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From Commodity Discovery to Production

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Abstract

Major resource discoveries have transformed growth prospects for many low-income countries. However, the sharp downturn in commodity prices in recent years is affecting resource investment in these countries, and may delay the development of recent discoveries into production. This study investigates lead times from discovery to production for a unique data set of gold and copper discoveries worldwide during 1950–2014. The study employs standard parametric and nonparametric duration analysis. The results suggest an important role for copper prices; for instance, an upswing at the time of discovery can hasten the development of the mine by two to three years in low-income countries. There appears to be a similarly beneficial impact on lead times of sounder macroeconomic policies and quality of governance.

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From Commodity Discovery to Production

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I. Introduction

The surge in commodity prices over the past decade has played a pivotal role in spurring faster growth in low-income countries (LICs). As industry exploration and investment spending climbed to record highs, a spate of commodity discoveries—notably "giant" oil and gas discoveries in East and West Africa—has transformed the long-term growth outlook in several countries (World Bank 2015a and b).[2] Mining has expanded rapidly in many LICs in Sub-Saharan Africa over the past decade. For example, the number of active industrial gold mines reached historic highs by 2011 across Sub-Saharan Africa after half a decade of soaring gold prices (Tolonen 2015).

However, with the post-2011 slide in commodity prices, industry spending on investment has dropped sharply.[3] In Africa, the number of oil rigs for on-land drilling has fallen by 40 percent from their peak in Q1 2014 (Figure 1) and mining production has been disrupted in Sierra Leone and Democratic Republic of Congo (DRC). There are risks of delays in major mining and energy projects under development in East African LICs that could affect growth prospects. In Uganda, for instance, slower-than-anticipated infrastructure development has already delayed oil production start dates, from 2016 to as late as 2020. In Tanzania and Mozambique, final investment decisions on major LNG projects have been repeatedly delayed (Bennot 2015).[4] In Afghanistan, investment plans for the development of copper and iron ore mines leased for development in 2008 and 2012 have been significantly scaled back.

Project delays are detrimental for several reasons. They prolong the period of heightened vulnerabilities associated with the pre-production investment and delay the boost to growth that is typically associated with production. Additional concerns arise in hydrocarbon projects where delays may increase the risk of "stranded assets" as global efforts to tackle climate change induce a shift towards less carbon-intensive technologies and greater energy efficiency (Stevens et. al. 2015, Carbon Tracker Initiative 2004, McGlade and Ekins 2015).[5] Such stranded assets pose financial and growth risks to the companies that own or operate them and the governments that back them.

This working paper discusses the evolution of macroeconomic vulnerabilities during the development of major resource discoveries, the impact of slowing commodity prices on development times, and policies to shorten these times. The analysis rests on a data set for gold and copper discoveries worldwide since 1950 (proprietary to MinEx Consulting). Over this period, gold and copper discoveries have accounted for two-thirds of non-ferrous discoveries.

[2] "Giant" fields are conventional fields with recoverable reserves of 500 million barrels of oil equivalent or more. Despite the increasing importance of unconventional shale oil and gas fields, current and future oil and gas supply is dominated by conventional giant fields (Bai and Xu 2014).

[3] The drop in industry investment has partly reflected growing concerns about misallocation of capital expenditures into exploration over the past decade (McIntosh 2015).

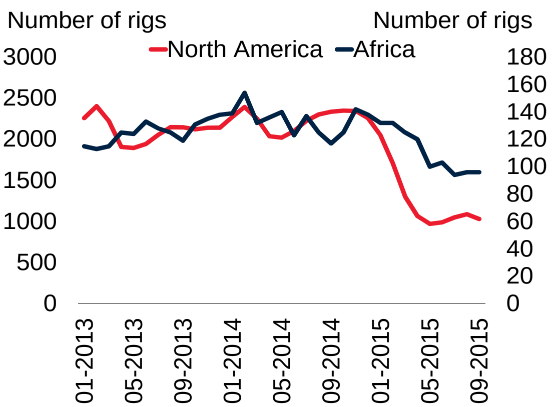
[4] Coal projects in Mozambique are reportedly losing money, because of the slump in coal prices, and inadequate infrastructure (Almeida Santos, Roffarello, and Filipe 2015).

[5] "Stranded assets" refer to resource capacity, specifically for hydrocarbons (coal, oil, gas), that remains unused as the world reduces its hydrocarbon consumption in order to reduce risks arising from climate change (Carbon Tracker Initiative, 2004, McGlade and Ekins 2015).

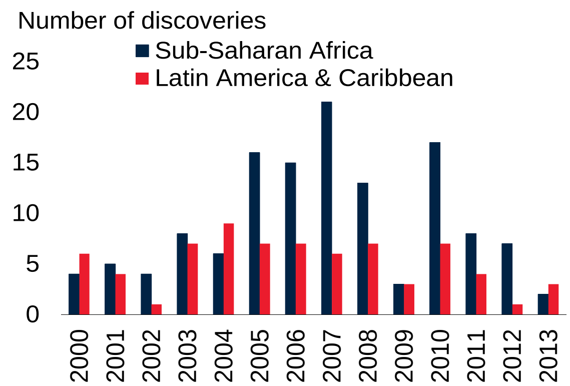
Figure 1. Prospects and risks from resource investment

Following a decade of major resource discoveries, the drop in oil prices raises concerns that long-planned investment to develop discoveries into production is delayed in low-income countries. This would set back growth.

