Maastricht University

UNITED NATIONS UNIVERSITY

UNU-MERIT

Working Paper Series

#2019-033

The Potential for innovation in mining value chains. Evidence from Latin America

Michiko Iizuka, Carlo Pietrobelli and Fernando Vargas

Maastricht Economic and social Research institute on Innovation and Technology (UNU-MERIT)
email: info@merit.unu.edu | website: http://www.merit.unu.edu

Boschstraat 24, 6211 AX Maastricht, The Netherlands
Tel: (31) (43) 388 44 00

UNU-MERIT Working Papers
ISSN 1871-9872

Maastricht Economic and social Research Institute on Innovation and Technology
UNU-MERIT

UNU-MERIT Working Papers intend to disseminate preliminary results of research carried out at UNU-MERIT to stimulate discussion on the issues raised.

The Potential for Innovation in Mining Value Chains. Evidence from Latin America *

Michiko Iizuka
National Graduate Institute for Policy Studies, Japan
mi-iizuka@grips.ac. jp

Carlo Pietrobelli
University Roma Tre and United Nations University-MERIT
pietrobelli@merit.unu.edu
carlo.pietrobelli@uniroma3.it

Fernando Vargas
United Nations University-MERIT and Inter-American Development Bank
Vargas@merit.unu.edu

September 8, 2019

Forthcoming in Daly A., Humphreys D., Raffo J and Valacchi G. (Eds.), 2019, *Innovation and Mining*, Cambridge: Cambridge University Press for WIPO.

Abstract

This paper tries to broaden the scope and understanding of innovation in the mining sector, with a focus on emerging countries based on the experience of Latin America. It discusses the innovation processes that are developing in the mining sector of emerging countries, and uses the global value chains (GVC) approach to analyze the potential available to local firms. The focus is on all forms of innovation, not only those eventually subject to patenting, to include innovations in products and processes, but also in business, marketing and organizational models and practices. The new features of scientific knowledge applied to the mining sector (e.g. ICT, new materials, biotechnology) open new opportunities for new suppliers to enter and add value in mining GVCs, and we illustrate this point with specific examples of Latin American suppliers.

However, in developing this argument, we cannot forget that in most of Latin American mining there is insufficient supply of local knowledge, indicators of R&D expenditures and researchers involved show a significant lag with respect to advanced countries. Multinational mining companies have not traditionally conducted intensive R&D activities near their operations, and local universities do not tend to specialize in scientific topics directly linked to the mining industry. The paper concludes by arguing that there is a need to rethink and innovate policy approaches, if countries aim at scaling up and broadening the many good examples of innovative suppliers.

J.E.L. O13, O32, O43.

Keywords: Global value chains, Natural resources, Mining, Latin America, Innovation and learning, public policies

* The authors wish to thank Beatriz Calzada and Caio Torres for their research assistance, and participants at the WIPO Conference on Innovation in the mining sector in Geneva (2017). We also appreciate the extensive comments given by David Humphreys, Julio Raffo and Giulia Valacchi.

Emerging countries are among the largest mineral producers in the world and in many cases, the mining sector represents a notable share of their economies. Considering their large mineral reserves and the increasing number of explorations underway, emerging countries' role in the mining sector is expected to rise.[1] In the past, the mining sector has not always been seen as an 'engine of growth' despite its economic significance in emerging countries. Early analysts of economic development expected manufacturing to play a much larger role in promoting fast development (Prebisch, 1950). However, today there are signs that this may be changing. The mining sector is increasingly organised along "value chains", with a global span. Mining companies tend to outsource their intermediate inputs and services to a larger extent than in the past, and scientific and technological developments are pervasive in the industry. Importantly, the increasing sophistication of mining technologies is placing more emphasis on the technological contribution of companies which are not themselves miners but which are nonetheless important links in the supply chain for mining. This potentially opens a window of opportunity for the structural transformation of emerging economies endowed with natural resources, and the scope for entering more knowledge-intensive and promising activities (Anderson, 2012, Marin et al, 2015, Pietrobelli and Katz, 2018, Pietrobelli et al., 2018).

This chapter discusses the innovation processes that are developing in the mining sector of emerging countries, and uses the global value chains (GVC) approach to analyse the potential available to local firms. The focus is clearly on all forms of innovation, not only those eventually subject to patenting. These include innovations in products and processes, but also in business, marketing and organisational models and practices. Moreover, the remarkable innovation that may powerfully develop through the interaction and linkages between mining companies, their suppliers, and other organisations active in the innovation ecosystem, cannot be underplayed.

After briefly reviewing the relative importance of the mining sector in emerging countries – and in particular Latin America - we discuss the potential of innovation to contribute to economic development in this sector. To illustrate the types of innovation implemented, we refer to specific examples of Latin American suppliers in mining value chains. However, in developing this argument, we cannot forget that in most of Latin American mining there is insufficient supply of local knowledge. For instance, indicators of R&D expenditures and researchers involved in the Chilean mining industry show a significant lag with respect to countries like Australia (Meller & Parodi, 2017). Multinational mining companies have not traditionally conducted intensive R&D activities near their operations (Pietrobelli et al., 2018); local universities tend to specialise in scientific topics that are not directly linked to the mining industry (Confraria & Vargas, 2019), while the majority of local METS lack the capabilities to actively participate in innovative projects. There are still several good examples of very innovative suppliers, but their success is limited in scale and is not shared by all suppliers. In Section 1 we stress the importance of mining activities in emerging countries; Section 2 discusses mining innovation focusing on its role in emerging countries; Section 3 suggests how global mining value chains could affect emerging countries, looking at some specific examples from the Latin American region; Section 4 discusses some policy experiences related to mining innovation in Latin America; Section 5 concludes.

[1] In this paper, we use the term 'emerging countries' in a broad form, to include also developing countries.

1. Importance of mining activities in emerging countries

The mining sector greatly contributes to the economies of emerging countries, in particular in Latin America and Sub-Saharan Africa. Table 1 (upper part) shows the proportion of ores and metals in merchandise exports along with rents from natural resources by income level and by geographical regions. This confirms that natural resources are more important among lower income countries from Middle East and North Africa (MENA), Sub-Saharan Africa and Latin America and Caribbean (LAC) regions. LAC and Sub-Saharan Africa are most dependent on ores and minerals, whilst the MENA region's main natural resources are oil and natural gas. In Latin America, despite a decline over the last decade, natural resources still represent a large share of GDP and exports (Table 1).

This general trend of continued importance of mining resources is likely to persist, as reserves for key minerals are mainly present in emerging countries, and notably in Latin America (Fig.1 and US Geological Survey, 2015). Indeed, the share of production from developing countries has been increasing in the last decade (Fig.2).

Table 1. Natural resources matter for GDP and trade for emerging and Latin American countries

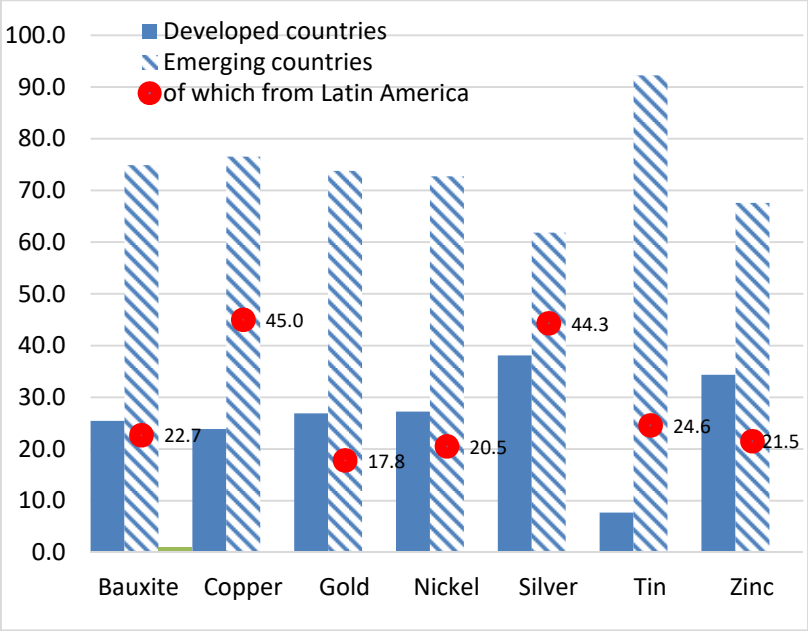
Indicators	Year	Level of income				Regions*				
		Low	L- Mid	Upper	High	EAsia&P	E&CAsia	LAC	MENA	SubAfrica
Ores & metals exports (% of merchandise exports)	2006	..	6.36	4.87	4.05	3.60	3.80	11.55	1.35	14.60
	2016	..	4.09	4.23	3.98	4.23	3.16	11.31	2.27	..
Total Natural resources rents (% of GDP)	2006	15.72	8.5	9.64	1.98	2.57	1.98	7.35	31.91	16.21
	2016	12.14	3.05	3.24	1.14	1.15	1.25	3.26	16.80	8.31

Indicators	Year	Latin American countries					
		Argentina	Bolivia	Brazil	Chile	Colombia	Peru
Ores & metals exports (% of merchandise exports)	2006	4.28	22.73	10.81	63.12	2.47	57.07
	2016	3.34	36.55	10.47	51.32	1.22	52.34
Total Natural resources rents (% of GDP)	2006	5.92	16.33	4.89	21.42	7.02	13.04
	2016	1.3	6.01	3.09	10.50	3.54	7.65

Source: World Bank Development Indicators. Total natural resource rents are the sum of oil, natural gas, coal (hard and soft), mineral and forest rents.

