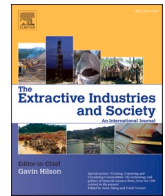




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Original article

Energy and the viability of downstream integration: Cross-country evidence from the copper industry

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ABSTRACT

Resource-rich developing countries have been increasingly pursuing downstream value addition to maximize the economic and political benefits of their mineral sectors. In light of policy initiatives to integrate mining with downstream industries, we examine the role of energy as a key factor in the viability of mineral processing. Using a cross-country panel dataset describing copper ore and refined copper production in 73 countries over 26 years (1990–2015), we estimate the impact of (i) industrial electricity prices, (ii) electricity generation and (iii) the time and cost to obtain an electricity connection on the size of local downstream activity. We also estimate the impact of these factors on a measure of downstream integration, defined as the share of refined copper in ore and concentrate sourced domestically, imported or recycled from scrap. We find that countries with greater levels of gross electricity production tend to produce higher levels of refined copper output. Downstream activity is also higher in countries where firms pay lower end-use prices of electricity. Among countries that produce ore, lower industrial electricity prices are associated with greater downstream integration.

1. Introduction

Recent global commodity booms have driven resource-rich developing countries to implement policies that promote forward linkages from their extractive sectors to their domestic economy. Seeking to capture more value from extractive production, states incentivize firms to process minerals into intermediate or semi-finished products locally as an alternative to exporting minerals in their unprocessed form (Bam and De Bruyne, 2017; Zhang et al., 2015). Countries use a combination of policy instruments that take the form of export taxes, quota and prohibitions, local content requirements, export licensing and permits schemes (Fliess et al., 2017a, 2017b). Some countries, like Indonesia and Zimbabwe, have imposed outright bans on the export of unprocessed minerals (Panggabean et al., 2013).

States implementing these policies view downstream integration as an opportunity to maximize the economic and political benefits of their mineral sectors. To developing countries, a large downstream sector can help their economies graduate from an enclaved structure where reliance on commodity exports renders them vulnerable to global commodity price cycles and external demand shocks (Ramdoo, 2013). Beyond diversifying the domestic economy, states assert that linkages of domestic industries to mineral extraction can drive job creation, enable

technology transfer, and spur manufacturing growth (Adewuyi et al., 2012; Bloch and Owusu, 2012; Fessehaie, 2012; Morris et al., 2012; Teku, 2012).

While the policy goals driving downstream integration have reasonable basis, outcomes from the recent implementation of such policies in developing countries have been mixed (Bam and De Bruyne, 2017). In a study on local value chains of industries in four African countries, Fliess et al. (2017b) do not find evidence that export restrictions promote downstream processing in copper, chromium, manganese and lead industries.

As more countries design and implement policies to foster beneficiation, there is a growing need for evidence that can guide policymaking in these areas (Morris et al., 2012; Bam and De Bruyne 2019). In particular, governments with large mineral sectors must anchor their decisions on credible evaluations of the viability of downstream processing in their country, as well as the associated risks of linking extractive sectors with downstream markets.

While existing work has broadly identified the economic prerequisites of downstream integration (United Nations Department of Technical Cooperation for Development, 1984), there has been little empirical work on the relative importance of critical infrastructure in the viability of mineral processing across countries. To fill this gap, this

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paper examines the role of energy in the viability of downstream integration in the copper industry. Using a cross-country panel dataset describing the production of refined copper and copper ore, we examine whether indicators of the cost and availability of electricity are related to the size of local processing activity and the degree of downstream integration. In particular, we estimate the relationship between the amount of refined copper produced by a country and three electricity-related variables: (i) industrial (end-use) electricity prices, (ii) the amount of electricity generated, and (iii) the time and cost to obtain a permanent electricity connection. We also test whether these same variables affect a measure of downstream integration defined as the share of locally processed output (refined copper) in total inputs (both copper concentrate and scrap). Here, we make a distinction between measures of the size of processing activity and downstream integration because there are cases where extraction and processing are not directly linked within a country. A country that produces refined copper does not necessarily source its inputs from its own extractive sector.

To estimate the relationships described above, we assemble a cross-country dataset describing copper ore and concentrate production over time. Overall, we find that countries with lower industrial electricity prices and greater electricity generation tend to produce more refined copper. Countries successful in integrating their downstream markets with their extractive sectors tend to have access to lower industrial electricity prices.

This paper is organized as follows: [Section 2](#) describes the global distribution of extractive activity in the copper industry with a focus on the global demand, production and supply chains. [Section 3](#) surveys the literature on linkages and industrial development in the development economics literature with a focus on forward linkages in the extractive sector. [Section 4](#) describes the conceptual framework and the empirical framework. [Section 5](#) outlines the data sources and relevant descriptive statistics. [Section 6](#) discusses the results of the estimation and [Section 7](#) concludes with policy implications and directions for future research.

2. The global copper industry

In this section, we provide an overview of the global copper industry and the components of the international copper supply chain. We also highlight trends in global demand and supply.

2.1. Demand for copper: applications and end-uses

Behind iron and aluminum, the market for copper is one of the largest of all metals with the value of refined copper consumption at 150 billion USD in 2013 ([Kabwe and Yiming, 2015](#)). As a metal with desirable chemical and physical properties, copper has a wide range of industrial and high-technical applications from electrical and electronic products to commercial and residential construction, industrial machinery and transportation.¹

Globally, copper demand has entrenched markets in major sectors in energy, transportation, telecommunications and manufacturing ([International Copper Study Group, 2017](#)). [Table 1](#) reports that electrical and electronic products, including power cables, account for over a third of total usage. Construction accounts for a similar share. Transport industries use roughly 13 percent of the total, industrial machinery and equipment nearly 11 percent, and the residual being used as a consumer and other products. In the United States, building construction accounts for over forty percent of copper and copper alloy usage with electronic products and transportation equipment accounting for 19 percent each

Table 1

Share of applications by End-use sector.

End Use Sector	Global Share (%)
Electrical and electronic products	31
Building construction	29
Infrastructure	16
Transport	13
Industrial	11

Source: ([International Copper Study Group, 2017](#)).

Table 2

Historical global demand for copper (in million tonnes).

Year	Global Demand for Copper (in million tonnes)
1960	3.7
1970	6.8
1980	9.0
1990	10.9
2000	15.1
2005	16.5
2010	19.1
2015	21.8

Source: ([International Copper Study Group, 2017](#)).

([U.S. Geological Survey, 2017](#)).