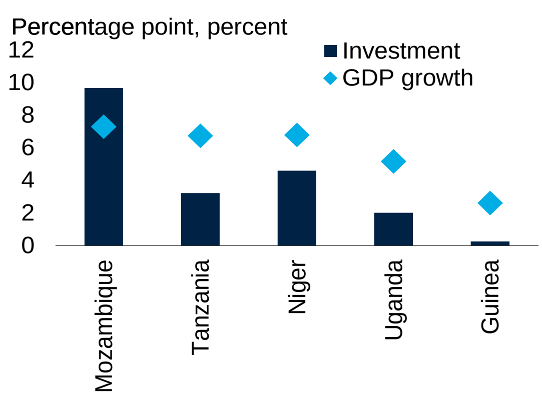
A. Rig counts in Africa and North America



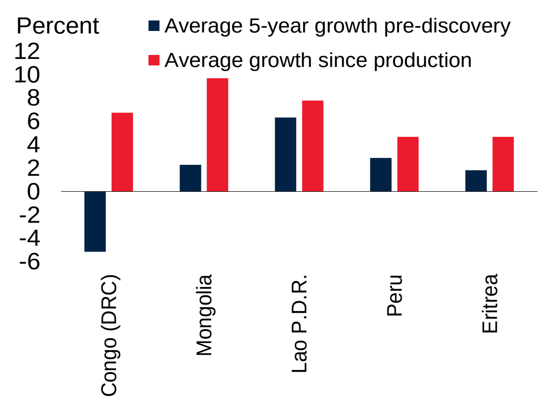
B. Resource discoveries eventually converted into production



C. Contribution of investment to real GDP growth, 2010-14



D. Growth in low- and middle-income countries with resource discoveries



Sources: World Bank staff estimates, Baker Hughes, World Development Indicators, MinEx Consulting.
A. The rig count is the number of oil rigs in operation.
C. Contribution of investment in percentage point, GDP growth in percent.

We add to a sparse existing literature by modeling the duration time from the discovery of these gold and copper resources to production. Specifically, we analyze whether, all else equal, the time duration or delay between discovery and production is affected by country-specific institutional and governance factors, by the macro-environment and by external global factors, notably whether commodity prices are high or low around the time of discovery. We use both non-parametric

(Kaplan-Meier) and parametric multivariate regression based on the accelerated-failure-time (AFT) model of Jenkins (2006) to shed light on these questions.

The results suggest an important role for the commodity price cycle, sound macroeconomic management and the quality of governance. Higher commodity prices, on average, are not significant determinants of lead times, probably because of the significant sunk costs involved in developing a resource, particularly in capital-constrained low-income countries. However, for copper deposits, an upswing in copper prices at the time of discovery can hasten lead times to development. For example, in LICs since 2000, our findings suggest that rising copper prices at the time of discovery may have shaved off about two to three years from lead times. Sound macroeconomic policies also appear to be important: multivariate parametric analysis indicates that lowering government debt below 40 percent of GDP accelerates development times by about 10 percent. Government debt may proxy for generally sounder and more predictable macroeconomic policies. Over the medium-term, better quality of governance also reduces lead times to production. Given prospects in commodity producers, particularly LICs, of a protracted adjustment to persistently lower commodity prices, our results suggest that better institutions and business and macroeconomic environments could help sustain growth in the resource sector even in an environment of low commodity prices.

The rest of the paper is structured as follows. Section II examines evidence and existing literature relating to typical lead times between discovery and production. In section III we examine how economies evolve between commodity discovery and production, Section IV describes the data set and key stylized facts that emerge from it. Section V models the duration between discovery and production, and the key factors that help accelerate or lengthen the time to the development of a natural resource, particularly in LICs. Section VI discusses the major policy implications and concludes.

II. Lead times between discovery and production

Typically, developing a resource discovery requires large upfront investments, over a considerable period. During this time, there may be high uncertainty about prices and macroeconomic and policy environments (IMF, 2012a).

Broadly, the process of development of most mines undergoes five major stages. Since cross-country data are not publicly available, four of these stages are illustrated in Figure 2 for two copper mines, one in the United States and another in Mongolia. The process begins with exploration to establish the existence of a *potentially* commercially viable deposit (4-5 years in the two illustrative examples).[6] Once such a deposit is confirmed, feasibility, environmental and other impact studies are conducted and financing plans developed to establish commercial viability. Once commercial viability has been confirmed, a mining license is obtained, a process that can take several years in some countries (2-3 years, on average, in Africa; Gajigo et al. 2012). Finally, the duration of construction of the physical facility (3 years in the two illustrative examples) depends on the accessibility of the deposit.

All steps depend on the quality of governance, the reliability of institutions, and macroeconomic

[6] In African LICs, the average duration of an exploration license is for three years (Gajigo et al. 2012).

stability that facilitates predictable policies. Investment risks tend to be high in the exploration, pre-feasibility and feasibility stages, and decline as a deposit gets closer to production. Stylized facts on lead times by type of commodity and size of deposit are as follows:

- **Oil and gas.** Conventional discoveries can take 30-40 years to develop (Clo 2000), but lead times for giant oil and gas discoveries can be shorter (Arezki et al. 2015). For oil deposits, such as shale, short lead times of 2-3 years reflect technological improvements since the 1980s, and reduced entry barriers for small, agile firms (Wang and Xue, 2014, World Bank 2015a). Monetizing gas discoveries is harder than oil discoveries: final markets are typically far away, so that simultaneous investments in drilling and transport infrastructure are required, and long-term price contracts need to be agreed with end-users (Huurdeman 2014).

- **Mining.** Lead times can range from a few years to decades, depending on the type of mineral, size and grade of the deposit, financing conditions, country factors and commodity prices (UNECA 2011, Schodde 2014).

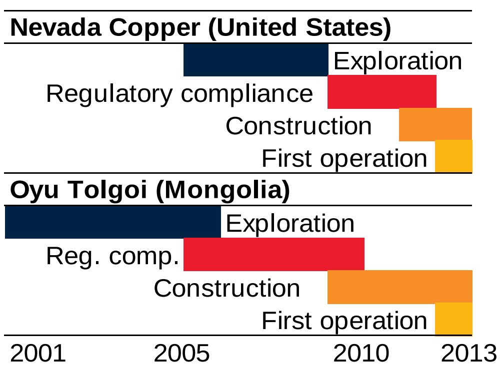
- **Copper mining versus other mining.** Average lead times for gold discoveries are 10 years, but more than 15 years for zinc, lead, copper and nickel discoveries (Schodde 2014). As discussed in more detail in Section IV, the data set used in this study indicates that average lead times to production have fallen sharply in recent decades (Figure 2). In addition, the development of most gold deposits tends to begin immediately, whereas a significant share of copper discoveries takes several decades to develop (Figure 4). For instance, one-third of copper discoveries since 1950 have had lead times to eventual production of 30 or more years, compared with only 4.5 percent of gold discoveries. Similarly, industry estimates place the period from early exploration to final production of copper mines at close to 25 years (McIntosh 2015). Longer lead times for copper mines reflect greater complexity and greater infrastructure investment to transport the ore to export markets.[7]

[7] For instance, the location of Chile's copper mines close to the sea has made it easier to profitably ship concentrates, whereas copper mines in central Africa have had to rely on local smelting and refining to reduce the volumes transported to ports (Crowson, 2011).