Note: L-Mid: lower middle income, EAsia&P: East Asia and Pacific, E&C Asia: Europe and Central Asia, LAC: Latin America and Caribbean, MENA: Middle East and North Africa, SubAfrica: Sub Saharan Africa

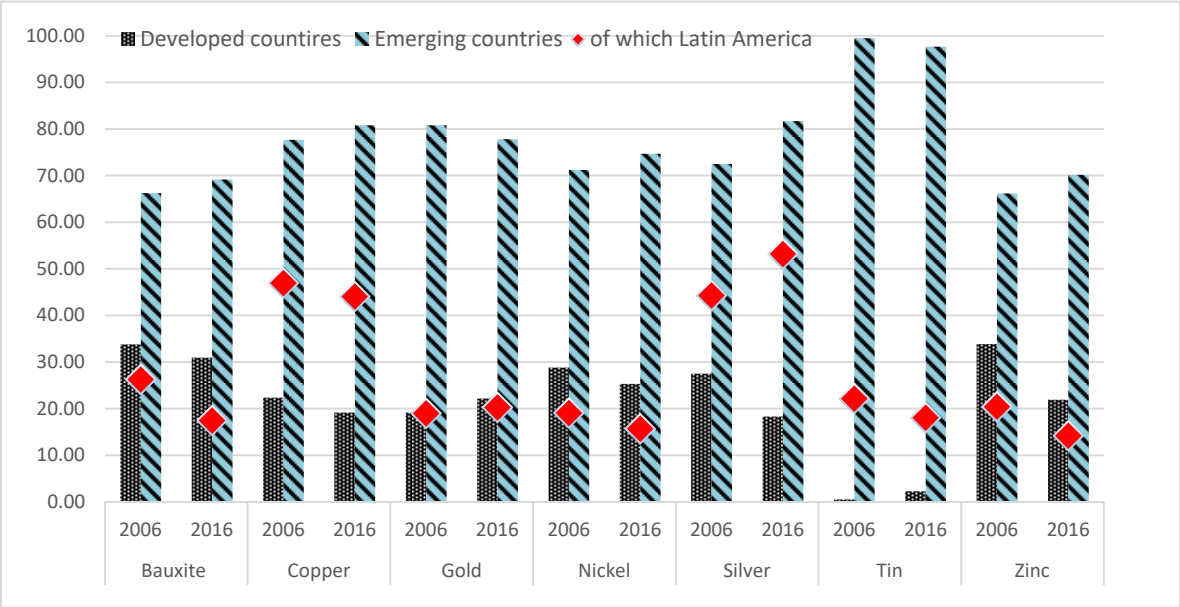
Fig.1 Reserves of key minerals by countries' income level (2015, %)



Source: US Geological survey, 2015

Note: The rest follows the IMF definitions.

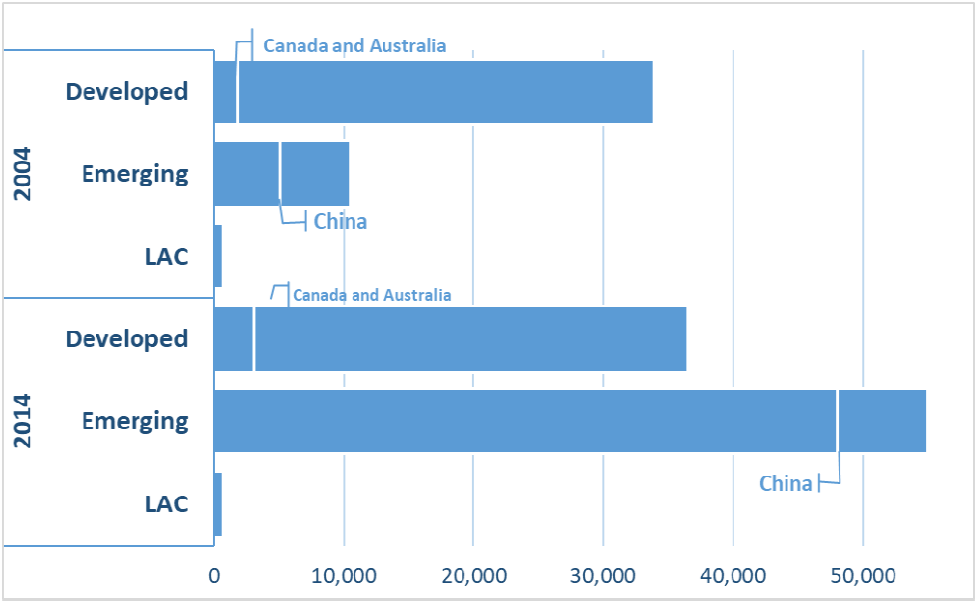
Fig.2 Proportion of mineral production (%)



Source: British geological Survey, 2018.

Note: The rest follows the IMF definitions.

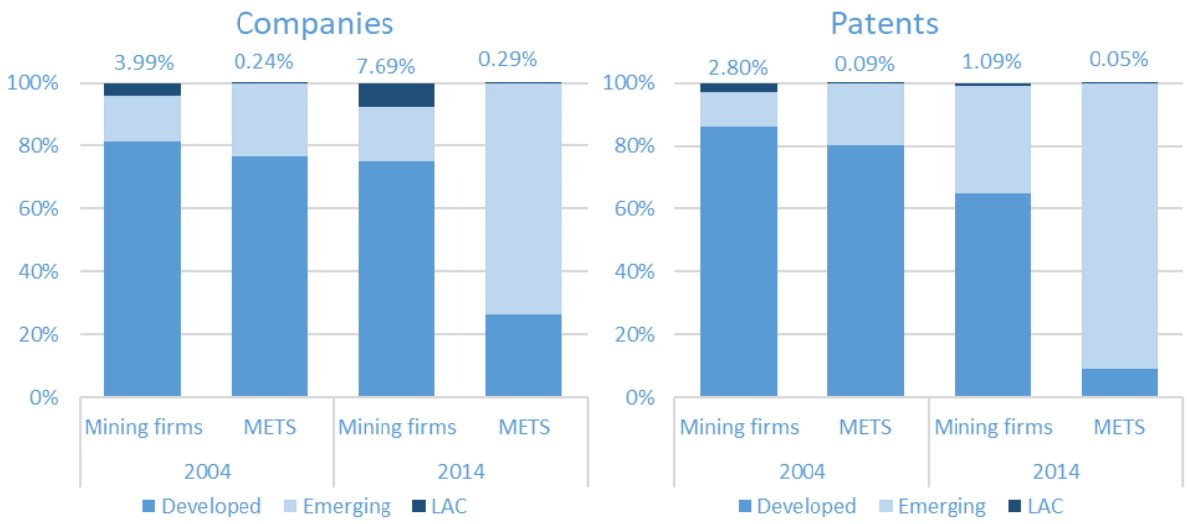
Fig.3 Number of mining patent families[2], by country of origin (2004, 2014)



Source: WIPO mining database. Note: The rest follows the IMF definitions.

The reserves of minerals and the proportion of mineral production do not correlate with the innovation patterns than can be observed in patent data (see Fig. 3). This is particularly true for Latin American countries that only represent a minor fraction of the mining patents, while developed economies are very active in this domain. Emerging countries as whole have seen a remarkable increase in the number of mining patents over the last decade. But most of this increase is due to the Chinese spectacular surge in this period.

Fig.4 Mining GVC firms and patents by type of firm and region (2004, 2014)



Note: % at the top of the bars represent the proportion of patents by LAC
Source: WIPO mining database & BVD ORBIS. Note: region determined by country of origin. Emerging countries exclude LAC. Detailed figures refer to LAC share.