The global demand of copper has increased threefold in the last half century (See [Table 2](#)). It has increased from 3.7 million tonnes in 1960 to 16.5 million tonnes in 2005. It is co-cyclical with capital expenditure on construction and infrastructure, and with spending on automobiles and consumer durables. The annual average rate of growth is 3.1 percent, but with marked annual and geographical variations ([International Copper Study Group, 2017](#)). Global demand for copper metal produced from refined copper and recycled scrap is projected to increase 4.2 percent per year through 2019 to 36.0 million metric tons, valued at 261 billion USD. [Table 2](#)

Global consumption patterns of copper have shifted in the past three decades. Rising income levels in China, India and other countries in the Asia-Pacific has reconfigured sources of global demand. In 2014, China's demand for copper accounted for more than two-fifths of the global demand. Similarly, India accounts a large share of the global copper metal market due to investments in construction driven by the expansion of its urban population and government infrastructure projects ([The Freedonia Group, 2015](#)).

As China, India, and other emerging economies urbanized and increased their investments in infrastructure, power, and transportation, the services sector in the United States and Western Europe continued to grow, as well as their reliance on foreign manufacturers of primary commodities. In the 2000s, the main markets driving copper demand moved from the United States, the European Union and Japan to Asia-Pacific ([The Freedonia Group, 2015](#)).

2.2. Global production of copper

Similar to global consumption, patterns of global production have also shifted in the past half century ([Humphreys, 2013](#)). In 1960, Central and South America produced less than 750,000 tonnes of mined copper, comprising 19 percent of world production. In 2016, production has increased to 8.3 million tonnes, representing 41 percent of the global amount (See [Table 3](#)).

In 2016, Chile and Peru were the leading regional suppliers of mined copper and concentrates. Chile accounted for almost one-third of world copper production with an output of 5.55 million tonnes of copper in 2016. Peru, which led the surge of copper production in Latin America in the 1990s, produced an estimated 2.3 million tonnes in 2016. To date, the largest copper mines are located in Chile and Peru, with six of the world's ten largest mines located in Chile ([International Copper Study](#)

¹ Copper exhibits high electrical and thermal conductivity, and anti-corrosive and antimicrobial properties. Copper is known for its superior electrical conductivity, second only to silver. When alloyed with other metals such as zinc, tin, or nickel, copper's value and versatility only increases.

Table 3
Global production of copper by region, 1960 and 2016.

Region	Share of Global Production (%)	
	1960	2016
North America	36	15
Europe	11	12
Asia-Pacific	6	18
Central and South America	19	41
Africa	25	9
Oceania	3	5

Source: (International Copper Study Group, 2017).

Group, 2017).² Table 3

Likewise, Asia-Pacific has also exhibited significant growth from 6 percent in 1960 to 18 percent in 2016. China is the third largest producer of mined copper with 1.74 million tonnes, after Chile and Peru. Indonesia, Russia, Kazakhstan, Mongolia, Laos are ninth, eleventh, twelfth, fourteenth and seventeenth largest producers, respectively. The second largest mine in terms of capacity is Grasberg in Indonesia, owned by Freeport Indonesia and Rio Tinto (International Copper Study Group, 2017).

China is also the largest producer of copper smelter output and refined copper production, as well as blister and anode. China accounts for almost a third of world copper smelter production, with Japan and Chile accounting for eight percent each and Russia at five percent (International Copper Study Group, 2017).³

2.3. The copper global supply chain

Extracted copper from naturally occurring ore bodies undergoes a series of processes to render it suitable for use. First, copper mined from copper-bearing ores is converted into concentrate. Second, concentrates are used as sources of feed for smelters to produce copper blister and anodes which are in turn, fed into refineries to produce copper cathodes. As refined copper, cathodes can either be directly sold in the market or melted or cast into shapes such as billets and cakes for easier processing. These cathodes and shapes are the major raw materials for manufacturers of semi-fabricated products. Finally, these products are transformed into cables and tubes or into semi-finished products which are further processed downstream as copper sheets or strips (European Copper Institute, 2018).

Copper is also one of the few metals where recycling plays a substantial role in the industrial chain. Scrap from products discarded in semi-fabrication or copper alloys derived from end-of-life products can be used as sources for smelters and refineries. Copper scrap and copper-containing products are routinely imported to supply chains to be processed and used as new products which are in turn exported back to global supply chains for consumption.

In the 1940s through the 1960s, copper supply chains in developed countries were generally vertically integrated as in the United States. Because the cost of transporting ores were prohibitive at that time, company mine ores supplied its domestic smelters and refineries.⁴ With falling transportation costs and more stringent environmental regulations, supply chains have increasingly fractured across countries with mining and processing activities occurring in different geographic

² Escondida mine, located in the Atacama Desert in Chile's Antofagasta Region, tops the list with a capacity of 1.2 million metric tons of copper, nearly twice the capacity of the world's second-largest copper mine, located in Indonesia.

³ Fossil fuel subsidies play a key role in China's competitiveness in smelting and other segments of the value chain, especially in the aluminum sector and other electricity-intensive sectors (OECD 2019).

⁴ During most of the post WWII period, the U.S. copper industry has had only three major producers: Anaconda, Kennecott, and Phelps Dodge.

Table 4
Copper supply chain.

	Process	Product	Illustrative Producers
Raw Material	Mining	Copper Ore	
Extraction	Concentration	↓ Copper concentrate	Chile (Codelco); Peru (Freeport-McMoRan); Zambia (Barrick Gold); Australia (BHP)
Raw Materials	Smelting	↓ Blister, anode	China (Jiangxi)
Processing	Refinery	↓ Refined copper cathode	Chile (Codelco)
	Fabrication	↓ Semi-finished copper and copper alloy products	Germany (Wieland)
Product	Manufacturing	↓ Cast into wire, rods, tubes, sheet, strips	Belgium (Aurubis), Austria (ASTA)
Recycling			

Source: European Copper Institute (2009).

locations (Kaplinsky, Morris, and Kaplan, 2011). From a vertically integrated structure, mining companies have outsourced processing to independent firms that have the requisite physical capital, including knowledge and high-technology inputs (Urzúa, 2011).

Generally, mining companies operating in copper-producing countries export concentrate to countries where downstream capacity exceeds upstream copper production capacity. In 2016, China, imported most of its copper concentrates from Chile, Peru and Australia. Asia-Pacific was also a significant source of copper concentrates. China, as a major hub of manufacturing, exports copper-containing products to the United States, the European Union and Japan. Table 4 illustrates a simplified diagram of the copper value chain.

3. Literature review

In this section, we review the literature on linkages and industrial development and discuss the arguments for and against forward linkages in the extractive sector. We also highlight recent studies that examine the determinants of downstream integration policies in the minerals sector and the location decisions of mineral companies.