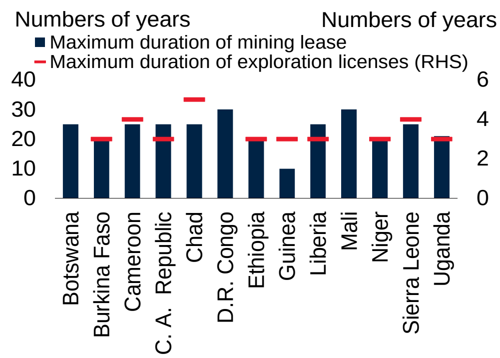
Figure 2. The mining project cycle

Most mining projects are characterized by several key stages that include exploration, discovery, feasibility assessments and regulatory compliance (including obtaining licenses), project construction, production and eventually closure.

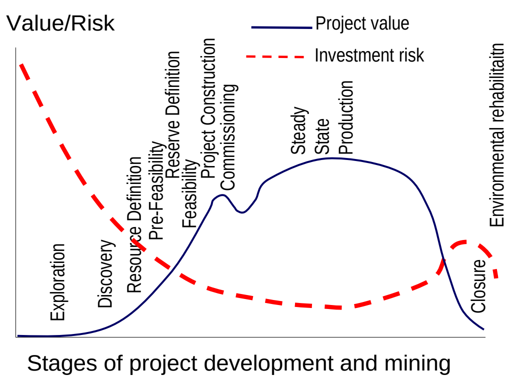
A. Time lines for mine development



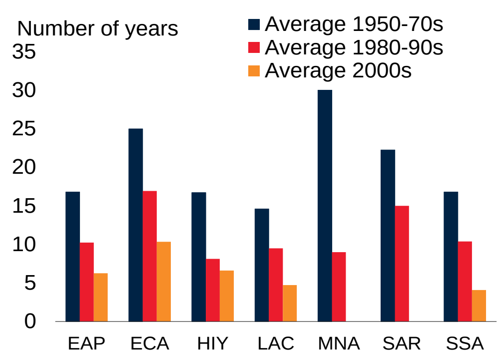
B. Duration of mining leases and exploration licenses in selected LICs



C. Investment risk over a mining project lifecycle



D. Number of years from gold and copper discovery to production



Sources: World Bank, Perott-Humphrey (2011); Gajigo et. al. (2012); http://ot.mn/history, http://pumpkinhollowcopper.com/project-timeline/, both accessed November 4, 2015.
A. Illustrative example of timeline from two copper mines, in the United States and Mongolia. Exploration is not included in lead times discussed in the text.
D. Based on a sample of 46 countries with copper discoveries and 73 countries with gold discoveries. SST denotes Sub-Saharan Africa. EAP = East Asia and Pacific; ECA = Europe and Central Asia; HIY = High-income countries; LAC = Latin America and the Caribbean; MNA = Middle East and Africa; SAR = South Asia; SSA = Sub-Saharan Africa.

III. Evolution from commodity discovery to production

Resource discoveries matter to the economy only insofar as they can be developed into production. However, since 1950, less than 60 percent of gold, zinc and lead discoveries have made it to eventual production, and less than 40 percent of copper and nickel discoveries (Schodde, 2014). Once developed, the market value of discoveries can be large compared to the size of LIC and MIC economies. For copper mines, for example, production in 2014 alone accounted for 6 percent of LIC GDP and 2 percent of MIC GDP, on average (Figure 3).

Depending on the commodity and the size of the discovery, during the lead time between commodity recovery and extraction, countries can accumulate sizeable vulnerabilities as investment rises and external liabilities grow. In the data set used here, investment growth increased sharply in the five to ten years before actual extraction of the resource began (Figure 3). This effect was only apparent in low-income countries. Since their economies tend to be smaller than middle- and high-income countries, the development of a large mine can create significant domestic demand pressures. Using a global database on giant oil discoveries (those exceeding ultimately recoverable reserves of 500 million barrels), including in Africa, Arezki et al. (2015a) find that investment growth rises immediately upon discovery and current account deficits widen. GDP growth and private consumption growth respond only once extraction begins. The full increase in GDP growth materializes with commercial production, when vulnerabilities unwind as exports expand.

The size of vulnerabilities depends on three factors: how mine construction is financed, whether governments borrow in anticipation of rising commodity revenues in the future, and whether private consumption and investment rises in anticipation of rising incomes. If rising imports and current account deficits are financed by FDI, which tends to be less prone to sudden stops than debt financing, short-term vulnerabilities are more limited (Levchenko and Mauro 2008). Nevertheless, a sudden stop in FDI projects could also disrupt foreign exchange markets and sharply dampen activity. In particular, expectations of greater FDI (including as a result of recent natural resource discoveries) can encourage long-maturity non-resource investment projects. If these expectations are not validated, a sudden stop could follow and trigger fire sales of long-term assets and a collapse in activity (Calvo 2014). Additional, fiscal risks arise if governments expand spending and borrow against future commodity revenues.

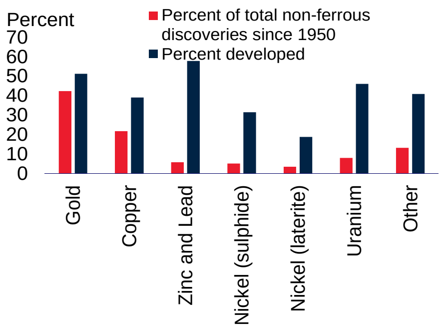
The following examples illustrate the heightened vulnerabilities associated with lead times in a number of LICs.

- **Sierra Leone:** The discovery of major iron-ore deposits in 2009 led to a substantial upward revision in growth forecasts to over 50 percent in 2012 as mining production came onstream. However, work stoppages and a breakdown in the railway system delayed the start of the mine, so that actual growth outcomes were much lower than initial projections. Since then, a collapse in global iron ore prices by 50 percent between 2011 and 2014 has led to severe financial difficulties at the country's two foreign-owned and highly indebted mining operators, with one declaring bankruptcy and the other halting operations (World Bank 2015e, IMF 2012b and 2015a). This and the outbreak of the Ebola epidemic set back activity, with the economy estimated to have contracted by 20 percent in 2015.

