0.000154)	(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.

Verifying the Mechanism

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 economies or open economies are able to attract more exploration investment and thus make more 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 natural resource exploration annually according to Rystad and SNL Metals and Mining. And while exploration is an extremely risky activity[14], in which "luck is obviously a major factor" (Harbaugh, Davis, and Wendebourg, 1995), exploration effort ought to be a key determinant of discoveries. To verify that proposition for our data we estimate the following equation

$$y_{itk} = B(L)expl_{itk} + \alpha_i + \theta_t + \sigma_k + \varepsilon_{itk}$$

where as before y_{itk} is the number of discoveries of natural resource k in country i at time t and α_i, θ_t and σ_k are country, year and natural resource fixed effects, respectively. $expl_{itk}$ is the logarithm of exploration spending in millions of constant (2010) U.S. dollars.[15] $B(L)$ is a pth order lag operator. The specification is very simple and designed to simply verify whether higher exploration spending increases discoveries.

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.

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[14] Today, 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.

[15] The exploration expenditures data are deflated using U.S. producer price index. Using alternative deflators lead 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

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 discoveries as the dependent variable. As above, we instrument openness with its predicted value.

We find a strong positive impact of opening on exploration spending. Table 7 presents the results. It should be noted that the period of analysis when using exploration spending is relatively short due to data constraints. To the best of our knowledge that is however the best available data. Exploration spending data is only available since 1994 while the openness variable is only available until 2004. The point estimate suggests an increase of over 100%. Opening up the economy thus leads to a large and significant increase in exploration spending that in turn results in additional discoveries.

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

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

Quantification

To obtain a finer quantification of the impact of institutions on discoveries, we use the ICRG political risk rating (which goes from 0 to 100) instead of the SW openness indicator.[16] The political risk rating, reflecting property rights and political stability, is found to be statistically and economically highly significant for natural resource discoveries (see Table 8).[17]

[16] We report results for the ZIP estimator and OLS rather than 2SLS in this subsection since we do not have an instrument for the ICRG index.
[17] Due to data availability the time period when using ICRG is quite different from the one using SW – 1985-2011 instead of 1964-2004. While the overlap between the two is thus only 19 years, the supplementary appendix shows the restricting the sample to this overlap period does not materially change the results.

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**	0.000545**	0.0245***	0.0219***
	(0.000217)	(0.000220)	(0.00727)	(0.00721)
Average Price Change Past 5 Years	-0.00154	-0.00302	0.780	0.512
	(0.00637)	(0.00659)	(0.756)	(0.722)
Stock of Discoveries, lagged	0.0160***	0.0216***	0.0170***	0.0520***
	(0.00229)	(0.00408)	(0.00559)	(0.0177)
Stock of Discoveries Squared, lagged		-9.97e-05		-0.000400*
		(7.58e-05)		(0.000222)
Polity 2 Score, lagged		-5.12e-05		-0.00440
		(0.000602)		(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 estimate from the Zero-Inflated Poisson 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 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.[18] Notwithstanding the dramatic increase in institutions implied by this thought experiment, the magnitudes unveiled

[18] 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 $e^{17*0.0219} = 1.45$. 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%.

suggest that institutions play an important role in driving exploration for and ultimately discoveries of natural resources.

ROBUSTNESS

In this section we present results obtained 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 unchanged in the various robustness exercises presented in Tables S1-S4. Table S1 in the supplementary appendix highlights that the results are virtually unchanged when we employ country-natural resource fixed effects rather than country and natural 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 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 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. 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 somewhat 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.[19] 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 investment profile sub-index and government stability are associated with higher numbers of resource 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 increase in Asian demand does not correspond with the North to South shift in discoveries (see Figure S1).

VII. Conclusion

This paper explored the effect of changes in market orientation and improvements in institutions on resource wealth using worldwide major hydrocarbon and mineral discoveries. We first 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 based on Pindyck (1978). We then estimated the effects of changes in market orientation on a large three-way panel—resource, country and year. Our empirical results are consistent with the predictions of the model. An increase in market-orientation cause a statistically and economically significant increase in the likelihood of resource discoveries over and above the effect of changes in resource prices and depletion forces. A thought experiment whereby Latin America and sub-Saharan Africa were to 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. Our results also suggest that the relationship between natural resource endowment and institutions is complex. Further research should attempt to revisit some of the key empirical findings including in the

[19] We lose some power when splitting the sample, hence the reduced significance levels.

resource curse literature on the mediating role of institutions for resource endowment. Theoretical models should attempt to account for the jointly determined nature of institutions and resource wealth.

