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Global Challenges for Innovation in the Mining Industries

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Introduction

People have been digging in the ground for useful minerals for thousands of years. Stone Age people dug for flints, Bronze Age people for copper. But the manner in which they have dug for minerals has changed out of all recognition. While early miners hacked small amounts of mineral from the ground with antler horns, some of today's mines employ 300 tonne trucks driven and scheduled by computers. Innovation lies at the heart of the story of mining.

Mineral materials are the foundation of modern industrial society. They are used in vast quantities to construct the infrastructure of our lives – the roads, the power stations, the airports and our homes. They are used for the durable products that we employ within this infrastructure – the cars, the planes, the hospital equipment and the refrigerators, as well as in the machinery required to produce these things. And they are used in the sophisticated gadgets that underpin the technology economy and the security products that keep us safe. The ordinary smartphone contains no less than seventy different mineral elements.

Mining ensures that we have an adequate supply of the raw materials to produce all these things, and at competitive prices. As the global population grows and standards of living of people in emerging and developing countries rises, so is demand for these mineral products increasing. In 1990, world demand for copper stood at 10.7 million tonnes. In 2017, it was over 23 million tonnes. If this rate of growth persists, by 2030 it will be 36 million tonnes.

Adding to the challenge that miners face in meeting this growing demand are two other factors. For many mineral commodities, the quality of the resources being worked is deteriorating, resulting in increased energy use and more waste. Second, the world is increasingly, and rightly, concerned about the social and environmental impacts of mining.

Innovation is central to meeting these diverse and challenging objectives. It is critical to developing techniques for finding new deposits of minerals, to enabling us to recover increasing amounts of minerals from the ground in a cost-effective manner, and to ensuring that this is done is a way that is environmentally responsible. How the industry and governments are addressing this challenge, and what they still need to do, is the subject of this book.

In this chapter, we begin by describing the mining industry and its major economic characteristics. We then discuss the role of innovation in the industry and the environment in which it takes place, and, finally, we summarize some of the major findings to emerge from the subsequent chapters in the book.

1.1 The Mining Industry

Mining is the business of recovering minerals from the ground and converting them into useable industrial materials and consumer products. The minerals we are talking about here are generally "hard" minerals, which is to say we exclude oil and gas but include the energy minerals coal and uranium. Within the category of hard minerals, the major subcategories are metals (and, within this, ferrous [iron-related] minerals, nonferrous metals and precious metals) and nonmetallics (construction minerals, industrial minerals and precious and semiprecious stones).

Although economically smaller than the oil and gas industry, the mining industry is still a very large, and very global, industry. Relative to the oil industry, the mining industry is much more diverse in its nature and much more geographically dispersed. Moreover, minerals are used in a much wider range of products. Whereas oil and gas are predominantly used in energy applications, minerals are used in everything from construction to soap powders. They are also the key constituents of the battery systems, wind turbines and solar panels used for the production and storage of renewable energy.

Determining the exact scale of the industry economically is not straightforward and, of course, valuations inevitably fluctuate from year to year along with the prices of mineral commodities. It has been estimated that the value of global mine production, at the mine gate, was around $1.3 trillion in 2014 (Lof and Ericsson, 2016). Coal accounted for around half of this, with the next biggest contributions coming from iron ore, gold and copper. If one looks at the market capitalization of the mining industry as determined on global stock markets, this is estimated to have been around $1.2 trillion at the end of 2016 (S&P Global, 2017). This equated to around 1.8 percent of the value of the global stock market at the time. It should be noted, though, that stock markets do not cover state-owned companies or the large number of small private mining concerns.

However, such broad valuations fail to capture the full economic significance of the industry for two reasons. Mineral raw materials are the starting point of long supply chains that involve substantial value adding through processing, fabrication and marketing. While the raw materials may represent only a small fraction of the value of the final marketed product, without the mineral raw material there would be no chain and no product. The value of the mineral at the mine gate is therefore just that. It says nothing about the form in which the mineral is eventually delivered to the end user or the value that has been added along the way. Very occasionally this value adding takes place at the mine but much more usually it takes place somewhere remote from it in an urban industrial center.

The second reason that global valuations offer only a partial perspective on the mining industry's economic importance is that estimates of global value fail to capture the specific importance of the mining industry to individual countries. Mining typically accounts for only a relatively small proportion of GDP (less than 10 percent) and employment (less than 5 percent) even in the world's largest mineral producing countries. However, the sector's contribution to foreign direct investment, to exports and to public finances can be very substantial indeed. The International Council on Mining and Metals (ICMM) lists 41 countries where minerals account for over 25 percent of exports by value, including 10 where they account for over 50 percent. And it lists 14 countries where receipts from mining account for more than 10 percent of government revenues (ICMM, 2016). Many of these countries are in Africa, although countries in Asia and Latin America are also represented. Such "mineral-driven" economies often have relatively few practical alternatives to mining for the promotion of their development.