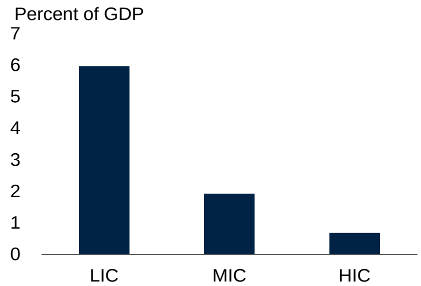
Figure 3. Developments during lead times between resource discovery and extraction

Gold and copper discoveries have been sizeable compared to the size of LIC and MIC economies. However, a significant portion of discoveries never get developed. Between resource discovery and production, investment growth rises sharply and vulnerabilities can increase. Growth can become vulnerable to setbacks in mining sectors.

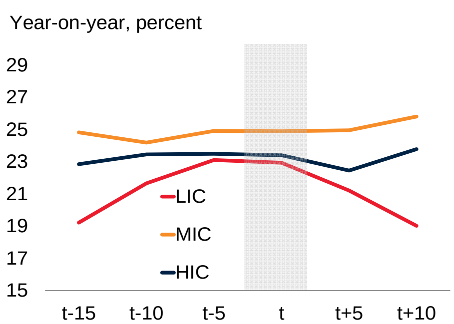
A. Share of non-ferrous discoveries converted into production



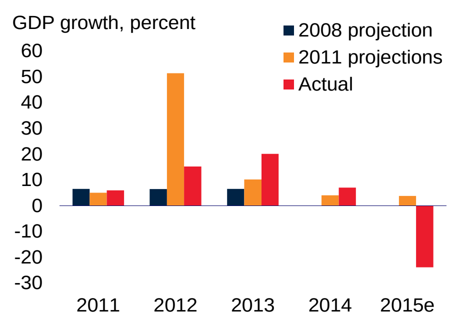
B. Average value of copper production, 2014



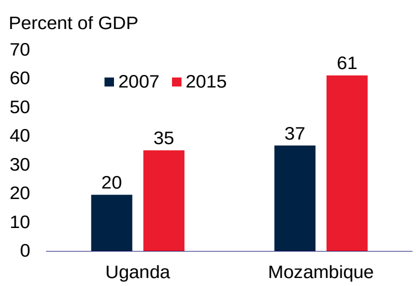
C. Investment growth during lead times



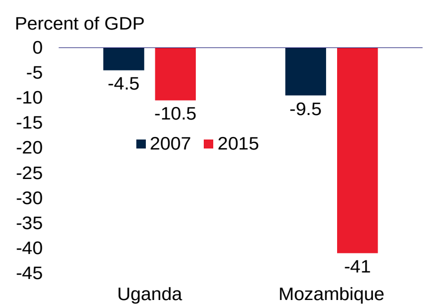
D. GDP growth in Sierra Leone



E. Public debt ratios in selected East African LICs



F. Current account deficits in selected East African LICs



Source: World Development Indicators, World Economic Outlook, MINEX Consulting, World Bank staff estimates., World Bank Commodity Markets Outlook World Bank (2015d).
A. Based on a sample of 46 countries with copper discoveries and 73 countries with gold discoveries

B.Annual copper production evaluated at average 2014 price in percent of GDP (World Bank 2015a).
C. LIC stands for low-income countries, MIC for middle-income countries, and HIC for high-income countries.
D. IMF projections for GDP growth in Sierra Leone, which discovered major iron-ore deposits in 2009.

- **Uganda:** Oil was discovered in 2006. Although production has yet to start, the government has borrowed in anticipation of future oil revenues. The public debt ratio has nearly doubled since 2007, reflecting loans from Chinese state banks and other lenders to finance large hydropower and other infrastructure projects. With production dates being postponed, infrastructure projects affected by cost overruns, and the current account deficit reaching over 10 percent of GDP in 2015, fiscal risks and external financing risks have increased (World Bank 2015f).

- **Mozambique:** The discovery of massive gas deposits in 2012 has lifted medium to long-term growth prospects. However, the sharp fall in oil and gas prices since 2014, delays in mining infrastructure projects and highly expansionary fiscal policies have generated major short-term challenges. Public debt ratios have risen sharply from 2007, to finance government infrastructure spending. But with finances under pressure, the country has turned to the IMF for financial support (IMF 2016).

IV. Data description and stylized facts

The data set comprises proprietary data from MINEX Consulting on 960 global mining discoveries in copper and gold between 1950 and 2014. The copper discoveries data set contains data on 46 developing and advanced countries covering 273 discoveries. The gold discoveries data set contains observations for 73 developing and advanced economies, and a total of 687 discoveries.

In addition, data are available on the size and quality of the deposits (Tier 1, 2 or 3 deposits with Tier 1 deposits referring to the highest quality deposits based on criteria that include concentration of ore and size of find). These data are augmented by other data including country specific institutional and governance variables (democracy, fragmentation/conflict); macroeconomic variables (government debt levels, inflation, public sector and external balances) and other control variables (levels of GDP per capita) and World Bank Income Classification categories to identify countries that are low-, middle- or high income. It is important to note that although the data do not have right or left censoring issues as is typically the case with most duration analysis, the data sample does suffer from "right truncation". In other words, the observation of a mine in the sample is conditional upon it having being developed to production during the sample period (which ends in 2014). Mines which have yet to be developed are not part of the sample.

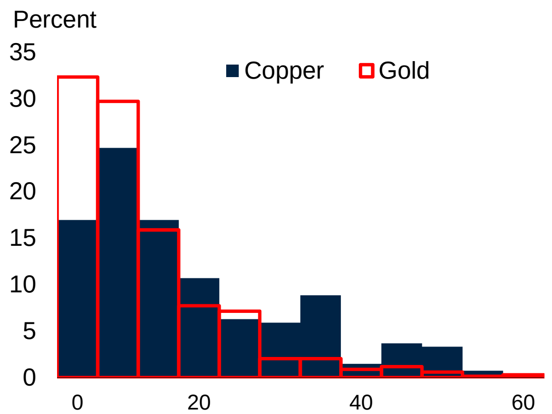
Most copper and gold mines in our data set tend to get developed within the first 10 years following discovery (Figure 4). However, the lead time to production is shorter for gold discoveries (10 years, versus. 17 years, on average, for copper). Only 4.5 percent of gold mines in the sample remain in production for 30 or more years, compared to almost a third of copper mines in the sample. On average, there does not appear to be any discernible difference across gold mines of different sizes or quality.[8] In contrast, copper deposits with shorter lead times to production are more often those of higher quality (Tier 1) deposits. By region, the largest number of discoveries in our data set is located in the Americas, Africa, Australia, and among Former

[8] This is also borne out in mean comparison tests, with t-statistics indicating that statistically significant difference in the average delay (or number of years to production) from discovery to production across gold and copper mines. Mean comparison tests, however, show no statistically significant difference across mines of different sizes.