From a broader perspective, our findings is at odds with the so-called peak oil hypothesis, which predicted that global oil production would peak in the year 2000. While we documented the importance of the institutional channel is driving the North to South shift in major discoveries there are countervailing forces including the emergence of new technologies. A notable example is the new so-called unconventional technology in the United States permits extraction of oil from tight rock formations once thought unsuitable for drilling. As a result, oil production in the United States has grown significantly in the past five years. The re-emergence of U.S. oil production suggests that technology, depending on how and where it is adopted, could to some degree attenuate the North-South shift in the frontier of global resource wealth. That said, as the South continues to develop an environment that encourages investment, the move of resource exploration and extraction to emerging market and developing economies will likely continue.

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Appendices

A. Theoretical Appendix

This appendix analyses equilibrium discoveries in the North and South by introducing global oil demand. Let world demand for oil in period one be iso-elastic and be given by $\Gamma_1 p_1^{-\varepsilon}$ and in period two by $\Gamma_2 p_2^{-\varepsilon}$, where $\varepsilon > 0$ is the price elasticity of demand and $\Gamma_t > 0$ is an exogenous shift to oil demand in period *t*. Market equilibrium on the world oil markets requires

(A1) $$R_1 + R_1^* = \Gamma_1 p_1^{-\varepsilon} \text{ and } R_2 + R_2^* = \Gamma_2 p_2^{-\varepsilon}.$$

Using initial exploration (9) and discoveries (10), the depletion equations become

(A2) $$\begin{gathered} R_1 + R_2 = S_1(p_1, R_1) + D(p_1, R_1, A, \gamma) \quad \text{and} \\ R_1^* + R_2^* = S_1^* = S_1^*(p_1, R_1^*, T_0^*) + D^*(p_1, R_1^*, T_0^*, T_1^*, A^*, \gamma^*). \end{gathered}$$

Using (9), the extraction rates follow from the Hotelling rules (2) and (3) or

(A3) $$\begin{gathered} p_1 - G\left(S_1(p_1, R_1)\right) = \frac{1}{1+r}\left[p_2 - G(R_2) + G'(R_2)R_2\right] \quad \text{and} \\ p_1 - G^*(S_1^*) = \frac{1}{1+r}\left[p_2 - G^*(R_2^*) + G^{*}{}'(R_2^*)R_2^*\right]. \end{gathered}$$

Equations (A1)-(A3) can be solved for extraction rate and prices $\left\{R_1, R_1^*, R_2, R_2^*, p_1, p_2\right\}$ and thus also for initial and future oil discoveries $\left\{S_1, S_1^*, D, D^*\right\}$ in terms of the ease of access for IOCs in the South $\left\{T_0^*, T_1^*\right\}$, the extraction cost parameters and geological conditions in the North and the South $\left\{\gamma, \gamma^*\right\}$ and $\left\{A, A^*\right\}$, and the global oil demand shocks $\left\{\Gamma_1, \Gamma_2\right\}$. Table A1 gives some numerical examples that illustrates how the shifting frontier of natural resources can result from a gradual improved access for IRCs in the South or from global oil demand shocks.

One could also 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.

B. Data Appendix

B.II. Data Description

Table B.II presents the description of the macroeconomic variables used 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