[2] A patent family is "a set of patents taken in various countries to protect a single invention (when a first application in a country – the priority – is then extended to other offices)". (OECD, 2001:60)

Companies from developed countries are also disproportionally represented in the sample of larger and more international firms in the mining GVC (Fig. 4).[3] However, companies from emerging countries have seen their participation increase in the past decade. LAC firms have grown in share in the mining segment, while other emerging economies – particularly China – have grown outstandingly in proportion of the Mining Equipment,Technology and Services(METS) segment. The increase of the Chinese METS companies correlates with a similarly impressive growth in patents. LAC companies patenting remains very modest in both GVC segments. In 2004, LAC mining companies accounted for almost 3 percent of the patenting activity, which is related to the patenting activities of large mining companies like Codelco and Vale.

2. Innovation in the mining sector

We adopt here a broad definition of innovation that includes technological and non-technological innovation to understand the mining sector. This includes a wide range of new products, processes, marketing methods, business models, organisational structures and new sourcing methods. Today, extending mining global value chains involves high tech equipment and service activities that require local specific knowledge and knowhow, opening up opportunities for local suppliers to upgrade their capabilities.

It is generally acknowledged that the mining sector has the following characteristics: (1) it is capital intensive, (2) miners are price takers, and (3) mining creates intense local interactions and impacts. These features greatly influence the patterns of innovation for mining companies and suppliers due to the several reasons underlined in other chapters of this volume.

First, in most cases, the capital-intensive feature of mining implies large investments upfront.[4] This self-selects those who can invest in starting a mine limiting them to large private or public corporations. The large-scale investment is usually followed by large-scale operations whose profits tend to rely on economies of scale. These conditions limit the type of suppliers to those who can respond to large-scale demand. The large scale and long time span of operation also contribute to risk averse and conservative technology choices. The life cycle of mines – typically 20 to 30 years – further slows technological change as the change must coincide with the mine's investment cycle. The mining companies' time lag in taking up new technologies has been estimated as 13 years on average (Barnett and Lopez, 2012). In other words, technological innovation in this sector has many restrictions due to the way business functions.

Second, the price of mineral products is determined by the global market as these are undifferentiated commodities. The mining companies, therefore, are price takers. This condition makes research and development (R&D) for adding value to product highly irrelevant because the price does not reflect the efforts exerted. On the other hand, innovation could be important for cost reductions of the production process, the only factor under firms' control, especially in times of decline in global prices. Some initial evidence appears to suggest that innovation occurs in such

[3] The data source, BVD Orbis, is biased towards large and international companies.
[4] This of course does not fully apply to small-scale, artisanal mining industry

circumstances, often in the form of better organisation of works, production processes and expanding domestic backward linkages to compensate the loss of profit (Calzada, and Iizuka, 2019).

The improvement in production process is mainly achieved through the collaboration with external actors, often including different types of Mining and Technology Suppliers (METS). This appears to occur in areas such as: (1) acquisition of technology embodied in machinery from large multinational firms (Lee and Prowse, 2014; Kaplan, 2012); (2) outsourcing (i.e. R&D spin off) in finding fully disclosed problems with high tech suppliers and startups; (3) open source collaboration, involving tech start-ups, research centers, universities and industrial organisation for finding short-term specific solutions; (4) collaborative ventures for R&D long-term solutions, involving suppliers, universities, research centers and other mining firms (e.g. Komatsu and five research centers in Australia with Rio Tinto).

Moreover, innovation in the mining sector often faces some restrictions due to the physical infrastructure of the mine (e.g. scale of architecture, width of corridors, layout and technological level of equipment installed etc.) designed at the start of the mine's life cycle, that can set certain limits to how many changes can be introduced at a later stage (Calzada, 2018).

Third, mining activities have intense socio-economic and environmental impacts on local and regional communities. As the mines are usually located in sparsely populated regions, the large-scale operation of mining activities can create both positive and negative disruptions (Katz and Pietrobelli, 2018). The absence of appropriate regulatory measures, policies and especially institutional capabilities may cause negative impacts for the local society. This may subsequently hamper the sustainable operation of the mine. On the other hand, mining activities can generate positive outcomes insofar as they are coordinated and well-integrated into the local and regional economies. Collaborative relations between miners, suppliers and other knowledge-related organisations can be achieved more easily where there is a clear and coherent regional development plan.One of the important contributions of mining activities is the generation of employment and the creation of entrepreneurial activities. As mining industries have the tendency to use METS for various purposes, linking mining operations to local suppliers can encourage industrial activities and upgrade their capacities. In this context, interactions with other local actors such as R&D centers, universities, financial institutions and firms become critical. In countries like Australia and Canada, industrial associations provide various forms of support in building innovation eco-systems and promoting linkages and technological and managerial capabilities (see Chapters 11 and 12).

Innovation in the mining sector in emerging countries

The mining sector can offer new opportunities for the development of resource-rich countries via generating employment, economic activities as well as foreign direct investment as can be seen from the successful examples of Australia and Canada. However, it is still an open question whether it is possible to develop mining engineering, technology and services domestically in emerging countries, in light of the special characteristics of innovation

Earlier examination of the characteristics of innovation in the mining sector revealed that this sector has both favourable and unfavourable characteristics for emerging countries. The favourable characteristics include the requirement of close collaboration between mining companies and their

local suppliers in solving location specific productive issues. Moreover, the speed of technological adoption is slow, with a focus on incremental improvements of the processes and organisation of production. Local specific knowledge (i.e. geological conditions, access to public utilities, presence of indigenous population) has a special value to solve location-specific problems that may directly or indirectly affect the productive process. These characteristics could in principle favour firms in emerging countries because they allow learning through interaction, catching up, and substantial non-technological innovation.

On the other hand, there are some features of the mining sector that could hinder firms from taking full advantage of innovation in emerging countries. The main factors include: (i) the large size/scale required for supplies and services, with this size asymmetry affecting the negotiation process between mining companies and METS; (ii) the large financial requirements to finance large-scale exploration and exploitation investments upfront: and (iii) the complexity of some technical problems which may require highly technical knowledge and expertise with sophisticated capital equipment and machinery. The poor access to financial resources, know-how, technical expertise and negotiation power that characterises many firms in emerging countries, together with the difficulty to coordinate efforts and set up collective actions, make it hard to generate innovation and benefit from it in the mining sector.

3. Lessons from Latin American case studies of innovations in mining value chains

Traditional development and innovation literature has often given a pessimistic picture of the development impact of natural resources and mining (Hirschman, 1958; Prebisch, 1950). Such an opinion has been based on various explanations, arguing that mining is often an “enclave”, that large mining operations tend to be controlled by multinational corporations which perform little local innovation and govern hierarchically their value chains to the disadvantage of local suppliers, or on the idea that natural resources would induce “Dutch disease” imbalances and rent seeking (Corden and Neary, 1982, Venables, 2016). However, in recent years mining companies have increasingly organised their activities along Global Value Chains and this may offer the advantage of strengthening linkages among firms and other actors, and avoid the “enclave” pattern that used to prevail in the past.

Global Value Chains

The term Global Value Chain refers to the full range of activities that firms and workers carry out to bring a product or service from its conception to its end use, recycling or re-use. These activities include design, production, processing, assembly, distribution, maintenance, disposal/recycling, marketing, finance and consumer services. In a global value chain setting, these functions are distributed among many firms in different countries. In this context, “lead firms” are groups of firms that operate at particular functional positions along the chain and that are able to shape who does what along the chain, at what price, using what standards, to which specifications, and delivering at what point in time (Gereffi et al., 2005, Ponte and Sturgeon 2014).

Understanding the opportunities and drawbacks that suppliers may suffer from integration into a GVC requires knowledge of how GVCs are governed through a specific division of labour between

lead firms and other actors, and how governance arises and is managed (Gibbon et al., 2008). For example, it has been noted that a more hierarchical governance of GVCs in Latin America has hindered innovation and upgrading processes in suppliers (Giuliani et al., 2005, Pietrobelli and Rabellotti, 2007). The concept of GVC governance is based on the observation that value chains are rarely coordinated spontaneously through market exchanges (Gereffi et al., 2005, Gibbon et al., 2008). Instead, they are governed as a result of strategies and decision-making by specific actors, the lead firms that manage access to final markets, globally but also at regional and national/local levels. Examining GVC governance then means studying the content and the management of these decisions across all suppliers and sub-suppliers, the strategies behind the decisions taken, the management methods chosen to implement them, and the systems through which their outcomes are monitored and implemented (Ponte and Sturgeon, 2014).

Furthermore, from a broader perspective, mining GVC governance is also shaped by actors that do not directly produce, transform, handle or trade products and services – such as civil society organisations, social movements, consumer groups, networks of experts and policy-makers (Katz and Pietrobelli, 2018).