3.1. Downstream integration and linkage theory

For resource-rich developing countries, participation in the global supply chain has historically been limited to raw material production. Developing countries endowed with mineral deposits have traditionally been exporters of commodities, including raw minerals. In the 1970s, many of these commodity-exporting countries were not involved in the processing of final products. In 1977, in particular, developing countries accounted for 20 to 30 percent of mineral processing capacity (United Nations Department of Technical Cooperation for Development, 1984). The 1984 UNCTAD special report on the mineral sector observed that several resource-rich economies in Africa, Latin America and Asia were pursuing downstream beneficiation as a strategy to accelerate growth. These countries either mandated or promoted the processing and manufacturing of useable products with the intention of linking extractive sectors to domestic value chains.

While the origins of beneficiation as a policy can be traced to the mercantilist era (Humphreys, 2013), the literature generally views beneficiation policy today through the lens of linkage theory developed by economists in the 1950s (Hirschman, 1958; Fleming, 1955). Here, linkages and strategic complementarities between industries play a key role in growth and industrial development (Krugman, 1992). In particular, two 'inducement mechanisms' allow countries to overcome

development obstacles. First, domestic production in an industry induces demand for inputs and create profit opportunities in upstream industries, resulting in increased private investment by suppliers in a variety of sectors ('backward linkages'). At the same time, increased production creates downstream industries that use the output that does not go to final demand ('forward linkages'). Linkages arise when industries are able to reduce the costs of its potential users, pushing them over the threshold of profitability.⁵

Linkage theory also provides a theoretical basis for the kinds of industrial policies implemented by developing countries with large extractive sectors. Because public investments in industries linked to the domestic economy have greater potential to impact growth, early policy prescriptions involved investments in industries with the most linkages and the formation of robust input markets.⁶ At the time, targeted state investments in strategic industries stood in stark contrast to policy strategies that sought economy-wide investments to achieve industrialization (Rosenstein-Rodan, 1943, 1961).

The recent literature has identified three benefits to linking extractive sectors to domestic value chains. First, it spurs resource-based industrialization (Ramdoo, 2015). For this reason, downstream beneficiation policies are almost always accompanied by efforts to build a solid industrial base. As part of national industrial policies, governments seek to develop clusters of manufacturing activities that use inputs from the extractive sector. To emerging economies, manufacturing products from raw minerals is a logical route to complete value chains.

Second, linkages reduce an economy's dependence on consumer and capital goods, including capital and technology sourced externally. Economies that heavily rely on export earnings from unprocessed minerals are vulnerable to global commodity price cycles and external demand shocks in developed economies (Ramdoo, 2013). By pursuing value-addition, an economy can diversify its portfolio of products generated within the local economy and enter new export markets, resulting in a current account more resilient to shocks that normally confront enclave economies (Kaplinsky et al., 2011; South Africa Department of Trade and Industry, 2014). As processed minerals are higher value products, intermediate or semi-final products can either be purchased by domestic firms or sold to the international market (Ramdoo, 2013).⁷

Third, linkages develop an economy's national capacity in terms of employment. Because exporting raw minerals offers limited local participation in the sector in terms of employment, downstream beneficiation can boost employment and provide spillover benefits through technology transfer to related industries. Aside from directly creating jobs, downstream integration spurs demand for skills in sales, trade and marketing of products which are transferable to other sectors. Many countries also justify downstream integration on social and national security grounds. Value addition can safeguard domestic supplies and protect the local manufacturing industry from foreign competition (Fliess et al., 2017a).

While the benefits of linkages in commodity sectors have been well articulated in the literature, there is no clear consensus on whether pursuing downstream integration in extractive industries is the optimal strategy to accelerate development for emerging economies. Some scholars argue that implementing beneficiation via local content policies can facilitate political patronage mechanisms and rent-seeking (Lange and Kinyondo, 2016) and deter foreign investment (Qiu and Tao, 2001). Others are broadly skeptical of beneficiation as a developing strategy.

⁵ In Fleming's model (1955), forward linkages arose from vertical external economies which occur when intermediate goods are produced subject to scale economies.

⁶ Hirschman (1958) referred to this growth strategy as the 'unbalanced growth hypothesis'.

⁷ Refined products weigh less and take up less space than raw commodities, hence lower transport costs.

For example, (Hausmann et al., 2008) are critical of beneficiation policies based on evidence that forward linkages have a smaller effect on patterns of production and structural transformation relative to the traditional factors that drive comparative advantage (e.g. factor intensities, technological requirements and other capabilities).

Recent empirical work has also pointed to the suboptimality of downstream beneficiation relative to alternative policies. For instance, Morris, Kaplinsky and Kaplan (2012) review several country experiences with linkage development in the mineral sector and find that compared to downstream (forward) linkages, upstream (backward) linkages predominantly provide "important and unrealized potential for industrial development in many resource-producing economies". Using an input-output product space analysis, Bam and De Bruyne (2019) evaluate the optimality of beneficiation as an industrial policy and find that when the unit of analysis is set at the level of product categories, targeting specific downstream activities that contribute to development (what they call a 'leap-frogging' approach) is superior to a strict beneficiation approach.

3.2. Empirical work on linkages in extractive sectors

The resurgence of downstream integration policies in the minerals sector has reinvigorated research in two related areas: one, linkages in extractive sectors and their determinants and two, the location decisions of mineral companies. Many studies in the latter area dovetail work in the broader literature on location decisions of manufacturing firms where costs, infrastructure, labor characteristics and government and political characteristics emerge as the key set of factors that influence location decisions of multinationals (De Bruyne, 2006).

The 1984 UNCTAD special report on the mineral sector was among the earlier studies that examined the viability of mineral processing and downstream development. The report outlined technical, economic and structural elements that enable mineral processing. Economic elements refer to capital, skilled labor, raw materials, complementary inputs, energy, economies of scale, technological growth, growth in demand, proximity of export markets, and transport costs while structural elements refer to sources of finance and technology, trade, investment and taxation policies. More recent studies explicitly look at factors driving downstream processing: Barbero et al. (2018) look at the role of market size, Wu and Yang (2018) examine transportation costs in the steel industry while Aguilar (2009) assesses cost advantages, available labor and road access in the lumber industry.

Focusing on downstream activity in the mining sectors, Östensson and Lof (2018) argue that vertical integration is primarily determined by technology and transport costs with trade barriers and corporate strategies playing a limited role. Overall, proximity to raw materials is insufficient to ensure that processing occurs.

De Bruyne (2006) provides a useful framework to organize existing theories explaining firm locational decisions. This framework makes a distinction between first-nature and second-nature theories: First-nature theories refer to exogenous factors underpinning neo-classical trade theories. Under neoclassical trade theory, firms locate in countries endowed with factors of production such as raw materials or skilled labor force. Thus, comparative advantage, whether driven by technology or relative factor intensity, drives firm location decisions.

Second-nature theories highlight the role of external economies in driving firm location. If positive externalities from complementary firms outweigh the costs from congestion, firms will tend to form clusters of economic activity. Here, the key factors are distance to suppliers of intermediate goods and the final market, the presence of intermediate suppliers and the size of the final market. Second-nature factors are generally endogenous variables. For instance, firms might locate in countries with large domestic markets or near economies with large markets.