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As regards the corporate structure of the mining industry, this is divided between a relatively small number of large companies and a large number of much smaller companies. An analysis conducted by the ICMM suggests that there are around 150 global and large-scale companies, often referred to as "majors"; maybe 350 intermediate companies operating in one commodity or one country, these possibly on a pathway to becoming majors; and perhaps 1,500 companies having just one mine. In addition, there are upwards of 2,500 small exploration companies, some with serious prospects and others largely speculative (ICMM, 2012a, 2012b).

The two poles of the industry have markedly different functions. The larger companies are *production focused*. They account for most of the capital of the industry, a large part of this coming in the form of debt financing, and a high proportion of its mine production. The small companies work smaller deposits or operate in niche minerals, while *exploration companies* are essentially focused on discovering and proving up mineral deposits, often with a view to selling them on to a major for development. The high risk of exploration generally means that banks will not lend to these companies, so they have to raise their finance in stock markets. The most important stock markets specializing in this kind of financing are located in Toronto, Sydney and London.

In addition to companies directly engaged in finding and developing mines, there are a large number of companies supplying the mining industry with equipment and technology, a sector commonly referred to as the mining, equipment, technology and services (METS) sector. These companies work very closely with mining companies to understand their requirements and to develop innovative solutions, be these in the design and manufacture of large earthmoving trucks or in the provision of process software. Because METS companies cover a wide range of activities and do not conveniently fit traditional industrial sector categories, the precise scale of the METS sector is hard to assess. However, for some countries it is economically significant. In Australia, which has one of the world's most developed METS sectors, it is estimated that the sector accounts for A$90 billion of sales, including A$15 billion of exports. The industry association catering for METS companies, Austmine, has over 450 members (Austmine, 2018).

Beyond the formal mining sector, there is a significant informal mining industry, populated by so-called ASMs (artisanal and small-scale miners). These are very low-tech operators, employing little capital and often unregulated. Except for a few commodities such as tin, tantalum, gold and precious and semi-precious stones, ASMs account for only a very small proportion of global mineral production. The sector does, however, employ a very large number of people and attract a lot of public attention. The low-tech nature of the activity means that it does not play too much of a part in the more sophisticated types of innovation which are the primary focus of this book, but there is a strand of innovation relating to so-called frugal technologies which is relevant to this sector.

1.1.1 Mining Activities

While mining, as noted, is normally thought of as the business of recovering minerals from the ground, the actual digging up of minerals is in fact only one step in the process in which the mining industry engages, and only one of the spheres offering scope for innovation. The full process is illustrated in Figure 1.1. All these steps are essential for the creation of a successful mine.

The first step, and in fact the step where a lot of the value of a mineral deposit is created, is discovery. Exploration is a challenging and high-risk activity and a very small proportion of deposits looked at ever make it into production. The initial process of exploration can take many forms: the painstaking study of geological maps (where these exist), the interrogation of geological models, fly-over geophysical surveys, on-the-ground geochemical analyses and, perhaps, some exploratory drilling. Exploration can be thought of as part of the industry's R&D in as far as it represents a search for new products.

It is only if these initial investigations suggest that there might be a deposit with sufficient size and grade to make for a commercial mining operation that the project will be taken to the next stage, that of trying to prove up the deposit and establish a resource. This involves some serious drilling and, since drilling is costly (upwards of $100 a meter), it is only warranted if there is a good chance of establishing a commercial deposit. Otherwise, the exploration company would do better to cut its losses and look elsewhere.

In the event that this hurdle is surmounted, then the next task is to undertake a whole lot more drilling, at greater density, to establish

Figure 1.1 Simplified view of the life of a mine
Source: Author's elaboration.

a reserve (that part of the mineral resource which might provide the basis for an operating mine). At this point, the would-be miner will also have to give consideration to all the other elements that need to go into the creation of a working mine, the type and scale of the operation, where power to the mine will come from, how the product will be transported from the mine to market, and the establishment of a constructive dialogue with communities liable to be impacted by the mine and which might provide employees to it. The culmination of this process is usually a bankable feasibility study, an extensive and detailed analysis of the project showing that every aspect of the mine project has been addressed and demonstrating how it can make money for its owners and lenders. This is an acid test and, inevitably, a number of projects fail it.