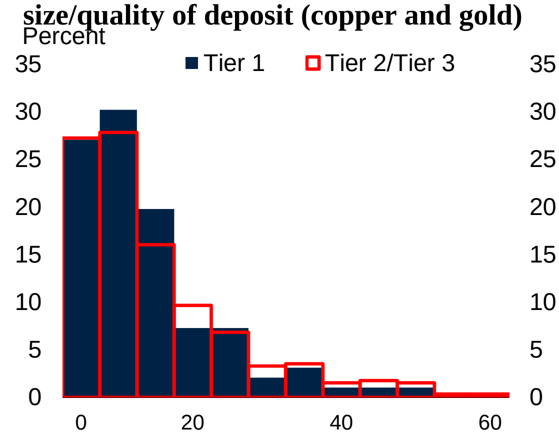
Figure 4. Stylized facts on lead times from discovery to production for gold and copper deposits

The bulk of gold deposit discoveries are developed more quickly than the average copper mine. However, almost 60 percent of high quality (Tier 1) copper deposits are also developed within the first 10 years following discovery.

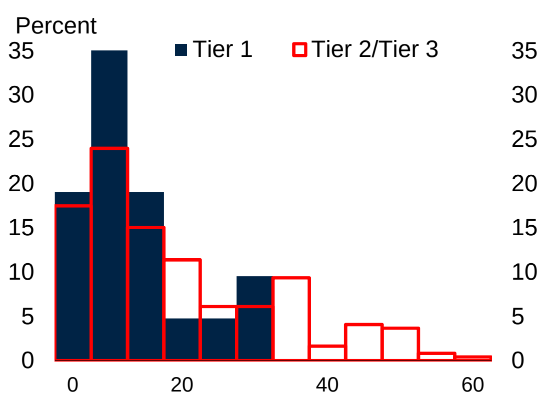
A. Lead times to production, by type of deposit



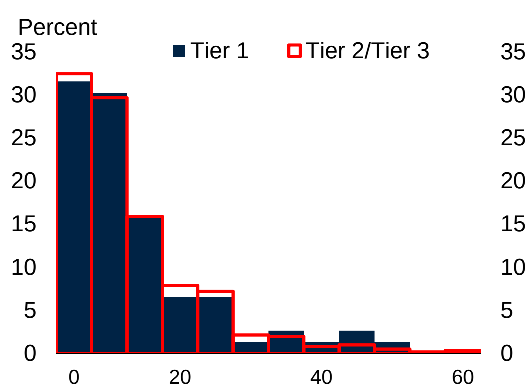
B. Lead times to production, by size/quality of deposit (copper and gold)



C. Lead times to production, by size/quality of copper deposit



D. Lead times to production, by size/quality of gold deposit

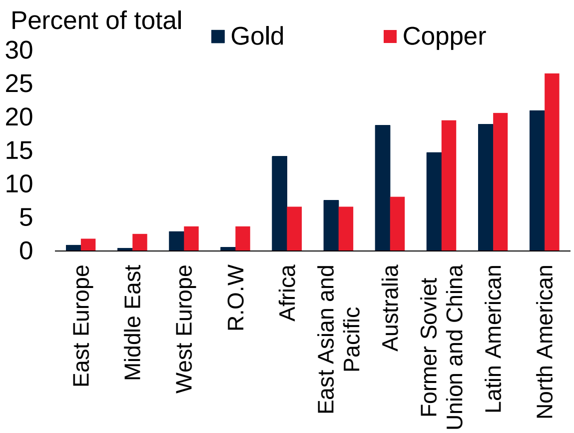


Source: World Bank Staff, MINEX Consulting,
B, C, D. Tiers refer to the size and quality of the deposit with Tier 1 deposits referring to the highest quality deposits based on criteria that include concentration of ore and size of find.

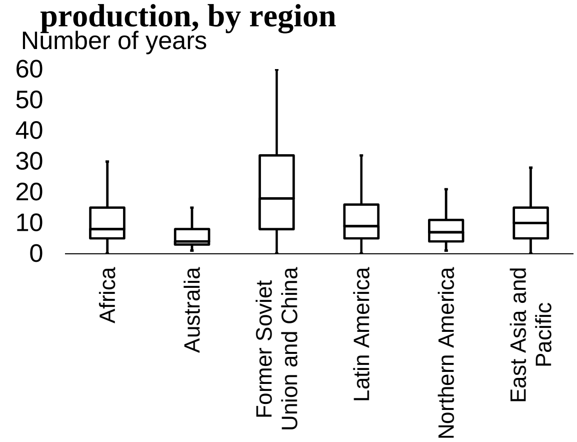
Figure 5. Gold and copper deposit discovery and extraction by region.