While the literature on firm location decisions in the mineral sector has been gaining traction in recent years, Bam and De Bruyne (2017)

find that existing work does not adequately explain the presence or absence of downstream linkages in a country's extractive sector. In their survey of the field, they find that linkage theory has historically been "more descriptive than explanatory in nature" (Bam and De Bruyne, 2017).

4. Conceptual framework and empirical strategy

The theoretical foundation of this analysis is based on the multinational firm's decision to fragment stages of its supply chain based on where that particular stage can be performed most efficiently. In the search for the optimal location of a specific task, the multinational firm considers a host of factors that affect its costs. In particular, it evaluates the state of its technology (e.g. information and communication technology), transportation costs and distance to export markets and existing plants, as well as business regulations and policies in a given location. For example, a multinational mining firm may choose to locate processing activity in a country based on its cost of electricity or the availability of regional transportation networks that allow it to fulfill contracts and meet delivery schedules. The firm compares the costs of performing a given task (e.g. converting concentrate to copper) across different locations.

As observed by Östensson and Lof (2018), if all locations were equally attractive from the firm's vantage point, processing firms would locate as close as possible to the mine or the site of the extraction (or alternatively, as close as possible to the final consumers). Because processed products are lighter than raw materials, firms incur less costs if raw materials were processed in local facilities and then consumed domestically or exported to global markets. On the other hand, if energy costs are prohibitive in the country where extraction takes place or if its business climate is generally unfavorable, then the firm may choose to fragment its supply chain and instead locate processing where it will be more efficient.

4.1. Empirical framework

To analyze the impact of the cost of electricity on downstream production and the extent of downstream integration, we estimate three models using a country-level dataset combining primary and secondary copper production, electricity production, electricity prices and proxies of the costs of securing an electricity connection. In selecting the control variables, we draw on existing reviews of factors that affect the viability of processing activity (De Bruyne, 2006).

4.2. Model 1: production of refined copper, electricity prices, and electricity generation

First, we test whether the cost and availability of electricity influences the production of refined copper. Eq. (1) describes the baseline specification for Model 1:

$$y_{it} = \alpha_0 + \delta p_{it} + \gamma g_{it} + \alpha_1 n_{it} + \alpha_2 m_{it} + \alpha_3 s_{it} + \beta' X_{it} + k_i + \varepsilon_{it} \quad (1)$$

where i and t represent countries and years, respectively. The term α_0 is the intercept. The term y_{it} represents the output of refined copper in metric tons. The regressors of interest are industrial electricity prices p_{it} , measured in US cents per kilowatt hour, and electricity production g_{it} measured in terawatt-hours. We expect δ to be negative and γ to be positive.

We control for the availability of raw materials sourced domestically, imported or recycled from scrap. The term n_{it} represents domestic production of copper concentrate, m_{it} represents imports of copper concentrate and s_{it} represents imports of scrap. Like refined copper, these variables are expressed in metric tons. Unobserved time-invariant country characteristics that vary with refined copper production are captured by country fixed-effects k_i while ε_{it} is an error term that rep-

resents all other unobserved factors.

The term X_{it} is a vector of country-level macroeconomic and institutional controls which include the following: (i) country i 's industry value added as a percentage of GDP, (ii) country i 's percentile rank in the Government Effectiveness and Regulatory Quality component of the World Bank's Worldwide Governance Index (WGI), (iii) an index of the real effective exchange rate for country i (base year 2010) which controls for price competitiveness due to relative currency differences and (iv) a measure of transport costs sourced from the UNCTAD Global Transport Costs Dataset for International Trade which estimates bilateral transport costs for specific commodities. All control variables enter the regression individually and all variables vary over time with the exception of the index of global transport costs for ore and concentrates. Table 5 provides detailed definitions of the variables in the model and Section 5 elaborates on the construction of these variables.

4.3. Model 2: production of refined copper, time and cost of accessing electricity

The second model tests whether the time and cost to obtain an electricity connection has an effect on the production of refined copper, controlling for the same set of control variables as in Model 1. Eq. (2) describes the baseline specification:

$$y_{it} = \alpha_0 + \lambda h_{it} + \varphi c_{it} + \alpha_1 n_{it} + \alpha_2 m_{it} + \alpha_3 s_{it} + \beta' X_{it} + k_i + \varepsilon_{it} \quad (2)$$

where i and t represent countries and years, respectively. The regressors of interest here are (i) the time required to complete procedures measured in calendar days h_{it} , and (ii) the cost required to complete the same procedures c_{it} expressed in USD. We expect λ and φ to be negative. All other terms here represent the same variables described in Table 5.

4.4. Model 3: share of refined copper in total inputs, electricity prices and generation

The third model estimates the impact of the same set of regressors on the extent of downstream integration. To measure the degree of downstream integration, we calculate a ratio D_{it} defined as the share of refined output in total input:

$$D_{it} = \frac{y_{it}}{n_{it} + m_{it} + s_{it}} \quad (3.1)$$

The numerator in Eq. (3.1) is the amount of refined copper output and the denominator is the sum of ore and concentrate production whether sourced domestically or abroad, including scrap. Östensson and Lof (2018) use a similar ratio as an indicator of geographic vertical integration wherein processing takes place in the same location or country. We include imports of copper concentrate and scrap in the denominator to account for the possibility that countries source their raw materials from abroad and not from domestic mines. In other words, this measure of downstream integration reflects the fact that copper value chains are fragmented across countries.⁸

With this measure, we can now estimate a model with the share of processed output in total inputs as an outcome variable. Eq. (3.2) describes the baseline specification for Model 3:

$$D_{it} = \alpha_0 + \gamma g_{it} + \varphi c_{it} + \beta' X_{it} + k_i + \varepsilon_{it} \quad (3.2)$$

where i and t represent countries and years, respectively. As the measure of downstream integration D_{it} is calculated from the ratio of refined copper to copper concentrate, we exclude the terms n_{it} , m_{it} and s_{it} which represent production inputs in country i . All other terms are

⁸ An alternative measure calculates the same variable with respect to ownership (where downstream facilities have the same corporate owner as upstream ones) but data availability constraints calculation of this variable.

Table 5

Variable definitions.