For those projects that obtain financing then comes the matter of actually developing the mine. Given that this will commonly involve building supporting infrastructure (for example, roads, ports, power lines), the purchase of large amounts of equipment, the construction of plant and waste disposal facilities, the preparation of the ore body (for example, removal of overburden) and the training up of staff, this process can easily take three to four years.

It is only at this point that mining, as the term is commonly understood, takes place, where the digging and the bringing to the surface of the mineral-containing ore can proceed. Beyond this is the stage of processing. Very few minerals can be shipped and sold in the form in which they come out of the ground. Most need to be subject to some kind of treatment – referred to in the industry as "beneficiation" – whether this is the relatively simple matter of washing and screening (as in the case of coal) or the upgrading of the ore into a mineral concentrate through a process involving crushing, grinding and froth flotation (as in the case of copper sulfides).

For reasons of transportation costs (it is uneconomic to carry large amounts of dirt long distances), this processing stage typically takes place at the mine site and is considered integral to the activity of mining, since, without it, mined products cannot be sold. Thus the product at the mine gate will typically be an upgraded product that can be transported elsewhere for further processing or that can be sold to a third party for such processing. For metals, this further processing generally means smelting into metal and then refining to increase its purity. In some instances, the availability of local infrastructure (for example, power and ports) and relevant skills favor doing smelting and refining at or near the mine but often it does not, so these activities are carried out elsewhere, remote from the mine.

The final stage in the life of a mine is its closure. Historically, many mines were simply abandoned when they ran out of ore, with environmentally disastrous consequences. Today, this is unacceptable and companies have to start preparing for the closure of their mines in a socially and environmentally responsible fashion right at the outset of mining. Indeed it may well be the case that permission to mine in the first place is contingent on the miner satisfying the licensing authorities that they have a plan and have made sufficient financial provision for the mine's closure.

Naturally, the precise path a project follows will depend on the mineral commodity being produced. Moreover, different stages in the process are more important for some commodities than for others. For copper and gold, the value of the final refined metal product is largely (90 percent plus) created through exploration and mining. For aluminium and steel, most of the value is created through processing, the ores from which they are made, bauxite and iron ore, being relatively abundant in nature.

There are also some important geographical aspects to the process described. Mining supply chains are truly global. As already noted, while the final processing of a mineral product into finished form sometimes takes place near to the mine, in many cases it does not. A substantial proportion of the world's iron ore and copper concentrates is converted into metal – steel and refined copper respectively – at a distance from the mine and very often in another country, giving rise to a large global trade in these products. A similar situation arises with the technologies and equipment employed in mining, international products commonly developed in one country and applied or sold in another. Accordingly, to understand how the industry works, and track the influences upon it, one necessarily has to adopt a global perspective.

1.1.2 *Economics of the Mining Industry*

The mining industry has some very specific economic characteristics which it is important to understand since they shape the way the industry works and the behavior of policy-makers toward it. They also have important implications for the targeting of innovation in the industry.

Minerals Are Non-renewable. Minerals are subject to depletion. Once mined, they cannot be mined again, although it may be possible to recycle the elements recovered by mining. Moreover, the quality of some mineral resources – which is to say their grade, the size of deposits, their depth and their ease of processing – is deteriorating as the better resources are worked out. To remain competitive, the industry has to battle continually to offset the effects of depletion through increased efficiencies and cost reductions.

Minerals Are Unevenly Distributed Geographically. Occurrences of minerals at sufficient concentrations to support viable mining operations are scarce. Their distribution follows the dictates of geology so miners do not have the luxury of choosing to go only to places with sound and stable institutions where infrastructure is readily available. They have to go to where the minerals are and they have to build the required plant and infrastructure in those locations, using the best available technologies wherever in the world these may have been developed. This can add substantially to upfront costs and to political risk. Minerals often have to be transported significant distances for processing and for fabrication, resulting in lengthy and complex value chains.

Mining Is Capital Intensive. The establishment of a mine involves large-scale expenditure, long before any revenues are generated. It is critically important to the economics of mining projects therefore that they are constructed as tightly and cost effectively as possible and that the mine and associated plant function as anticipated when the project was committed. The capital intensity of mining is also a factor encouraging the exploitation of economies of scale and in favoring projects with long lives. Given the long life of many mines, it is important to get production technologies right because, once committed, these are effectively baked into the operation for a very long time.

Miners Are Price Takers. Miners sell their products into global markets over which they have little or no control. Prices in the industry tend also to be highly volatile, reflecting both the sensitivity of mineral demand to changes in the rate of global economic growth and to the slow response times of mineral supply, which follows from the capital intensity of the industry. In the absence of any influence over prices, producers are required to focus on the matters over which they do have control to ensure their profitability, namely their capital spend and operating costs.