The largest number of discoveries in our data set are located in the Americas, Australia, Africa and among Former Soviet Union (FSU) economies and China. Among these regions/countries, the median time to production (after discovery) is lowest in Australia

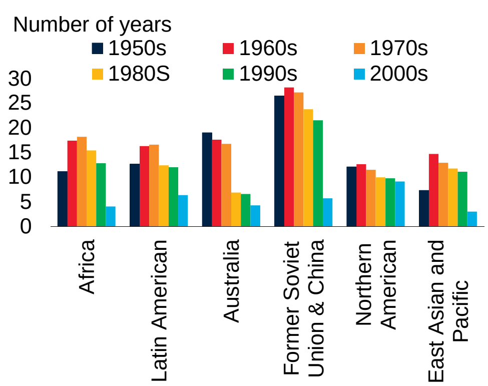
A. Distribution of discoveries



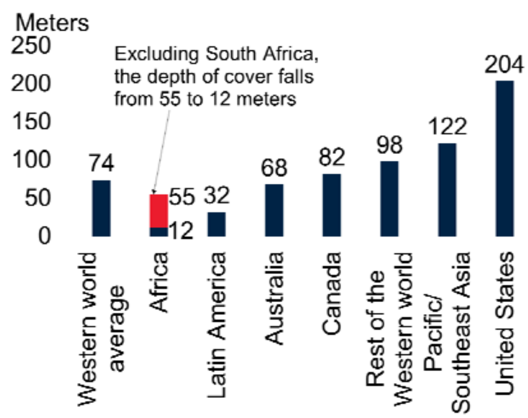
B. Number of years from discovery to production, by region



C. Lead times to production, by regions over time



D. Average depth of cover for discoveries, 2012



Source: World Bank Staff, MINEX Consulting, Soviet Union (FSU) economies and China (Figure 5). Among these regions/countries, the median time to production (after discovery) is lowest in Australia (6.4 years) and the highest in FSU economies and China (20.3 years).

The average lead time from discovery to production has fallen sharply across all regions over time (Figure 5), likely reflecting technological advances and the surge in global investment in the commodities sector over the last decade. Lead times to production were the lowest in Africa during the 2000s, possibly reflecting mining discoveries closer to the surface than in most other major regions and improvements in macroeconomic stability and political environments.

V. Factors determining lead times from discovery to production

Modeling lead times from discovery to production– non-parametric analysis

Lead times to production depend on a wide range of technical, economic, social, and political factors. They include the accessibility and quality of the discovery, commodity prices, and policy environments. Larger discoveries closer to the surface in more predictable policy environments appear to see faster development (World Bank 2015a). Higher commodity prices increase the feasibility of marginal projects, and could accelerate the start of development after discovery (Schodde 2014). Once started, however, sunk costs may make mining companies reluctant to disrupt ongoing projects, particularly if development is already well advanced (McIntosh 2015, Crowson 2011).[9]

Before showing the effects of the explanatory variables on the duration of time from discovery to production in a multi-variate regression setting, we relate various individual explanatory variables to the Kaplan-Meier (1958) maximum likelihood estimator which shows the probability of survival (S(t)) past time t. "Survival", in the context here, denotes an additional year without development. The estimator is non-parametric in that it makes no assumption about the underlying hazard distribution. For each unit of time interval, the survival probability is estimated from the cumulative probability of surviving each of the preceding time intervals given that an episode has lasted until that point.

$$\hat{S}(t) = \prod_{t_i < t} \frac{n_i - d_i}{n_i}. \qquad (1)$$

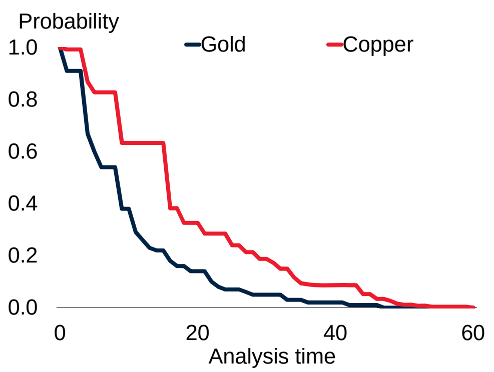
The Kaplan-Meier survivor functions suggest a significant difference between copper and gold mines, with copper mines likely to experience a higher probability of survival as undeveloped mines (i.e., a longer lead time to production) at any given points in time (Figure 6). The Kaplan-Meier functions also suggest that hazard rates (the probability that a mine gets developed at time t given that it has survived undeveloped up until that point) are not constant over time. The

[9] In general, the option value of delaying project completion may be lower in the resource sector than in non-resource sectors, due to a limited number of alternative feasible projects, and heavy involvement of the state, which provides some insulation from political shocks (Crowson, 2011).

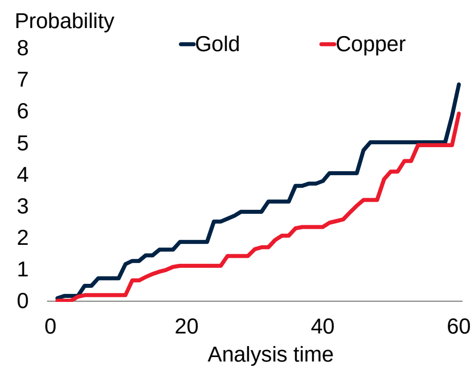
Figure 6. Kaplan-Meier (K-M) survivor and cumulative hazard functions, and bivariate analysis

The Kaplan-Meier survivor functions suggest that copper mines are likely to experience a longer lead time to production at any given point in time. Hazard rates (the probability that a mine gets developed at any point in time) are not constant. Countries characterized by fiscal surpluses, the absence of a credit boom, and democratic institutions experience shorter lead times to production as do high income countries.

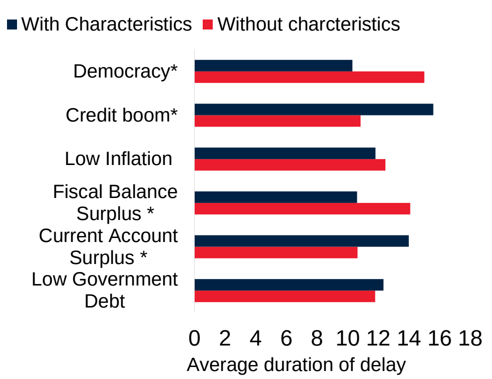
A. K-M survivor function curve, by type of deposit



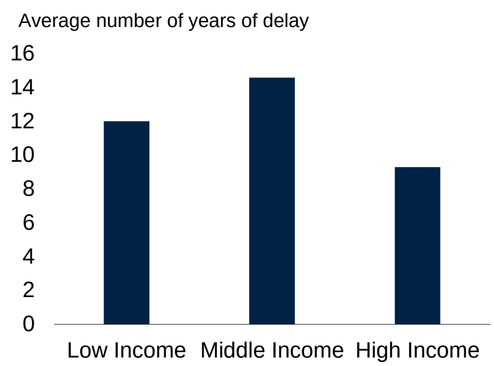
B. K-M cumulative hazard function, by type of deposit



C. Effect of country characteristics



D. Country income classification



Source: World Bank, MINEX Consulting, World Bank staff estimates
A, B. Copper = 1 indicates copper mines, copper = 0 indicators gold mines.
C. Low inflation is below 10% while low government debt is below 40% of GDP. Credit boom is defined as periods when percent of private credit out of GDP is at least 0.5 times standard deviation above mean. * Indicates statistical significant of the log-rank test of the difference at the 5 percent level.