Variable (Source)	Units	Definition
<i>Regressors of interest (Source; Relevant years)</i>		
Industrial electricity prices at constant <i>ppp</i> prices (Enerdata; 2000-2015)	usc/kWh	End-use prices paid by large consumers in the industrial or manufacturing sectors purchasing energy in the wholesale market, reported in U.S. cents per kilowatt-hour, at constant purchasing power parity terms and reflect taxes paid
Electricity net generation (Enerdata; 1990-2015)	TWh	Gross electricity production including public production by private and public electricity utilities and auto producers, covering all types of power plants
Getting Electricity – Time (World Bank Getting Electricity Survey; 2004-2015)	days	Median number of calendar days it takes a firm to complete all procedures to obtain an electrical connection, assuming completing the entire process with minimum follow-up and no extra payments
Getting Electricity – Cost (World Bank Getting Electricity Survey; 2004-2015)	USD	All fees and costs needed to complete a procedure to connect a warehouse to the electricity grid, exclusive of value added tax and bribes
<i>Control variables</i>		
Industry, value added (% of GDP) (World Bank; 1990-2015)	percentage	Net output of mining, manufacturing, construction, electricity, water, and gas after adding up all outputs and subtracting intermediate inputs. Calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources. Measures the value of a currency against a weighted average of several foreign currencies divided by a price deflator or index of costs
Real effective exchange rate (indexed at 2010) (World Bank; 1990-2015)		
Worldwide Governance Index – Government Effectiveness (World Bank; 1990-2015)	percentile	Captures perceptions of the quality of public services, quality of the civil service and degree of its independence from political pressures, quality of policy formulation and implementation, and the credibility of the government's commitment to such policies
Worldwide Governance Index – Regulatory Quality (World Bank; 1990-2015)	percentile	Captures perceptions of the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development
Unit transport costs related to bilateral trade (UNCTAD/World Bank Global Transport Costs Dataset for International Trade, 2016 – assumed constant in data)	USD	Monetary price charged to transport a commodity from the exporting country to the importing country; calculated as average of exporting country's transport cost across all ores and concentrates (HS 2603)

defined as in Models 1 and 2.

4.5. Estimation approach

Because there are unobserved factors that likely influence the size of downstream production and the extent of downstream integration, the appropriate estimation approach must be able to partial out the effect of time-invariant characteristics to consistently estimate the effect of the regressors of interest. This approach must account for the possibility that unobserved country-level factors such as policy changes vary with either

electricity production, electricity prices or other proxies of electricity costs. Estimations that fail to account for this possibility will result in biased estimates of the effect on the size and extent of downstream integration.

For these reasons, we employ two approaches to estimate Eqs. (1), (2) and (3): First, we use a fixed-effects (FE) estimator that exploits country variation in copper production over time and second, a Hausman-Taylor estimator (1983) which is a two-step transformed random effects (RE) estimator. Unlike the FE estimator which only provides consistent estimates for time-varying regressors, the Hausman-Taylor estimator captures the effects of the time-invariant measure of transport costs which drop out in a fixed-effects estimation.⁹ The FE estimation assumes that any unobserved time-invariant characteristics are unique to each country and are uncorrelated with other individual characteristics. In contrast, the Hausman-Taylor estimator requires that some of regressors are uncorrelated with the fixed effect term and that all regressors are uncorrelated with the idiosyncratic error term.

5. Data sources and summary statistics

The assembled dataset tracks refined copper production covering 73 countries from 1990 to 2015. We also draw from a number of sources that collect macroeconomic and governance indicators at the country level. This section describes sources in detail, the measurement issues that arise, and construction of the key variables.

5.1. Copper production: domestic production, imports of ore and scrap

Data on copper production is sourced from the United States Geological Survey (USGS) Minerals Yearbook. The USGS provides historical country-level data on the current use and flow of minerals and mineral-based materials collected through annual questionnaires, mineral industry publications and company reports. We are interested in the production of concentrates, leaching and electrowon copper (referred to as Group 1) and refinery production including electrowon copper (Group 2). Refined copper is obtained from unrefined copper or scrap and is derived via pyrometallurgical or electrolytic refining methods.

Figures on copper ore, concentrate, and scrap metal imports are drawn from the UNCTAD COMTRADE database which reports trade value and volume in metric units. In particular, we use the 6-digit HS commodity code 260300 to identify trade flows of copper ores and concentrate.

5.2. Industrial electricity prices and total electricity production

The most important feature of the dataset is the inclusion of historical annual data on industrial electricity prices compiled by *Enerdata*. We use end-use prices paid by large consumers in the industrial or manufacturing sectors purchasing energy in the wholesale market. Information on energy prices and taxes are collected from country statistical offices and government agencies including national energy ministries and central banks.¹⁰ The prices are reported in US cents per kilowatt-hour at constant purchasing power parity (*ppp*) terms and reflect all taxes paid. As a result, these prices are readily comparable across countries.

⁹ In particular, the *within transformation* wipes out the effect of any time-invariant variables. When time-invariant variables are included in a fixed effects model, they drop out as they are perfectly collinear with the fixed effects. The Hausman-Taylor estimator recaptures these effects and is more efficient than the within estimator.

¹⁰ Depending on the price-formation mechanisms in place in a country, annual average end-use prices may be calculated based on price revisions or on price monitoring systems, i.e. utility company surveys. The International Energy Agency (IEA) describes country-specific methodology.

Enerdata also provides data on gross electricity production in a country, including public production by private and public electricity utilities and auto producers. Production encompasses all types of power plants.

5.3. Time and cost to obtain an electricity connection

To measure access to electricity, we use two indicators from the World Bank Doing Business Survey on Getting Electricity which measure the time and cost of complying with all procedures to obtain a new electricity connection. The first indicator captures the median duration it takes a firm to complete all procedures. In particular, it measures the number of calendar days necessary to complete the entire process with minimum follow-up and no extra payments. The World Bank relies on data from electricity distribution utilities which is then verified by electricity utility regulators and experts.¹¹

The second indicator measures the cost to obtain an electricity connection. Costs refer to all fees and costs needed to complete a procedure to connect a warehouse to the electricity grid, exclusive of value added tax and bribes. Sources of costs are gathered from local experts and fee schedules and regulations from different local government agencies. The original indicator is expressed as a percentage of income per capita of the country but we express this measure in USD by multiplying it by GNI per capita in the assembled dataset.

While the indicators from the Getting Electricity survey are measured under narrow assumptions, they serve as suitable proxies for the performance of a country's electricity sector.¹² Greater time and cost to get an electricity connection are correlated with lower electrification rates (Geginat and Ramalho, 2015). Moreover, additional connection procedures are more likely to occur in economies where the electricity supply is weak as a result of high losses in the transmission and distribution systems.

5.4. Governance and regulatory quality measures, macroeconomic variables

Perception indices measuring government effectiveness and regulatory quality are sourced from the World Bank's Worldwide Governance Indicators (WGI) which aggregate individual data sources to construct a broad measure of governance comparable across countries and over time. We use standardized scores that range from -2.5 to 2.5 with zero mean and unit standard deviation.

All macroeconomic variables – per capita gross domestic product, the real effective exchange rate index and industry value added – are sourced from the World Development Indicators (WDI) dataset. Industry value added captures the net output of all industries and is expressed as a percentage of GDP. Industry here refers to all sectors belonging to ISIC divisions 10-45, including manufacturing, mining, construction, electricity, water and gas.