Mining Has Intense Local Impacts. Mining can be a powerful force for local and regional economic development, creating infrastructure, stimulating local businesses and providing jobs. However, it can also be socially and environmentally disruptive. Mining involves the removal of billions of tonnes of earth and the generation of large quantities of solid and liquid wastes. These problems are likely to get more challenging over time as mineral demand increases and public expectations of the industry rise. In addition, the generation of waste from mining is growing faster than the growth of mine production as the quality of resources being mined deteriorates. This will add to pressures on the industry to develop innovative ways to deal with the environmental consequences of mining as well as to work more closely with affected communities.

Collectively, these characteristics add up to an industry that requires a close focus on production costs and on operating in a socially and environmentally responsible manner. Moreover, the challenge of doing these things is getting greater as a result of resource depletion and growing restrictions on where and how companies in the industry can operate.

The key to unlocking cost reductions and reducing waste in a world of depleting ore resources is productivity growth – which is to say, growth in the output of mines per unit of factor inputs – driven by innovation. Historically, the industry has been remarkably successful in growing its productivity and in offsetting the effects of depletion, as evidenced by the fact that, over a very long period, the cost of producing minerals has not generally risen, and in a number cases has actually declined (Humphreys, 2013). Given the nature of mining, these advances have often come in the form of gradual and incremental improvements rather than through major breakthrough technologies. The physical laws governing mining militate against the sort of productivity improvements achievable in the technology sector as represented, for example, by Moore's law which holds that processing power for computers doubles every two years. But, over time, like compound interest, the cumulative effect of these incremental improvements has delivered dramatic increases in the mining industry's productivity.

History may or may not prove to be a reliable guide to the future. It could be that the industry will continue to deliver advances in productivity which offset the effects of depletion well into the future. But this is not something that can be taken for granted. There are strong upward pressures on capital and operating costs in the industry (Humphreys, 2015). Worryingly, it would appear from the data presented in Figure 1.2 that productivity in some major mining countries has actually declined since around 2000. There may be a cyclical element to this. Typically, industry productivity declines when commodity prices are high and producers are focused on the volume of

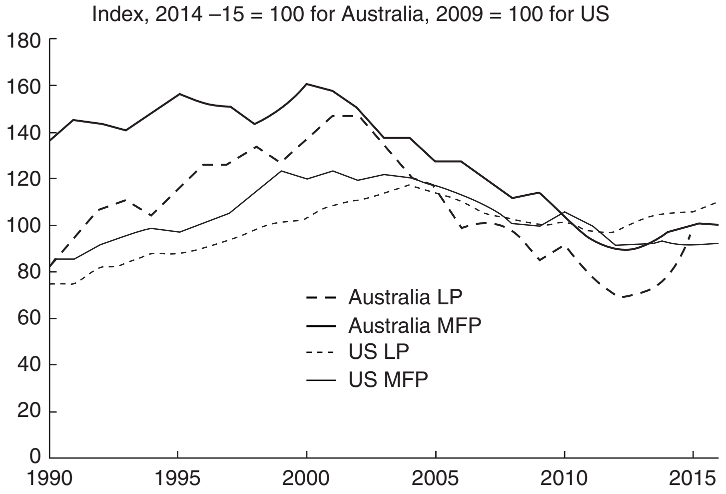

Figure 1.2 Productivity in the Australian and US mining industries
Notes: Labor productivity (LP) measures industry output per unit of labor input. Multifactor productivity (MFP) measures output per unit of total combined inputs, including labor, capital, energy and materials.
Sources: ABS (2018) and BLS (2018).

output rather than productivity. The last few years have seen a modest reversal of the negative trend, but it cannot yet be ruled out that there are longer-term structural forces at work here too. It should also be noted that there is mounting evidence of a decline in the productivity of exploration spending. It has been estimated that the cost of discovering an ounce of gold or a tonne of base metals has roughly doubled since the 1980s (BCG, 2015).

Miners may have to look in new places for their productivity growth in future. In the past, economies of scale have provided a major contribution to productivity growth but the industry may be reaching the limits of what these can contribute. Mines are not getting bigger and the growth in the scale of mining equipment has slowed. In future, productivity growth will have to come from other sources, particularly from innovative technologies that enable miners to work "smarter." These may include the application of high-powered computing and big data, the "Internet of things" and operating technology–information technology integration, increased automation and robotics, and the use of high-powered satellites in exploration (Mining Magazine, 2016). The challenge is a substantial one and the scope for the application of innovation considerable.