Involvement in GVCs can offer opportunities for the suppliers to innovate. In the mining sector, a new context is emerging, which is opening new opportunities for innovation and fruitful linkages between lead firms and METS, which did not exist before (Perez, 2010, Andersen, 2012; Marin et al., 2015). These new opportunities are associated with a larger and more diversified demand for natural resources, new knowledge and technology advances applicable to these sectors, outsourcing along GVCs, together with the search for local technological solutions, and an increasing pressure to innovate to reduce environmental impact (Dantas, 2011; Iizuka and Katz, 2010; Morris et al., 2012).

The results from a variety of new studies in the emerging countries of Latin America (Pietrobelli et al. 2018) indeed confirm these ideas and suggest that some local METS carry out important innovative activities. They have developed advanced levels of innovation capabilities, reflected in patents, new product developments, international awards, exports of goods, services and technology, and technologies in use. However, this same evidence reveals that local suppliers' innovative activity has not emerged out of rich linkages between the suppliers and the mining companies, as sometimes happens in GVCs (Pietrobelli and Rabellotti, 2011). Large mining companies have rarely built formal long-term linkages and commit themselves to joint innovation with local suppliers (Molina, 2018, Stubrin, 2018). Instead, they tended to rely on established suppliers, and when new technological challenges emerged, they relied either on solutions coming from headquarters based abroad, or on their first-tier suppliers. In other words, value chains with the typical characteristics of mining GVCs, may have governance structures that could to some degree generate a market failure for innovation. This is particularly true in emerging countries where the local and national innovation system may not provide the underlying knowledge base for the suppliers to "upgrade" into the possible technological opportunities.

In spite of these difficulties, a new potential for innovation in mining providers is apparent, and derives from demand for innovation coming from large mining companies and often related to local specific contexts. Moreover, such potential also derives from the supply-side, in terms of technological opportunities related to the use and the recombination of technologies from different

domains, and from the active attitude of local innovative suppliers investing in capabilities (Morrison et al., 2008).

The key for emerging countries with an active mining sector lays in successfully upgrading and diversifying economic activities. The upgrading in GVC entails three possible avenues (Gereffi et al., 2005): 1) product and process upgrading at the same stage of the chain; 2) functional upgrading, moving to higher value added position in the chain; and 3) moving to different chains using the knowledge and capabilities acquired in a GVC. This means that overcoming obstacles and making full use of favourable characteristics of innovation in the mining sector can be a springboard for development. Collaborative innovation systems are essential to strengthen knowledge flows, fix information asymmetries and encourage interactive and continuous learning (Lundvall, 2010). The selected examples analysed in the following section reveal that some opportunities are indeed emerging, and this is relevant for many other countries in Africa and Latin America with abundant mineral resources.

Incentives to innovation coming from demand

Upgrading GVCs requires active investments in innovation by firms, which are usually driven by adequate incentives. Chapter 1 explained how some of the incentives to innovation in mining companies and METS come from specific demands, such as for example the decreasing productivity of existing mines. In Peru for instance, due to the depletion of clean deposits (deposits with low levels of impurities), mining companies are dealing with deposits of copper, silver and gold which need to be increasingly cleaned. Moreover, mining activity in both Peru and Chile is performed at high altitudes. The La Rinconada mine, in Puno, at 5,100 meters above sea level, is the highest in the world (Molina et al., 2016) and similar conditions prevail in Chile. Existing equipment and solutions underperform, and there is a need to adapt them or develop new ones tailored to local conditions. Similarly, in Brazil most of the activity has been moved to deeper mines, where the treatment of the mineral is more complex (Figuereido and Piana, 2016). These conditions pose pressing demands for innovation.

Additional demands for innovation come from the social and environmental challenges faced by mining companies. Local communities are concerned with livelihood security, environmental degradation and the perception that the wealth created is not fairly shared. Governments react by introducing more stringent environmental regulations and requiring some local involvement in decision making (Katz and Pietrobelli, 2018). Again, the demand for innovative solutions and sustainable methods of production is rising fast (see Chapter 6).

The very hierarchical structure of the mining GVCs analysed, being characterised by important power and resources asymmetry (Arias et al., 2014, Pietrobelli et al., 2018) is posing substantial problems for the upgrading of local suppliers.[5] We identified linkages with very poor potential to encourage innovation in mining GVCs: large mining companies are in general very resistant to try

[5] On "upgrading" in value chains see the discussion above, and Gereffi et al., 2005 and Pietrobelli and Rabellotti, 2011. Here we rely on the standard categorisation of product, process, functional and inter-chain upgrading.

new solutions that have not been tested worldwide. They demand successful pre-testing conducted in several mines before even trying it, particularly when the solution comes from domestic suppliers (Pietrobelli et al., 2018). In Peru, it has been detected that the communication channels with the lead mining firm are only available for METS that are already working with the mining company (Molina, 2018). It is the suppliers themselves that need to incur the transaction costs needed to approach the mining companies and offer their services, and often lack these capabilities, intrinsically different from purely technological capabilities.

In sum, at least for Chile and Peru, our results from case studies (Pietrobelli et al., 2018) confirm that exchanges of information within the mining GVCs happen, but they are mainly informal, and mostly focused on the identification of the problem, rather than on finding a solution. Indeed, few exchanges were reported during the R&D stage. The experience of Brazil seems to suggest partly different conclusions. Figueiredo and Piana (2016 and 2018) found evidence of rich "learning linkages" between Vale and its suppliers, as well as between Vale, some Brazilian Universities, and sometimes firms from different industries (e.g. Petrobras). They report that from 2009 to 2012 Vale developed 161 R&D projects with universities (151 of them from Brazil) with an estimated value of about USD 88.8 million. In some instances, it appears that Vale encouraged the development of learning linkages between other MNC subsidiaries and local mining suppliers, for example with regard to the development of belts to transport iron ore (Figueiredo and Piana, 2016, p.140). Important learning linkages also occurred with public R&D centres and sectorial institutions. For instance, with the Mineral Resources Research Company (CPRM), a government organisation that seeks to generate and disseminate geological and hydrogeological knowledge in Brazil (Figuereido and Piana, 2018). Chapter 8 deepens the analysis of innovation practices in Brazil with a focus on the role of Vale.

Incentives to innovation coming from the supply side

Incentives to innovation may also come from the supply side, i.e. the new availability of scientific discoveries, new technologies and equipment, new forms of organisation. Existing studies have documented how recent advances in knowledge have opened new technological opportunities also for the mining industry (Pietrobelli et al., 2018, and the studies contained in the same special issue). These are related to the massive advances in information and communication technologies (ICT), computer vision systems, satellite and other remote sensing applications, advances in molecular and in synthetic biology for bioleaching and bioremediation for copper and gold. Such supply side incentives seem to be more effective in mining GVCs. In what follows, we will see some examples of this emerging tendency.

In Chile, the company Micomo, developed highly innovative monitoring technologies through optical fiber that help extraction processes, and obtained two patents and one international award (Stubrin, 2018). Power Train technologies entered the market with new remote-control systems for trucks that operate at very high temperatures, required for performing mining at high altitudes. High Service from Chile obtained three patents related to remote monitoring and wireless communication which allows predicting wear points for key equipment, and in this way anticipate replacements and avoid to stop operations, which can cost the company around USD 150 thousand per hour. Geoambiente, from Brazil, entered the mining GVC developing sophisticated geological maps,

sensors and radar images that help in the exploration phases, predicting contents of minerals and areas or erosion and are useful to monitor environmental impact (Figueiredo and Piana, 2018). The innovativeness of the company made it the largest Google partner in Brazil and helped it diversify into markets and countries beyond mining.

Another important area of new knowledge opportunity that companies are exploiting is new materials. Neptuno from Chile, for instance, developed pumps for one of the biggest open-pit mine in the world, adapted them to operate at 4,500 meters above the sea levels by improving materials, incorporating superior alloys and advanced engineering thermoplastic and extending the life of pumps. This gained Neptuno ten national and three international awards. One company from Brazil became a supplier of Vale developing new metal alloys, with longer durability at high temperatures (Figueiredo and Piana, 2018). Using the same kind of opportunities, Verti from Brazil developed dust suppressants that use glycerine left over from biodiesel plants, and new technological routes to recycle materials and to treat waste water. Aplik from Chile has entered the mining GVC exploiting the technological opportunity offered by robotics. One of the main innovations of the company is a new tool for controlling irrigation at key parts of the exploitation process, helping to detect failures through irrigation maps and an alarm system. This new system is in the process of being patented and has received several national and one international award (Stubrin, 2018).

The application of biotechnology is making the mining process more efficient and cleaner. Aguamarina is a pioneering Chilean company that managed to enter the value chain by developing first bioleaching (i.e. the extraction of metals from their ores through the use of living organisms), and then expanded into new product lines, all biotechnology-based solutions for mining companies. The main areas of activity of Aguamarina are biolixiviation, biocorrosion, bioremediation, bioreactors, water treatment and dust control (Benavente and Goya, 2012). For example, Aguamarina created unique solutions for dust control based on bacteria and microalgae. This was a new solution for a long-dated and crucial problem as mining operations create enormous amounts of dust that affect the environment, the maintenance of the machinery, and even the health of mine workers and inhabitants of nearby communities. The company obtained three patents in the US, and won five national awards.