D. Country income classification are defined by the World Bank, based on GDP per capita

cumulative hazard rate, for instance, for gold discoveries increases at an accelerating rate and then begins to taper off.

Next, we examine the Kaplan-Meier survivor functions based on policy, institutional or governance variables. From (1), using the sample with or without the characteristic of interest, we calculate the expected duration of non-development, captured in the Kaplan-Meier survivor function. Statistical significance is given by a log-rank test of the difference between the two estimated survival curves. Countries characterized by fiscal surpluses, the absence of a credit boom, and democratic institutions experience shorter lead times to production as do high income countries. The results are statistically uninformative for debt and inflation variables (although they are statistically significant in the multi-variate analysis that follows).

Modeling lead times from discovery to production– multivariate analysis

Thus far, we have examined individual country characteristics and their association with lead times to production. However, many of these individual country characteristics rarely occur in isolation. For instance, high credit growth rates are often associated with high inflation and high fiscal deficits. Controlling for different variables requires multivariate analysis. We do this by using parametric duration modeling techniques based on a standard accelerated-failure-time (AFT) specification (Jenkins, 2006), based on the gamma distribution. In AFT models, the natural logarithm of the survival time, log t, is expressed as a linear function of the covariates, yielding the linear model:

$$\log t_j = x_j \beta + z_j$$

where x_j is a vector of covariates and β is a vector of regression coefficients. The choice of z_j determines the regression method. Here, and based on the Akaike Information Criterion to evaluate the best fit across types of distributions, the standard generalized Gamma distribution appears to be most appropriate rather than the Weibull, lognormal and exponential distributions. [10] The highly flexible functional form is also appropriate given earlier indications that hazard rates are not constant over time.

The effects of the explanatory variables on the baseline are given by time ratios (the exponentiated coefficients). These are reported below for each explanatory variable. The magnitude of these time ratios denotes the factor by which the expected lead time to production would be shortened or lengthened by a one-unit change in a variable. A one-unit change in the variable changes the time scale by a factor of $\exp(x_j \beta)$. Depending on whether this factor is greater or less than 1, time is either accelerated or decelerated. That is, if a subject at baseline experiences a probability of survival past time t equal to $S(t)$, then a subject with covariates x_j would have probability of survival past time t equal to $S(t)$ evaluated at the point $\exp(x_j \beta)t$ instead.

The main explanatory variables x_i are measures for commodity prices (an indicator if prices are rising at time of discovery and the price change between discovery and production); indicators of the macro policy environment (dummies if public debt ratios are greater than 40 percent and inflation rates higher than 10 percent); and measures for governance, including the ICRG Index of Quality of Governance (as reported by the Quality of Governance Institute), and the World Bank Governance Indicator for control of corruption (Dahlberg et al 2015). By choosing all these explanatory variables at the time of discovery, i.e. before the lead time begins, concerns about reverse causality are attenuated.[14] Given that data on some of these variables (in particular, the governance variables) are not available for much of the 1980s (QOG) and the early and mid-1990s

[10] The generalized gamma distribution is the most generalized functional form, nesting the Weibull and the lognormal (Cleves et.al. 2010).

(governance indicator), the earliest available values are taken to indicate the quality of governance for discoveries that occurred prior to those dates. Control variables are the logarithm of the size of the discoveries, a dummy variable for copper deposits, and dummy variables for middle-income and low-income countries. In the absence of mine-specific information on the depth of the deposit over time (as the deposit is depleted), it is not possible to control for the ease of access to gold or copper directly. Country dummies proxy for unobserved characteristics like the landlocked nature of the country.[11]

A "good" policy environment conducive for resource investment—as well as non-resource investment—has many dimensions. It includes sound macroeconomic policies that ensure sustainable fiscal positions (as measured by government debt in percent of GDP at the time of discovery) and contain domestic demand pressures (as proxied by inflation at the time of discovery). A more stable macroeconomic environment can be associated with more predictable tax and expenditure decisions. A conducive policy environment includes high quality of institutions, at the time of the discovery, that affect mining operations. This is proxied by the World Bank Governance Indicators for Control of Corruption and by the QOG Institute's Index of the Quality of Government.[12] These are some of the same conditions that would help avoid the macroeconomic volatility and stunted growth in resource-based economies that has been labelled the "resource curse" (Sachs and Warner 2001; Mehlum, Moene and Torvik 2002; Humphreys, Sachs and Stiglitz 2007).

The regression in Column (1) in Table 1 shows that expected times to production are nearly twice as long for copper deposits, and similarly 30-40 percent higher in MIC and LIC countries. Column (2) shows that high levels of debt lengthen the lead time to production by 16 percent respectively. Higher inflation also lengthens the lead time (by about 8 percent) but the results are only marginally significant. On its own, the commodity price cycle measure is not statistically significant. However interacted with copper mine size, shows that copper mines tend to get developed faster when commodity prices are rising. These results are robust to the inclusion of additional variables in Columns (3) and (4). Finally, governance variables indicate that when governance improves (indicated by higher values of the corruption index), expected times to production fall by nearly 10 percent. The quality of government index is not statistically significant on its own, but when interacted with the variable indicating a copper deposit, shows that times to production of a copper mine fall by nearly 30 percent when governance improves.

The results suggest an important role for the commodity price cycle, sound macroeconomic management and the quality of governance. Higher commodity prices, on average, are not significant determinants of lead times, probably because of the significant sunk costs involved. However, for copper deposits, an upswing in copper prices at the time of discovery—the crucial

[11] Regression results are robust to the use of decadal dummies which could help control for the decelerating time to production since the 1950s.

[12] The importance of the policy environment is borne out in anecdotal evidence. For instance, the Oyu Tolgoi mine in Mongolia—despite being one of the largest copper deposits in the world—took nearly a decade to become operational in 2013, following initial exploration in the early 2000s, lengthy feasibility studies and negotiations between the government and Rio Tinto over the financing of the mine's construction.