5.5. Unit transport costs and other variables

We obtain a measure of global unit transport costs for all ores and concentrates (HS26) from a recently developed dataset from UNCTAD and the World Bank. The dataset measures transport costs across five

modes of transport (sea, air, railway, road and others) for traded commodities between exporting countries (origin) and importing countries (destination). The dataset was constructed using a transport-costs model and a specific quantity-value model to impute missing quantity values.¹³

We calculate a country-level unit transport cost for ore and concentrate (in nominal USD) by taking the mean of all the bilateral cost pairs for a single exporting country. While unit transport costs are only available for the year 2016, it serves as a suitable proxy for the costs a mining or processing firm will incur to ship materials across borders.

5.6. Summary statistics

Table 6 reports descriptive statistics for a wide country sample by income group.¹⁴ Panel A compares the production of copper across countries. Panel B reports statistics for the regressors of interest: electricity prices, electricity production, time and cost to access an electricity connection. Panel C contains the macroeconomic and institutional variables including ratings on government effectiveness and regulatory quality. The share of refined copper in primary inputs is reported in Panel D.

High-income countries produce, on average, more copper concentrate relative to upper-middle, lower-middle and low income countries. While high-income countries also produce the most refined copper, upper-middle income countries import the most ore and concentrate and the most scrap. Firms in industrial and manufacturing sectors in lower-middle and low-income countries face the highest electricity prices, closely followed by high-income countries. Electricity generation in lower-middle and low income countries is well below the average gross production in high and upper-middle income countries. Firms in high-income countries take the least days to obtain an electricity connection with firms in lower-middle and low-income countries taking the most days to successfully secure a permanent electricity connection. Notably, the cost to comply with the procedures to access a connection is significantly higher in lower-middle and low income countries.

5.7. Measures of downstream integration

In the sample of 73 countries that produce either refined copper or copper ore and concentrate, 64 countries (87.7 percent) produced copper concentrate in at least one year over the 26-year period while 53 countries (72.6 percent) produced some form of refined copper in at least one year. There are 20 countries in the sample that solely produced ore and concentrate and did not produce refined copper (commodity exporters) while nine countries exclusively process copper into refined products (commodity importers) with no reported production of domestic concentrate. The first group includes countries like Namibia and Papua New Guinea while the latter group includes Belgium and Austria. The final dataset for estimation does not cover countries that neither produce concentrate nor refined copper.

Over the 26-year period, 44 of the 73 countries produced both concentrate and ore. Panel E in Table 6 reports calculated measures of downstream integration for these countries, defined as the share of refined output in total input. Low-middle and low income countries tend to have the lowest shares of refined copper in total input, followed by high-income countries. Upper-middle and lower-middle income countries are the most integrated in terms of this measure.

¹¹ The World Bank Getting Electricity methodology assumes each procedure takes a minimum duration of one day and do not start on the same day. Furthermore, the firm obtaining a connection is assumed to commit to completing all procedures without delay.

¹² To ensure comparability across countries, the survey reports procedures, time and cost for a small to medium-size business to obtain a permanent electricity connection for a standardized warehouse with standardized electricity needs. The warehouse is assumed to be located in the largest business city, in an area where electricity is most easily available.

¹³ Refer to the following for the detailed methodology used by UNCTAD/World Bank: <https://unctadstat.unctad.org/wds/TableViewer/summary.aspx?ReportId=207050>

¹⁴ Income groups are defined following the World Bank's classification of economies. See Appendix A.

Table 6
Summary Statistics by income group (mean, standard deviation).

Variable	All countries N = 220	High Income N = 79	Upper Middle Income N = 57	Lower- Middle and Low Income N = 84
Panel A: Copper production				
Domestic production, copper concentrate ('000 MT)	222.36 (629.46)	436.92 (1,069.94)	181.48 (302.91)	90.50 (191.38)
Domestic production, refined copper ('000 MT)	309.60 (662.26)	396.55 (633.77)	369.59 (912.11)	102.42 (172.71)
Imports, copper ore and concentrate ('000 MT)	238.94 (891.26)	274.68 (823.99)	288.22 (1,243.03)	106.49 (370.14)
Imports, scrap copper concentrate ('000 MT)	59.68 (367.24)	51.40 (98.92)	122.30 (681.51)	7.12 (27.07)
Panel B: Regressors of interest				
Industrial electricity price (usc / kwh)	9.86 (5.48)	10.17 (5.32)	8.73 (5.63)	10.66 (5.40)
Electricity production (twh)	358.99 (737.69)	409.35 (800.90)	346.27 (756.08)	197.76 (267.07)
Time to obtain an electricity connection (days)	106.34 (77.12)	84.76 (53.85)	98.37 (48.21)	127.02 (98.48)
Cost to obtain an electricity connection (as % of GNI)	1,928.87 (4,247.96)	98.32 (107.82)	527.36 (406.95)	4,151.86 (5,829.72)
Panel C: Macroeconomic and institutional variables				
Industry, value added (% of GDP)	27.10 (13.92)	27.91 (16.85)	29.85 (13.30)	24.62 (11.40)
Real effective exchange rate (index)	100 (26)	98 (15)	97 (23)	108 (39)
WGI Government Effectiveness, score	-0.02 (1.00)	1.16 (0.61)	-0.23 (0.60)	-0.76 (0.53)
WGI Regulatory Quality, score	-0.02 (1.00)	1.12 (0.55)	-0.25 (0.71)	-0.72 (0.59)
Unit transport costs	3.75 (15.25)	5.32 (17.44)	3.09 (15.36)	2.91 (13.05)
GDP per capita (USD)	12,450.25 (18,045.67)	32,751.02 (20,355.80)	5,670.09 (2,921.30)	1311.96 (938.90)
GNI per capita (USD)	13,071.63 (18,014.81)	34,359.14 (18,287.91)	5947.60 (2804.13)	1347.46 (978.25)
Panel D: Measure of downstream integration				
Share of refined copper in ore and concentrate	0.28 (9.97)	0.12 (0.95)	0.90 (19.43)	0.02 (0.10)

6. Estimation results

6.1. Model 1: downstream activity and cost and availability of electricity

Table 7 reports estimates of Eq. (1). Each column presents an econometric specification of the model with refined copper production as the outcome of interest. Column 1 contains the most parsimonious specification, regressing refined copper production on primary production, electricity prices, electricity production, and country fixed effects. Columns 2 and 3 each present a specification with a richer set of controls. As the specification described in Column 3 includes unit transport costs which is a time-invariant variable, Eq. (1) is estimated here using a

Hausman-Taylor approach.