The integration of different areas of knowledge also creates opportunities for the development of completely new or adapted products. Neptuno develops novel, innovative pumps combining knowledge about new materials, chemistry, engineering and 3D printing; Innovaxxion developed the new technology known as Earless – which reduces from 20% to 10% scrap waste in the copper mining process – by integrating knowledge about mechanical engineering, robotics and electrical engineering; Aplik integrates knowledge about electronics, informatics, mechanics and metallurgy; Geoambiente's unique results derive from combining traditional knowledge about geology with new knowledge related to communication.

Sometimes the integration of different areas of knowledge is useful to improve and upgrade existing tools and machinery. For example, Exsa in Peru, combining knowledge about engineering, explosives, new materials and chemistry developed a new method of rock fragmentation (Quantex) that generates savings of up to 20% of total costs and has positive environmental impact. The technology has been patented in Peru and the US (Molina et al., 2016). Resemin developed special jumbos for

narrow veins, and for coping with extreme environmental conditions of underground mining in Peru by combining different elements of knowledge about metalworking, geology, engineering and IT (Molina, 2018). Some of the jumbos developed by the company, like the Muki, are now patented in the US.[6] Although the largest mining suppliers have developed drilling jumbos to operate in these veins, they have faced limitations to run in sections of 1.8m width or less; this has never been the top priority for these suppliers. Narrow veins is an important niche market that Resemin took advantage of when they introduced the Muki. This also meant increased mining productivity, drilling a 2.4m. hole in 40 seconds, unlike traditional methods which take seven minutes, and mechanisation in tunnels, which improves safety of the operators (Molina, 2018).

One important result that emerges from studies reported above is that technological opportunities appear to have been exploited mainly in areas where more experienced multinational suppliers did not have the incentive or could not meet the challenge.

Local Suppliers Strategies and Capabilities

Although new demands for innovative solutions as well as technological opportunities are emerging in mining value chains, this potential appears to have been exploited only by a handful of local firms that developed strong scientific and technological capabilities and opened specific channels of communication with lead firms and large first-tier providers. In order words, firm-level strategies to develop capabilities also play a central role.

In the sample of firms interviewed in Pietrobelli and Olivari (2018), all the firms share a characteristic of substantial levels of investment in advanced levels of scientific and technological capabilities. They all perform R&D and carry out other high-level search and innovation efforts. Many suppliers from Chile invest on average almost one quarter of their sales on innovative activities and employ good shares of their total employees in R&D (Stubrin, 2018). In Peru the interviewed firms – in different mining suppliers' sectors - declared to employ between 3 and 4% of their total labour force in R&D (Molina et al., 2016).

Neptuno Pumps invested heavily in the capabilities to adapt pumps to specific geographical conditions, and thereby allowed energy savings of up to US$ 650,000 a year. A similar case is that of Power Train Technologies, that develops and sells diesel engines and other engines adapted for trucks that operate at high altitudes and extreme weather conditions. As pointed out by the company managers, engines developed by large MNCs do not work in these conditions, and the MNC would not find it profitable to invest and adapt its engines. The engines adapted by the local Chilean supplier managed to deliver a product that saves up to 10% in fuel consumption, improves performance and reduces carbon prints.

One of the most successful upgrading firms is Resemin that is a leading global supplier of drilling equipment in the underground mining equipment sector in Peru (Bamber et al., 2016, Box 4). The company's upgrading trajectory began as parts supplier, shifting to parts manufacturer, followed by final equipment production, using reverse engineering and finally own engineering for new

[6] Muki is a micro-jumbo of 1.05m width created to face narrow veins and to withstand the high temperatures, lack of water, excessive corrosion, humidity and high altitude of underground mining.

equipment design. The specific conditions of mining in certain areas of Peru, where veins are very narrow and the climatic conditions extreme, favoured Resemin upgrading process.

Drillco Tools develops percussion hammers and drills specially adapted to the type of rock where they are used. In the early 1990s the company developed customised products required to enter the GVC. Interestingly, the company started adapting products to the specific conditions of Chile, but currently, and with the same approach, it sells hammers and drills through its subsidiaries in Brazil, United States, Peru, Italy and South Africa (Stubrin, 2018). The firm exports 77% of its production, and offers an interesting case of upgrading into different GVCs in different countries. Linkages with clients to understand the specific requirements prevailing in each location were crucial.

In sum, there are many examples of mining suppliers in emerging economies that reached remarkable levels of innovative technological capabilities. However, many of them had to overcome the difficult challenge to manage their integration into the GVC and to create their own markets to take full advantage of the innovations developed. This includes not only the creation of new technology, but also the establishment of the conditions for the transaction, the contracts, the agreement on the value of the innovation, on the rules of the game, on the distribution of benefits. This is specific to mining as well as other sectors where the availability of new knowledge and technologies from other sectors, and new forms of organisation in value chains, are transforming the nature of business. This is true, for example, for precision farming and for seeds production in several middle-income countries (Lachmann and Lopez, 2018). However, this process appears to be still incipient in many instances, and often hindered by the hierarchical and conservative governance of the GVCs discussed above.

In conclusion, new opportunities for innovation are emerging in the mining sector. Some may be patentable, but many others are not, and they are more related to the organisation of the business and of the network of transactions with different actors along the value chain. e Technology opportunities coming from both demand and supply, and especially the latter are very strong and related to basic science. Such opportunities call for advanced firm-level capabilities, that are not only technological but also related to value chain integration and to the creation of a new market– (Marin et al., 2016). Groups of innovative suppliers are emerging in Latin America. However, hierarchical value chains dominated by few large firms and the resulting poor linkages are often blocking the diffusion of innovations and hindering suppliers' development. This often prevents innovation and success to spread to a larger number of local companies.

Many research challenges remain open and deserve attention in the future. Thus, the capabilities complementary to production and necessary for market access and GVC integration need to be better understood. Similarly, the role of the various tiers of suppliers and their relationships with other local providers deserves future research. The role of public policies also needs to be explored in much greater details in a context characterised by remarkable uncertainties and by the coexistence of many actors with different and sometimes potentially clashing interests. These include civil society and the long-term interests of sustainability and environmentally sound management of the resource, lead-firms and their tiers of suppliers, and the inter-generational distribution of costs and opportunities deriving from the mining industry.

4. Implications and selected policy experiences in Latin America's mining sector

The innovation cases developed by suppliers presented in the previous section have been an exception rather than the rule in the mining industry in LAC. Since these examples showcase the potential benefits for domestic suppliers of more innovation in the industry, some mining countries have made attempts to accelerate innovation by establishing programmes to support innovation in mining suppliers. In this section, we focus on the lessons learned from one of the most famous examples of this type of initiative: The World Class Suppliers (WCS) programme in Chile.

The WCS programme was designed to try to alleviate the transaction costs and market failures that hinder the development of the innovation market. On the one hand, large mining companies know their operational problems but codifying them into terms that can be understood by external parties is a costly endeavour, which may not necessarily be always profitable. On the other hand, even when some of the operational problems are codified, potential suppliers who may have the capacity to solve them may not know these opportunities or the, efforts to find these new opportunities may be too costly. Furthermore, the tacit knowledge component of each operational problem gives rise to asymmetries of information between the mining companies and suppliers. The latter is exacerbated when suppliers are providing a service (Rubalcaba, 2015). The programme is built around the effort made by mining companies to codify part of their operational problems and make them accessible to potential suppliers. On top of that, the platform through which the programme is organised also allows to reduce suppliers' transaction costs, since they do not need to rely only on their resources to approach mining companies and establish a new commercial relationship.

The World Class Suppliers (WCS) programme in Chile

The WCS programme is a public-private initiative, launched in the late 2000s, whose primary objective is to promote the technological development of knowledge-intensive mining suppliers (KIMS) through increasing the demand for innovations and promoting internationalisation. This initiative was developed entirely by the private sector. Indeed, the multinational company BHP-Billiton created this programme in 2008 and two years later Codelco, the state-owned and largest copper mining company in Chile, joined the programme.

The programme works as follows (Navarro, 2018). The mining companies participating in the programme identify a list of operational problems suitable to be solved by a subcontractor. The list of problems is filtered by considering criteria relevant to the performance of mining companies, such as the potential economic gains, expected timeframe, and perceived risks of new solutions, but also potential benefits to suppliers, such as scalability of the potential solution and suitability of that solution to be co-created with the mining company. The final projects portfolio is uploaded to a website, managed by the local think-tank *Fundación Chile*, including a detailed description of the magnitude and characteristics of each of the operational challenges. Selected companies are invited to apply, but the list of challenges remains open to all potentially interested suppliers.