C. Supplementary Appendix

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

	(1)	(2)	(3)	(4)
VARIABLES	Number of Discoveries	Number of Discoveries	Number of Discoveries	Number of Discoveries
SW/Wacziarg Openness, lagged	0.0601***	0.0597***	0.0569***	0.0621***
	(0.0179)	(0.0182)	(0.0171)	(0.0216)
Average Price Change Past 5 Years	0.0122	0.00948	0.00977	0.0123
	(0.0123)	(0.0123)	(0.0117)	(0.0121)
Stock of Discoveries, lagged		-0.00482	0.0269*	0.0273*
		(0.00464)	(0.0151)	(0.0157)
Stock of Discoveries Squared, lagged			-0.000507**	-0.000468**
			(0.000198)	(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***	0.0542**	0.0597**	0.0621**
	(0.0215)	(0.0239)	(0.0235)	(0.0284)
Average Price Change Past 5 Years	0.0267*	0.0273*	0.00948	0.0123
	(0.0160)	(0.0160)	(0.0117)	(0.0116)
Stock of Discoveries, lagged	0.0224***	0.0344***	-0.00482	0.0273*
	(0.00362)	(0.00448)	(0.00500)	(0.0145)
Stock of Discoveries Squared, lagged		-0.000233***		-0.000468**
		(8.40e-05)		(0.000213)
Polity 2 Score, lagged		-0.000103		-0.000471
		(0.000573)		(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**	0.0366***	0.0418***	0.0461***
	(0.0133)	(0.0141)	(0.0156)	(0.0167)
Change in Prices	0.00234	0.00224	0.00322	0.00290
	(0.00263)	(0.00268)	(0.00286)	(0.00294)
Change in Prices, lagged		-0.00199	-0.00263	-0.00241
		(0.00369)	(0.00382)	(0.00419)
Change in Prices, lagged 2			0.00830**	0.00797**
			(0.00342)	(0.00348)
Change in Prices, lagged 3				0.00669*
				(0.00369)
Stock of Discoveries, lagged	0.0345***	0.0345***	0.0346***	0.0346***
	(0.00474)	(0.00477)	(0.00481)	(0.00483)
Stock of Discoveries Squared, lagged	-0.000237***	-0.000236***	-0.000236***	-0.000237***
	(6.70e-05)	(6.74e-05)	(6.78e-05)	(6.79e-05)
Polity 2 Score, lagged	0.000179	0.000133	5.21e-05	1.51e-05
	(0.000358)	(0.000367)	(0.000379)	(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***	0.0618***	0.0610***	0.0568***
	(0.0211)	(0.0211)	(0.0210)	(0.0198)
Average Price Change Past 5 Years	0.0159	0.0195	0.0188	0.0148
	(0.0141)	(0.0151)	(0.0148)	(0.0153)
Stock of Discoveries, lagged		0.0205***	0.0302***	0.0300***
		(0.00308)	(0.00524)	(0.00546)
Stock of Discoveries Squared, lagged			-0.000180**	-0.000166**
			(8.29e-05)	(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**	0.171*	0.182*
	(0.147)	(0.0931)	(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***	0.604*	0.401**
	(0.150)	(0.314)	(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**	0.327*	0.494***
	(0.166)	(0.188)	(0.177)
Average Price Change Past 5 Years	1.894**	1.821***	1.904*
	(0.829)	(0.576)	(1.013)
Stock of Discoveries, lagged	0.0629***	0.0585***	0.0235***
	(0.0124)	(0.0128)	(0.00701)
Stock of Discoveries Squared, lagged	-0.000597***	-0.000554***	
	(0.000155)	(0.000195)	
Openness x Stock of Discoveries, lagged		0.00583	-0.00667
		(0.0150)	(0.00695)
Openness x Average Price Change Past 5 Years	-0.135		-0.917
	(0.814)		(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	0.000800	0.00988
	(0.0118)	(0.0118)	(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	0.493	0.484	0.544	0.506	0.490
	(0.716)	(0.717)	(0.719)	(0.720)	(0.720)	(0.716)
Stock of Discoveries, lagged	0.0545***	0.0528***	0.0524***	0.0525***	0.0522***	0.0535***
	(0.0183)	(0.0188)	(0.0185)	(0.0187)	(0.0185)	(0.0191)
Stock of Discoveries Squared, lagged	-0.000435*	-0.000412*	-0.000405*	-0.000405*	-0.000403*	-0.000420*
	(0.000227)	(0.000230)	(0.000229)	(0.000233)	(0.000227)	(0.000235)
Polity 2 Score, lagged	0.00404	0.00966	0.00498	0.00669	0.00267	0.00938
	(0.0197)	(0.0214)	(0.0204)	(0.0201)	(0.0207)	(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