As observed in Columns 1 to 3, countries with higher electricity prices tend to produce less refined copper. Moreover, greater electricity production is associated with an increase in refined copper production. Controlling for institutional and macroeconomic variables diminishes the estimates of the impact of electricity prices on refined copper production (Column 2 and 3).

The model also shows that higher domestic production of copper concentrate is associated with higher production of refined copper (Columns 1, 2 and 3). Countries that import more concentrate also tend to produce more refined copper (Columns 1, 2 and 3). The variable indicating the quantity of scrap imported does not have statistically significant effect on refined copper production.

While institutional quality in terms of government effectiveness and regulatory quality are positively correlated with larger downstream activity (Columns 2 and 3), the effect is not statistically significant when macroeconomic variables are accounted for. Finally, industrial value added and the real effective exchange rate are positively associated with refined copper production.

6.2. Model 2: downstream activity and time and cost to obtain an electrical connection

Estimates of Eq. (2) are reported in Table 8. Here, refined copper production is regressed on the time and cost required to obtain a permanent electricity connection, as well as a set of primary production variables and country fixed effects. Column 5 presents the most parsimonious specification while Columns 6 and 7 include the full set of controls.

A striking finding in this model is the cost to complete the necessary procedures to obtain an electricity connection is negatively associated

Table 7

Estimates of the impact of electricity prices and electricity production on refined copper production.

	Outcome: Refined copper production (MT)		
	(1) FE	(2) FE	(3) Hausman-Taylor
Domestic ore and concentrate (MT)	0.189*** (0.041)	0.106** (0.046)	0.173*** (0.042)
Imports of ore and concentrate (MT)	0.248*** (0.021)	0.291*** (0.024)	0.309*** (0.022)
Imports of scrap ore and concentrate (MT)	0.042 (0.036)	0.038 (0.032)	0.046 (0.032)
Electricity production (Twh)	681.494*** (43.930)	688.318*** (48.052)	626.281*** (44.634)
Industrial electricity price (usc/ mWh)	-43.972*** (10.222)	-36.948*** (10.854)	-40.120*** (10.779)
Government effectiveness		234.957 (272.632)	174.625 (266.968)
Regulatory quality		319.696 (237.806)	326.663 (233.297)
Industry value added (% of GDP)		3,619.808** (1,584.179)	3883.728** (1,544.165)
Real effective exchange rate		678.176** (302.870)	715.759** (301.464)
Unit transport costs			7,883.814 (5,330.887)
N	605	452	452
R ²	0.860	0.917	0.912
Adjusted R ²	0.849	0.909	0.910
F Statistic	686.333***	502.831***	4594.903***

Notes: ***Significant at the 1 percent level.

**Significant at the 5 percent level.

*Significant at the 10 percent level.

with refined copper production (Columns 5 to 7). This means that countries where firms incur larger costs to apply for a permanent connection to the electricity grid, acquire clearances from government agencies and receive inspections tend to produce less refined copper. However, the number of days it takes to complete each procedure is unrelated to refined copper production as the effects are not statistically significant.

When institutional and macroeconomic variables are controlled for, the estimates of the effect of primary production sourced domestically or abroad are positive and statistically significant (Column 7). In terms of macroeconomic variables, industrial value added and the real effective exchange play a role in explaining refined copper production.

6.3. Model 3: downstream integration and electricity prices

Table 9 reports estimates of Eq. (3B) with the measure of downstream integration regressed on electricity production and electricity prices. Here, the share of refined output in total copper concentrate is transformed using an inverse hyperbolic sine (IHS) function. An IHS transformation allows the model to estimate economically important nonpositive values without discarding these observations (Bellemare and Wichman, 2020).

Controlling for institutional quality and macroeconomic variables, countries where firms face lower electricity prices tend to have greater downstream integration as measured by the share of refined copper over total inputs sourced domestically, abroad and recycled from scrap (Columns 8 and 9). However, electricity production does not exert a significant influence on the extent of downstream integration. Similarly, ratings of government effectiveness and regulatory quality are not associated with a more integrated sector once transport costs are accounted for (Column 9). Similar to the previous models, a larger

Table 8

Estimates of the impact of time and cost to obtain a permanent electricity connection on refined copper production.

	Outcome: Refined copper production (MT)		
	(5)FE	(6)FE	(7)Hausman-Taylor
Domestic ore and concentrate (MT)	0.146*** (0.032)	0.175*** (0.051)	0.359*** (0.036)
Imports of ore and concentrate (MT)	0.089*** (0.029)	0.117*** (0.043)	0.167*** (0.037)
Imports of scrap (MT)	0.191 (0.154)	0.104 (0.222)	0.302 (0.190)
Time to obtain an electricity connection (days)	-1.272	65.986	96.034
Cost required to complete each procedure (USD)	(41.793) -50.938***	(92.534) -95.034***	(101.607) -87.610***
Government effectiveness	(13.441)	(24.709) 384.628* (221.254)	(27.578) 339.008 (243.262)
Regulatory quality		69.157 (249.775)	-25.114 (254.031)
Industry value added (% of GDP)		3,565.428*** (955.590)	4,414.222*** (1,063.647)
Real effective exchange rate		819.783*** (294.769)	936.798*** (347.222)
Unit transport costs			6,893.987** (3,418.463)
N	891	442	354
R ²	0.072	0.159	0.416
Adjusted R ²	-0.168	-0.081	0.399
F Statistic	10.934***	7.217***	244.635***

Notes: ***Significant at the 1 percent level.

**Significant at the 5 percent level.

*Significant at the 10 percent level.

Table 9

Estimates of the impact of electricity prices and electricity production on the extent of downstream integration.

	Outcome: Share of refined output in primary output (%)	
	(8)FE	(9)Hausman-Taylor
Electricity production (Twh)	0.00003 (0.00004)	0.00003 (0.00003)
Industrial electricity price (usc/mWh)	-0.0001** (0.00002)	-0.0001** (0.00002)
Government effectiveness	-0.001* (0.001)	-0.001 (0.0005)
Regulatory quality	0.0001 (0.0005)	0.0003 (0.0004)
Industry value added (% of GDP)	0.008*** (0.003)	0.006** (0.003)
Real effective exchange rate	0.002*** (0.001)	0.002*** (0.001)
Unit transport costs		0.002 (0.005)
Constant		0.101 (0.146)
N	452	452
R ²	0.045	0.038
Adjusted R ²	-0.040	0.022
F Statistic	3.266*** (df = 6; 414)	17.355**

Notes: ***Significant at the 1 percent level.

**Significant at the 5 percent level.

*Significant at the 10 percent level.

industrial base and a higher index of the real effective exchange rate increases the share of refined output in total inputs.