Proposal submissions are collected and pre-screened by the mining company and by *Fundación Chile*, which plays the role of an honest broker of the scheme. The preselection process is mostly based on the estimated capabilities of applicant firms, and the mining company manages the final list of proposals. When minimum criteria are met, the mining company selects a 'winner' and the process

of negotiation of a contract begins. Although the detail of the contracts of the selected projects are kept private, because these are co-innovation projects, mining companies are expected to provide access to facilities and non-pecuniary resources during project development. Besides bringing its resources to the project, the selected supplier may also apply to public financial support. Specifically, the Chilean Development Agency, CORFO, favors mining suppliers participating in the programme when these companies apply to innovation support schemes. A critical characteristic of the programme is that it is expected that the selected supplier retains the ownership of any intellectual property created during the project. Therefore, facilitating the supplier's development through commercializing and exploiting the new (protected) knowledge.

The implementation of the projects typically lasts between 15 to 27 months (Fundación Chile, 2012). Completed projects lead suppliers to receive technical assistance on commercialisation of the recently developed innovation. The mining company provides the financing for this consultancy, while domestic accelerators and business consultants offer their services.

Although the programme lacks a proper impact evaluation, some detailed results have been examined by Navarro (2018). Between 2009 and 2016, 92 projects were assigned to 75 suppliers.[7] The estimated pool of mining suppliers in the country ranges between 4500 to 6000 (Comisión Nacional de Productividad, 2017). 31 of the 75 suppliers participating in the programme had applied for patents before participating in the programme (Navarro 2018). This high rate of patent-active firms contrasts with the 10% of the product innovative companies that fill for patents in the rest of the Chilean economy.[8] Even within the subsample of experienced patenting companies, merely one of every five companies filed for new patents after the completion of the projects. Although only indicative, the latter reflects the non-patentable nature of a not trivial share of the operational challenges of large mining companies.[9]

Analysis and performance

The results of the programme suggest that addressing these market failures has had some impact on a selected group of suppliers. Nevertheless, the complex interaction between buyers and suppliers in the mining GVC is the subject of other market mechanisms that can be more of a deterrent to the development of domestic knowledge-intensive mining suppliers (Urzúa et al., 2017). One of the main issues however, remains the insufficient supply of local knowledge. R&D expenditures and researchers involved in the Chilean mining industry show a significant lag with respect to countries like Australia (Meller & Parodi, 2017), there appears to be low involvement of multinational mining companies in R&D activities near their operations (Pietrobelli et al., 2018), and local universities do not contribute to a large extent to the industry (Confraria & Vargas, 2019). These 'symptoms' may be linked to business environment conditions that require interventions that go beyond a single

[7] Of all suppliers, 62 developed only one project.
[8] Own calculations using Chilean National Innovation Survey of 2017.
[9] If we assume that all suppliers that applied for patents before participating in the WCS programme had used that knowledge as the main input of the solution they developed (40% of participants), and that all new patent applications are made by suppliers which did not have patents before the programme (20% of participants), the results of the programme imply that at least 40% of the companies participating in the WCS did not filled for new patents after the completion of the project.

programme to be adequately addressed. For instance, the bias of mining multinationals towards conducting R&D in home countries is a response to efficiency in knowledge management and returns to investments. This type of company conducts R&D in host countries only when there are opportunities to increase their corporate knowledge from these external sources (Belderbos, Leten, & Suzuki, 2013; Belderbos, Lykogianni, & Veugelers, 2008). The lack of incentives in academia to engage in industry research may also be linked to the rewards scheme of the academic system for researchers in local universities. Finally, capabilities failure in domestic suppliers sets limits to the number of companies that would be able to engage in innovative projects that could eventually lead to knowledge-driven growth.

Although the WCS programme has allowed to increase, to a certain extent, the demand for innovations, the relatively small number and size of the projects contracted under the programme suggest the existence of other restrictions to innovation on the demand side. We speculate that this may be explained by the existence of principal-agent problems inside the large mining companies. While the WCS programme responds mainly to a need for Corporate Social Responsibility, and is managed by the corresponding departments, procurement decision-making is driven by operational optimisation, considering risk management and efficiency. Therefore, the procurement incentives of large mining companies are not necessarily aligned with the programme (Meller & Parodi, 2017).

In brief, the WCS programme was an innovative initiative to lessen the asymmetries of information between mining suppliers and large mining companies, driven by the operational problems of the latter. Some results show that indeed certain companies benefited from the interaction, but generally the scheme has done little to accelerate the growth of domestic METS or the industry. Some other constraints in the market hinder the intensity of the collaborations between mining companies and suppliers, and the number and capacities of the latter. As Meller and Parodi (2017) remark, regardless of the design and effectiveness of the WCS programme, the size of the interventions is not commensurate with the magnitude of the challenge it is seeking to address.

New policies

Since implementing WCS-type programmes is not a sufficient condition to make an impact at a more aggregate level, the Chilean government developed a new initiative to leverage the mining industry to develop knowledge-intensive companies. Backed by the learning process on WCS programme and previous national and regional scale policies like the Cluster Development Programme and the Regional Development Agencies in the 2000s (Bravo-Ortega & Muñoz, 2018), the Chilean government launched the *Alta Ley*[10] programme in 2015.

Alta Ley is a *smart specialisation strategy* programme (Foray, 2017), led by the public sector through CORFO, the Ministry of Economy and the Ministry of Mining. Besides focusing on promoting the development of the METS sector, this programme also targets productivity increase in the industry. The board of the programme is made of members of the public sector, NGOs and universities, and more importantly, the private sector. The latter is represented by the major mining companies of the country, and representatives of the mining suppliers' industry associations.

[10] It translates literally as "High Grade"

The primary function of the programme is to coordinate efforts to match the supply of knowledge with the demand for specific knowledge solutions demanded in the industry. Mining firms demand knowledge and technological solutions that are not always necessarily provided by other firms in the industry. The expansion of the WCS programme aims at better matchmaking demand and supply of mining-related knowledge. *Alta Ley* impacts on the supply of knowledge by facilitating coordination between different stakeholders of the industry to increase the size and efficiency of public and club goods in the industry (Castillo et al., 2018).[11] On the demand side, the Alta Ley programme identified the five main *drivers* of innovation for the industry.[12] The strategy is reflected in roadmaps that would guide the decision-making of stakeholders participating in the initiative. The implementation is made through programmes designed by the Alta Ley programme team. The financing comes from competitive applications to public sources.[13] One of the six programmes currently implemented is the *Expande* programme, which is the continuation of the WCS programme (Meller & Parodi, 2017).

The *Expande* programme is based on the WCS programme and inspired by the open innovation strategy concept (Chesbrough, 2003) (see Chapter 9). Therefore, its operational mechanism goes beyond producing a bilateral transaction between a single innovation provider and the mining industry. Indeed, the main difference with the WCS programme is that METS are also allowed to provide solutions to operational problems that have not been previously codified by any large mining company. On top of that, the main players of the industry are participating in the initiative and signalling the main productive challenges of the mining sector for the coming decades, and it also opens the supply side of innovation to new actors like universities, research centers and companies not previously working with the mining industry. *Fundación Chile* maintains the role of a broker but its performance becomes more critical, participating more actively in the production of information and matchmaking between mining companies and METS. *Fundación Chile* measures and surveys the local technical capacities that may be useful for the industry, while also translating the operational challenges of the industry to project-type potential suppliers. Since the *Expande* programme has been in implementation for a short period of time, is it not possible to assess its outcome. However, at least in principle, by acting on both the supply and demand sides of innovation we should expect more projects than in the WCS programme. However, there is no signal so far that the size of the programme has been increased in a significant way, nor that the procurement policies of the large mining companies have been affected in any way.

Although Alta Ley has existed for a short time, from its design we may consider it a step forward towards solving the shortage of knowledge supply to the industry. Allowing coordination between large mining companies and signaling the main challenges of the industry to other actors of the system is expected to lower barriers to collaborative R&D and decrease the uncertainty of innovation investment decisions for the rest of the actors of the system. At the same time, better coordination between private companies and the government may increase the efficiency of the provision of knowledge and other public goods to the industry. The technological roadmaps are expected to align private and public research and innovation investments towards the leading

[11] Skill-based technical education, public infrastructure, institutions and regulations, and suppliers' development.
[12] Mining operations, concentration of minerals, tailings, hydrometallurgy, and smelting and refining.
[13] For example the Strategic Investment Fund.

technologies and operational challenges of the industry as a whole. Their scope and magnitude is expected to be large enough to increase knowledge investments and eventually, promote innovation to a significant extent.