Table 1. Duration regression of lead times

	Column (1)	Column (2)	Column (3)	Column (4)
Log(size of deposit, mt cu)	1.000	1.000	1.010	1.010
	0.770	0.900	0.660	0.610
Copper	1.74***	1.72***	1.74***	2.29***
	0.000	0.000	0.000	0.000
Comm. price upswing at discovery	0.940	0.950	0.950	0.990
	0.160	0.270	0.290	0.860
Comm. price upswing x Copper mine Size	0.91**	0.92*	0.930 †	0.910 †
	0.040	0.070	0.130	0.100
Comm. price change during lead time to production	1.00***	1.00***	1.00***	
	0.000	0.000	0.000	
LIC	1.33***	1.25***	1.020	1.260 †
	0.000	0.000	0.850	0.120
MIC	1.42***	1.33***	1.11	1.55***
	0.000	0.000	0.290	0.000
Debt>40%		1.16***	1.16***	1.38***
		0.000	0.000	0.000
Inflation>10%		1.080	1.080 †	1.010
		0.160	0.150	0.920
Corruption			0.92**	
			-0.020	
Quality of government				1.120
				0.630
Copper x Quality of government				0.710 †
				0.140
Non-linear interaction terms				
Copper x Comm. price upswing + Comm. price upswing	0.85**	0.87**	0.89**	0.9 †
Copper x Quality of government + Quality of government				0.79
Kappa	0.92	0.88	0.86	0.49
N	948	948	943	921
Log Likelihood	-1080.04	-1072.31	-1059.94	-1166.18
Akaike Information Criterion	2180.09	2168.61	2145.88	2358.36

Note: P-values are given below coefficient estimates. † indicates statistical significance at 15%, * at 10%, ** at 5%, *** at 1%. The Pagan-Harding measure of commodity prices is based on the Pagan-Harding algorithm (2002) which identifies turning points in a times series as local minima and maxima. These are used to identify up-cycles (when gold and copper prices are rising). Higher values of the Corruption indicator correspond to better outcomes (i.e. lower corruption) as do higher values of the ICRG Quality of Government indicator. As interaction terms are non-linear, the combined impact of these is shown separately.

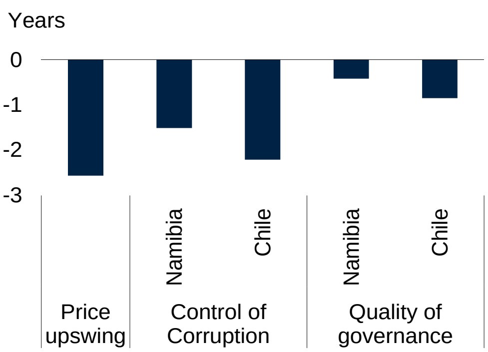
period when licenses are obtained and exploration and extraction rights negotiated—accelerates development. For example, in LICs since 2000, rising copper prices at the time of discovery may have shaved off about two to three years from lead times. For the largest quartile of copper discoveries in LICs since 2000, the price boom may have reduced lead times by 2½ years (Figure 4). Sound macroeconomic policies also appear to be important: lowering government debt below 40 percent of GDP accelerates development times by about 10 percent. These variables may proxy for generally sounder and more predictable macroeconomic policies.

While lower commodity prices could lengthen lead times for copper mines, their effects can be mitigated by strengthened policies. Had the average LIC had the same quality of government index or the same control of corruption index as Chile or Namibia, the lead times for the development of copper discoveries since 2000 might have been shortened by as much as two years (Figure 7).

Figure 7. Lead times between resource discovery and extraction

Lead times between discovery and production are considerably longer for copper deposits than gold deposits, especially when commodity prices are low. However, they can be shortened by improving business environments.

A. Scenarios: Reductions in lead times for copper mines



Source: World Bank staff calculations, MinEx Consulting.
Note: Reduction in average lead times for average LIC mine if price downturn shifts to price upswing, if control of corruption is improved to the level of Chile or Namibia, or if quality of governance was improved to the level of Chile or Namibia. Derived from differences in predicted values predicted by a duration model described in Section V. "Price upswings" denotes reductions in lead times for the largest quartile of copper discoveries in LIC since 2000 as a result of switching from a commodity price downturn to an upswing. Reductions in other variables for the same mines as a result of raising control of corruption and quality of governance to average levels prevailing in Namibia and Chile.

VI. Conclusion

Many low-income countries remain at the frontier of resource exploration and they are expected to be a major source of commodity supplies over the long-term (ICMM, 2012). Under the right conditions, new resource production should boost their exports and growth. With fiscal institutions in place to manage the volatility of resource revenues (World Bank 2015a), new resource production could provide a major opportunity for development over the medium to long term.

However, the sharp drop in commodity prices since 2014 is already affecting resource sector investments and could further delay the development of discoveries in several LICs. This, in turn, could prolong vulnerabilities—inflation, fiscal and balance of payments pressures—often associated with resource development as governments and private sectors borrow and invest in anticipation of future income growth. For the largest deposits, a price downturn in the early stages of development, when licenses and extraction rights are negotiated, could potentially delay development by a few years, which could be critical for some LICs with growing fiscal and current account pressures.

Countries in which resource development is still in initial stages could consider accepting further delays to contain vulnerabilities and reduce the long-term risk of stranded assets (Steven et. al. 2015). Where development is already far advanced, this option may be unattractive. In these countries, especially, improvements in business environments could offset some of the price pressures on resource development. At the same time, they would benefit non-resource investment and help reduce macroeconomic vulnerabilities (Loayza and Raddatz 2007). Other means of expediting resource developments are likely to be less helpful in the long-run, including increased tax incentives for mining companies. Mining companies have reportedly often negotiated tax exemptions that go above provisions specified in enacted legislation and are higher than warranted by mine profits (Curtis et al. 2009; Gajigo et al. 2012).

Overall, with one-third of the world's poor located in LIC countries (World Bank 2015c), their growth prospects are key to reducing global poverty. A robust policy environment can strengthen growth to levels that can make a clear dent in poverty. For commodity-exporting LICs, this includes policies that ensure that the growth potential from natural resources is used effectively: reducing regulatory hurdles, clarifying legislation and strengthening infrastructure. [13]

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