Table 11 reports estimates of Eq. (3B). Here, the time and cost of obtaining an electricity connection serve as the main regressors of interest. When unit transport costs are not accounted for, the time to obtain a connection is negatively associated with the share of refined copper in primary output, meaning countries where firms take longer to complete all procedures have less integrated copper sectors (Column 10). However, when unit transport costs are incorporated in the model, the effect is no longer statistically significant (Column 11). Overall, these results suggest that the effect of changes in the costs of obtaining an electricity connection on the extent of downstream integration is not robust.

One potential weakness in the estimation is the absence of a variable capturing the effect of renewable energy (RE) on downstream integration. Several recent studies have found evidence in support of a negative relationship between the price of electricity and RE production. For example, Macedo et al. (2020) finds that electricity production from wind power is negatively associated with the price of electricity. Mulder and Scholtens (2013) finds a similar relationship for wind speed and electricity prices. This price dampening effect of renewable energy was also validated by Kolb et al. (2020) in the German electricity market and Sánchez de la Nieta and Contreras (2020) in the Spanish market. The fact that the share of renewables in the energy mix of a country has an effect on electricity prices means that investments in renewable energy generation may likely improve a country's potential to develop its downstream industries.

7. Conclusion

While downstream integration is an attractive policy for resource-rich developing countries rich, a careful analysis of the factors that influence downstream processing reveals that the viability of beneficiation hinges on the capacity of the energy sector. In stimulating downstream activity, electricity production and industrial electricity prices emerge as important factors in ensuring integrated downstream markets. Overall, energy plays a key role in sustaining downstream activity.

Table 11

Estimates of the impact of the time and cost to obtain an electricity connection on the extent of downstream integration.

	Outcome: Share of refined output in primary output (%)	
	(10) FE	(11) Hausman-Taylor
Time to obtain an electricity connection (days)	-0.002** (0.001)	-0.001 (0.001)
Cost required to complete each procedure (USD)	0.001** (0.0003)	0.0005 (0.0003)
Government effectiveness	0.006** (0.003)	0.005** (0.003)
Regulatory quality	-0.002 (0.003)	-0.006** (0.003)
Industry value added (% of GDP)	-0.018 (0.011)	-0.016 (0.011)
Real effective exchange rate	-0.013*** (0.003)	-0.016*** (0.004)
Unit transport costs		0.0002 (0.017)
Constant		2.344*** (0.628)
N	439	351
R ²	0.080	0.071
Adjusted R ²	-0.175	0.052
F Statistic	4.962***	26.252***

Notes: ***Significant at the 1 percent level.

**Significant at the 5 percent level.

*Significant at the 10 percent level.

In the context of a competitive market for refined copper, countries that successfully integrate their downstream sectors with their extractive sectors have access to lower end-use electricity prices. Because the inputs required for downstream processing complement each other, developing countries must be cautious when implementing downstream value addition. Targeted policies to increase local value addition can be counterproductive if prerequisites to scale and sustain long-term demand and profitability are lacking.

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Appendix 1: Data sources

Dataset	Units	Source
Domestic production of refined copper	K metric tons	US Geological Survey (USGS) Minerals Yearbook, Copper
International transportation costs		
Unit transport costs	USD	UNCTAD/World Bank Global Transport Costs Dataset for International Trade
Availability of raw materials		
Domestic production of copper concentrates	metric tons	US Geological Survey (USGS) Minerals Yearbook, Copper
Domestic production of copper leaching, electrowon	metric tons	US Geological Survey (USGS) Minerals Yearbook, Copper
Imports of copper ore and concentrate	kilogram	UN International Trade Statistics Database (Comtrade)
Imports of scrap copper ore	kilogram	UN International Trade Statistics Database (Comtrade)
Availability of inputs		
Industrial electricity prices (at constant ppp prices)	usc/kWh	Enerdata
Electricity net generation	TWh	Enerdata
Getting Electricity – time to obtain an electricity connection	days	World Bank Doing Business
Getting Electricity – cost to obtain an electricity connect	USD	World Bank Doing Business
Market Size		
Industry, value added (% of GDP)	Percentage	World Bank national accounts; OECD National Accounts
High-technology exports (% of manufactured exports)	Percentage	World Development Indicators (WDI) – World Bank
Medium-technology exports (% of manufactured exports)	Percentage	World Development Indicators (WDI) – World Bank
Real gross domestic product (at constant 2011 prices)	million USD	World Development Indicators (WDI) – World Bank
Real effective exchange rate, index		World Development Indicators (WDI) – World Bank
Quality of Investment Regime		
Government Effectiveness	Percentile Rank	Worldwide Governance Indicators (WGI)
Regulatory Quality	Percentile Rank	Worldwide Governance Indicators (WGI)

Appendix 2: List of countries in the sample, N = 73

High income	Upper middle income	Low-middle and low
Australia	Albania	Armenia
Austria	Argentina	Bolivia
Belgium	Bulgaria	Congo (Kinshasa)
Canada	Brazil	Egypt
Chile	Botswana	Georgia
Cyprus	China	Honduras
Czech Republic	Colombia	Indonesia
Germany	Cuba	India
Spain	Dominican Republic	Laos
Finland	Ecuador	Morocco
France	Iran	Burma
United Kingdom	Kazakhstan	Mongolia
Hungary	Mexico	Mozambique
Italy	Macedonia	Mauritania
Japan	Malaysia	Nepal
Korea, Republic of	Namibia	Pakistan
Norway	Peru	Philippines
Oman	Romania	Papua New Guinea
Poland	Russia (USSR)	Korea, North
Portugal	Serbia	Tanzania
Saudi Arabia	Thailand	Ukraine
Slovakia	Turkey	Uzbekistan
Sweden	South Africa	Vietnam
United States		Zambia
		Zimbabwe

Appendix 3. Estimation results – Downstream integration as outcome variable

	Outcome:Share of refined output in primary output (%)	
	(A1)FE	(A2)Hausman-Taylor
Electricity production (Twh)	0.0002 (0.001)	0.0001 (0.0002)
Industrial electricity price (usc/mWh)	0.00005 (0.0001)	0.00004 (0.0001)
Time to obtain an electricity connection (days)	0.001 (0.001)	0.001 (0.001)
Cost required to complete each procedure (USD)	-0.00001 (0.0001)	0.00000 (0.0001)
Government effectiveness	-0.002** (0.001)	-0.001 (0.001)
Regulatory quality	0.001 (0.001)	0.001* (0.001)
Industry value added (% of GDP)	0.015*** (0.005)	0.014*** (0.004)
Real effective exchange rate	-0.001 (0.001)	-0.001 (0.001)
Unit transport costs		0.001 (0.007)
Constant		-0.211 (0.240)
N	152	152
R ²	0.145	0.108
Adjusted R ²	-0.133	0.051
F Statistic	2.412**	17.125**

Notes: ***Significant at the 1 percent level.

**Significant at the 5 percent level.

*Significant at the 10 percent level.

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