In sum, as we notice the positive and original policy developments, it remains to be seen if the new public-private collaborative approach through smart specialisation strategies succeeds in easing the primary constraints to get more intense and stronger interactions between domestic METS and large mining companies. Efforts like the WCS programme, although valuable on its own as an innovative approach to connect mining companies with new suppliers, are not enough to lead the way towards a larger METS sector. We argue that the size of the industry and the potential gains require investments of a higher order of magnitude.

5. Conclusion

This chapter tries to broaden the scope and understanding of innovation in the mining sector, with a focus on emerging countries based on the experience of Latin America. The central underlying idea is that today innovation can foster growth of many countries endowed with natural resource in new ways that were not considered or not available in the past. New opportunities for innovation are emerging in the mining sector. Some may be patentable, but many others are not, and they are more related to the organisation of the business and of the network of transactions with different actors along the value chain. Innovation may powerfully develop through the interaction and linkages between mining companies, their suppliers, and other organisations active in the innovation system. Moreover, the new features of scientific knowledge applied to the mining sector (e.g. ICT, new materials, biotechnology) open new opportunities for new suppliers from emerging countries to enter and add value in mining GVCs.

In this chapter we analyse how some successful examples prove that these developments are real and offer new opportunities that were hard to visualise before. However, this does not reduce the role of public policies; indeed it promotes the need to rethink and innovate policy approaches, as the brief policy review revealed. Mining cannot become a true engine of growth for emerging economies unless linkages within mining value chains and beyond are enhanced and the system that produces the required advanced knowledge and capabilities is strengthened.

References

Andersen, A.D. 2012. "Towards a new approach to natural resources and development: the role of learning, innovation and linkage dynamics". *Int. J. Technological Learning, Innovation and Development*, vol. 5(3) 291–324.

Arias M., Atienza M. y J. Cadenmatori (2014) "Large mining enterprises and regional development in Chile" *Journal of Economic Geography* 14 73-95.

Bamber P., Fernandez-Stark K., and Gereffi G., 2016, "Peru in the Mining Equipment Global Value Chain. Opportunities for Upgrading", January, available at https://gvcc.duke.edu , accessed April 26, 2018.

Barnett R. and Lopez, L. 2012. *The Rise of the Machines*. Perth, https://www.ventureconsultants.com.au/FINAL_REPORT-Rise_of_the_Machines.pdf, accessed August 7, 2018.

Belderbos, René, Bart Leten, and Shinya Suzuki. 2013. "How Global Is R&D?: Firm-Level Determinants of Home Country Bias in R&D." *Journal of International Business Studies* 44 (8): 765–86. doi:10.1057/jibs.2013.33.

Belderbos, René, Elissavet Lykogianni, and Reinhilde Veugelers. 2008. "Strategic R&D Location by Multinational Firms: Spillovers, Technology Sourcing, and Competition." *Journal of Economics & Management Strategy* 17 (3): 759–79. doi:10.1111/j.1530-9134.2008.00194.x.

Benavente J.M. y D. Goya (2011) "Copper mining in Chile", Sectorial Report, Project Opening up Natural Resource-Based Industries for Innovation: Exploring New Pathways for Development in Latin America, IDRC

Bravo-Ortega, Claudio, and Leonardo Muñoz. 2018. "Mining Services Suppliers in Chile: A Regional Approach (or Lack of It) for Their Development." *Resources Policy*, no. May. Elsevier Ltd: 1–19. doi:10.1016/j.resourpol.2018.06.001.

British Geological Survey 2018 World Mineral Production 2012-2016. British Geological Survey.

Calzada, B., 2018. "Innovation in Mining", UNU-MERIT mimeo, May for "Innovation in mining GVCs" project.

Castillo, Jonathan, Felipe Correa, Marco Dini, and Jorge Katz. 2018. "Políticas de Fomento Productivo Para El Desarrollo de Sectores Intensivos En Recursos Naturales: La Experiencia Del Programmea Nacional de Minería Alta Ley." 218. Serie Desarrollo Productivo. Santiago.

Chesbrough, H. W. 2003. *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Cambridge, MA: Harvard Business School Publishing.

Comisión Nacional de Productividad. 2017. "Productividad En La Gran Minería Del Cobre En Chile," no. 1: 1–445.

Confraria, H., & Vargas, F. (2019). Scientific systems in Latin America: performance, networks, and collaborations with industry. *The Journal of Technology Transfer*, 44(3), 874-915.

Corden, M., & Neary, P. (1982). Booming Sector and De-Industrialisation in a Small Open Economy. *The Economic Journal*, 92(368), 825–848.

Dantas, E. (2011). The evolution of the knowledge accumulation function in the formation of the Brazilian biofuels innovation system. *International Journal of Technology and Globalisation*, 5(3-4), 327–340.

ECA, 2013, *Making the Most of Africa's Commodities: Industrializing for Growth, Jobs and Economic Transformation, Economic Report on Africa*, United Nations Economic Commission for Africa, Addis Ababa, https://www.uneca.org/sites/default/files/PublicationFiles/unera_report_eng_final_web.pdf, accessed May 9, 2018.

Figueiredo P. and Piana J., 2018, "Innovative capability building and learning linkages in new entrant knowledge-intensive service SMEs in the mining industry: Evidence from Brazil", *Resources Policy*, Vol.58, October, pp.21-33, http://dx.doi.org/10.1016/j.resourpol.2017.10.012

Figueiredo, P.N., Piana, J., 2016, "When "one thing (almost) leads to another": A micro-level exploration of learning linkages in Brazil's mining industry". *Resources Policy*, Vol.49, September, pp.405-414, http://dx.doi.org/10.1016/j.resourpol.2016.07.008

Foray, Dominique. 2017. "The Economic Fundamentals of Smart Specialisation Strategies." Advances in the Theory and Practice of Smart Specialisation, January. Academic Press, 37–50. doi:10.1016/B978-0-12-804137-6.00002-4.

Gereffi, G., Humphrey, J. and Sturgeon, T. (2005) 'The Governance of Global Value Chains', *Review of International Political Economy*, 12(1): 78–104.

Gereffi G., Korzeniewicz, M. and Korzeniewicz, R. (1994) 'Introduction: Global Commodity Chains', in G. Gereffi and M. Korzeniewicz (eds) *Commodity Chains and Global Capitalism*, Westport, CT: Greenwood Press, pp. 1–14.

Gibbon, P., Bair, J. and Ponte, S. (2008) 'Governing Global Value Chains: An Introduction', *Economy and Society*, 37(3): 315–38.

Giuliani E., Pietrobelli C., Rabellotti R., 2005 "Upgrading In Global Value Chains: Lessons From Latin American Clusters", *World Development*, Vol.33(4), pp. 549–73.

Hirschman, A.O. (1958). *The Strategy of Economic Development*. New Haven, Conn.: Yale University Press.

Iizuka, M. & Katz, J., 2015, `Globalisation, Sustainability and the Role of Institutions: the case of the Chilean salmon industry, *Tijdschrift voor Economische en Sociale Geografie*, Vol 106, No2: 140-153 DOI:10.1111/tesg.12132.

Kaplan D., 2012, "South African mining equipment and specialist services: Technological Capacity, export performance and policy", *Resources Policy*, 37 pp.425–33, http://dx.doi.org/10.1016/j.resourpol.2012.06.001

Katz J. and Pietrobelli C., 2018, "Natural resource-based growth, global value chains and domestic capabilities in the mining industry", *Resources Policy* Vol.58, October, pp.11-20, https://doi.org/10.1016/j.resourpol.2018.02.001

Lachman, J. and López, A. (2018). "Nuevas oportunidades y desafíos productivos en la Argentina: Resultados de la Primera Encuesta Nacional a Empresas de Agricultura y Ganadería de Precisión". IIEP-BAIRES, Serie Documentos de Trabajo 38, Buenos Aires, diciembre.

Lema R., Pietrobelli C., Rabellotti R., 2018, Innovation in Global Value Chains, UNU-MERIT WP, 2018-038, UNU-MERIT, Maastricht, https://www.merit.unu.edu/publications/wppdf/2018/wp2018-038.pdf

Lundvall,B-A (1992 reprinted in 2010) User-producer relationships, National systems of innovation and Internationalisation in Lundvall B-A (ed) *National Systems of Innovation: Towards a theory of innovation and interactive learning*. London and NY, The Anthem Press:p 47-70.

Marin, A., Navas-Aleman, L. y Perez, C. (2015). Natural Resource Industries as a Platform for the Development of Knowledge Intensive Industries. *Tijdschrift Voor Economische en Sociale Geografie*. Vol 106, Issue 2.

Marin, A., Dantas, E. y Obaya, M. (2016). "Alternative technological paths in new NR-related industries: the case of seeds in Argentina and Brazil", CENIT Working Paper http://www.fund-cenit.org.ar/alternative-technological-paths-in-new-nr-related-industries-the-case-of-seeds-in-argentina-and-brazil/publicacion/392/es

Meller P. (2002) "El cobre chileno y la política minera" en Meller P. (Eds) *Dilemas y Debates en torno al Cobre*, Publicaciones Cieplan.

Meller P. and Parodi P.. 2017. "Del Programmea de Proveedores a La Innovación Abierta En Minería." Mimeo CIEPLAN.

Molina O., 2018, "Innovation in an Unfavorable Context: Local Mining Suppliers in Peru", R*esources Policy*, Vol.58, October, pp. 34-48, https://doi.org/10.1016/j.resourpol.2017.10.011

Molina O., Olivari J. and Pietrobelli C., 2016, "Global Value Chains in the Peruvian Mining Sector", Inter-American Development Bank IDB-TN-1114 http://dx.doi.org/10.18235/0000468

Morris, M., R. Kaplinsky y D. Kaplan (2012) "One thing leads to another- commodities, linkages and industrial development" *Resources Policy* 37; 408–416

Morrison, A., Pietrobelli, C. and Rabellotti, R. (2008) 'Global Value Chains and Technological Capabilities: A Framework to Study Learning and Innovation in Developing Countries', *Oxford Development Studies*, 36(1), pp. 39–58. https://doi.org/10.1080/13600810701848144 .

Navarro, Lucas. 2018. "The World Class Supplier Programme for Mining in Chile: Assessment and Perspectives." *Resources Policy*, Vol.58, October, pp. 49-61 http://dx.doi.org/10.1016/j.resourpol.2017.10.008 .

Organisation for Economic Co-operation and Development, Economic Analysis and Statistics Division, OECD science, technology and industry scoreboard: towards a knowledge-based economy, OECD Publishing, 2001, ISBN 92-64-18648-4.

Pérez C. (2010), "Technological dynamism and social inclusion in Latin America: a resource- based development strategy" *CEPAL Review*, N 100, pp 121-141.

Pietrobelli C. and Rabellotti R., 2007, *Upgrading to Compete. Global Value Chains, SMEs and Clusters in Latin America*, Cambridge Ma.: HARVARD University Press http://www.hup.harvard.edu/catalog.php?isbn=9781597820325

Pietrobelli C. and R. Rabellotti (2011) "Global Value Chains Meet Innovation Systems: Are There Learning Opportunities for Developing Countries", *World Development* 39(7):1261-1269.

Pietrobelli C., Marin A., Olivari J., 2018, "Innovation in mining value chains: New evidence from Latin America", *Resources Policy*, Vol. 58, October, Pages 1-10, https://doi.org/10.1016/j.resourpol.2018.05.010

Pietrobelli C and Olivari J. (Eds.), 2018, *Special Issue on Mining Value Chains, Innovation and Learning*, *Resources Policy*, Vol. 58, Pages 1-314, October.

Ponte S. and Sturgeon T., 2014, “Explaining governance in global value chains: A modular theory-building effort”, *Review of International Political Economy*, Vol. 21, No. 1, 195–223, http://dx.doi.org/10.1080/09692290.2013.809596.

Prebisch, R., 1950. *The economic development of Latin America and its principal problems*. Economic Bulletin for Latin America 7, 1-12.

Stubrin L., 2018, “Innovation, learning and competence building in the mining industry. The case of knowledge intensive mining suppliers (KIMS) in Chile”, *Resources Policy* Vol. 58, October, Pages 62-70, https://doi.org/10.1016/j.resourpol.2017.10.009

Urzúa, Osvaldo, Alejandra Wood, Michiko Iizuka, Fernando Vargas, and Jakob Baumann. 2017. “Discovering New Public-Private Partnerships for Productive and Technological Development in Emerging Mining Countries.” 5. Working Document.

US Geological survey, 2018, *Mineral Commodity Summaries 2018*, USGS Mineral Resources

Venables, A.J., 2016. "Using Natural Resources for Development: Why Has It Proven So Difficult?" *Journal of Economic Perspectives*, 30(1): 161-84. https://doi.org/10.1257/jep.30.1.161

The UNU-MERIT WORKING Paper Series

2019-01 *From "destructive creation" to "creative destruction": Rethinking Science, Technology and innovation in a global context* by Luc Soete
2019-02 *Do young innovative companies create more jobs? Evidence from Pakistani textile firms* by Waqar Wadho, Micheline Goedhuys and Azam Chaudhry
2019-03 *What gains and distributional implications result from trade liberalization?* by Maria Bas and Caroline Paunov
2019-04 *FDI, multinationals and structural change in developing countries* by André Pineli, Rajneesh Narula and Rene Belderbos
2019-05 *The race against the robots and the fallacy of the giant cheesecake: Immediate and imagined impacts of artificial intelligence* Wim Naudé
2019-06 *The middle-technology trap: The case of the automotive industry in Turkey* by Ibrahim Semih Akçomak and Serkan Bürken
2019-07 *The impact of a mathematics computer-assisted learning platform on students' mathematics test scores* by Marcelo Perera and Diego Aboal
2019-08 *Health insurance and self-employment transitions in Vietnam* by Nga Le, Wim Groot, Sonila M. Tomini and Florian Tomini
2019-09 *Knowledge economy and economic development in the Arab region* by Samia Mohamed Nour
2019-10 *Migration of higher education students from the North Africa region* by Samia Mohamed Nour
2019-11 *Job automation risk, economic structure and trade: a European perspective* by Neil Foster-McGregor, Önder Nomaler an Bart Verspagen
2019-12 *The breadth of preferential trade agreements and the margins of* exports by Rod Falvey and Neil Foster-McGregor
2019-13 *What a firm produces matters: diversification, coherence and performance of Indian manufacturing firms* by Giovanni Dosi, Nanditha Mathew and Emanuele Pugliese
2019-14 *Brazilian exporters and the rise of Global Value Chains: an empirical assessment* by Caio Torres Mazzi
2019-15 *How has globalisation affected the economic growth, structural change and poverty reduction linkages? Insights from international comparisons* by Aradhna Aggarwal
2019-16 *R&D, innovation and productivity* by Pierre Mohnen
2019-17 *Domestic intellectual property rights protection and exports: Accessing the credit channel* by Gideon Ndubuisi
2019-18 *The role of early-career university prestige stratification on the future academic performance of scholars* by Mario Gonzalez-Sauri and Giulia Rossello
2019-19 *The employment impact of product innovations in sub-Saharan Africa: Firm-level evidence* by Elvis Korku Avenyo, Maty Konte and Pierre Mohnen
2019-20 *Embodied and disembodied technological change: the sectoral patterns of job-creation and job-destruction* by G. Dosi, M. Piva, M. E. Virgillito and M. Vivarelli
2019-21 *Can we have growth when population is stagnant? Testing linear growth rate formulas and their cross-unit cointegration of non-scale endogenous growth models* by Thomas H.W. Ziesemer

2019-22 *Technical progress and structural change: a long-term view* by Alessandro Nuvolari and Emanuele Russo

2019-23 *No evidence of an oil curse: Natural resource abundance, capital formation and productivity* by Mueid al Raee, Denis Crombrughe and Jo Ritzen

2019-24 Far from random? The role of homophily in student supervision by Giulia Rossello and Robin Cowan

2019-25 *Semi-endogenous growth models with domestic and foreign private and public R&D linked to VECMs* by Thomas H. W. Ziesemer

2019-26 *Characterizing growth instability: new evidence on unit roots and structural breaks in long run time series* by Emanuele Russo, Neil Foster-McGregor and Bart Verspagen

2019-27 *Measuring attitudes on gender equality and domestic violence in the Arab context: The role of framing, priming and interviewer effects* by Ann-Kristin Reitmann, Micheline Goedhuys, Michael Grimm and Eleonora E. M. Nillesen

2019-28 *Imported intermediates, technological capabilities and exports: Evidence from Brazilian firm-level data* by Caio Torres Mazzi and Neil Foster-McGregor

2019-29 *Japan's productivity and GDP growth: The role of GBAORD, public and foreign R&D* by Thomas Ziesemer

2019-30 *The decline in entrepreneurship in the West: Is complexity ossifying the economy?* by Wim Naudé

2019-31 *Modern industrial policy in Latin America: Lessons from cluster development policies* by Carlo Pietrobelli

2019-32 *Testing the employment and skill impact of new technologies: A survey and some methodological issues* by Laura Barbieri, Chiara Mussida, Mariacristina Piva and Marco Vivarelli

2019-33 *The Potential for innovation in mining value chains. Evidence from Latin America* by Michiko Iizuka, Carlo Pietrobelli and Fernando Vargas