Critical Metals Handbook

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2. The mining industry and the supply of critical minerals

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Mineral products are bought for their utility, this utility being reflected in the price which consumers are prepared to pay for them. Properly functioning markets should ensure that an appropriate supply of such products is available to meet consumer demand. A shortage of the sought-after mineral serves to push prices up and stimulate companies to invest in new production capacity. A surfeit of supply leads to a fall in price and a curtailment of output.

The issue of a mineral's 'criticality' enters into the equation because the global economy is composed not just of companies and consumers but also of nations, and nations have strategic interests. Within the broader, strategic, context, mineral products are viewed not only as having utility to consumers but also in terms of the contribution they make to national projects, such as raising the living standards of the nation's citizens, maintaining a capability to produce certain important industrial goods, or ensuring that the nation has the ability to defend itself militarily. In making the transition from being simply 'useful' to being 'critical', minerals and their supply become not just matters for the market but also matters of national security. The process of transition is thus often referred to as 'securitisation'.

The role played by the mining industry in meeting the demand for minerals is subject to a similar duality. The economic function of mining companies is to respond to the requirements of the market, as expressed through mineral prices. For the most part, the industry does this quite effectively. The industry has always had a strong enterprise culture and rising mineral prices can usually be relied upon to prompt mining and exploration companies to develop mines and search for new mineral deposits.

As with mineral consumers, producers operate in a national setting. National authorities are responsible for establishing the legal, fiscal and environmental parameters within which mining companies work. However, like consuming nations, producing nations have strategic objectives. In this context, mining may be perceived as a vehicle for the promotion of broader objectives such as economic development, the reduction of poverty or the assertion of national self-determination. In a direct parallel with the process of securitisation in consuming countries, the assertion of these strategic priorities results in the politicisation of the mineral products and conditions the ability of the mining industry to respond to market signals and thus to supply the minerals that consumers require.

This chapter is divided into five sections. The first looks at the mining industry and its major corporate components, the miners and explorers. The second discusses how the mining industry

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Table 2.1 World's largest mining companies by market capitalisation, mid-March 2013. (Data from author's estimates based on web sources.)

Rank	Company	Country	Market Cap $bn
1	BHP Billiton	Australia	190
2	Rio Tinto	UK	92
3	Vale	Brazil	90
4	Xstrata	Switzerland	51
5	Anglo American	UK	39
6	Freeport McMoRan	USA	34
7	Grupo Mexico	Mexico	32
8	Norilsk Nickel	Russia	32
9	Barrick Gold	Canada	29
10	Goldcorp	Canada	26
11	Newmont Mining	USA	20
12	Newcrest Mining	Australia	18
13	Teck Resources	Canada	17
14	Antofagasta	UK	16
15	Fresnillo	UK	16
16	AngloGold Ashanti	South Africa	13
17	Fortescue Metals Group	Australia	13
18	Yamana Gold	Canada	11
19	Impala Platinum	South Africa	9
20	Kinross Gold	Canada	9

responds to the demand for minerals and to changes in the level of demand. The third examines the factors which inhibit the mining industry's responses to changes in demand. The fourth looks at some of the specific issues posed for miners by the minerals currently deemed 'critical' and at the role of China in mineral markets. The fifth considers some of the things that governments of consuming countries can do to promote the supply responsiveness of the mining industry.

Suppliers of minerals – miners and explorers

The mining industry exists to meet the mineral requirements of consumers and, in so doing, make profits for shareholders. Although not on the scale of the oil and gas industries, the mining industry is, nevertheless, a very large industry. The enterprise value[1] of the global mining industry in 2010 is estimated to have been around US$2100 billion (Citi, 2011a). London lies right at the heart of this industry, and is host to the headquarters of several of the world's largest mining companies. As of March 2013, there were thirteen mining and metals companies in the FTSE 100 having a combined market capitalisation of US$340 billion, 12.7 per cent of the total value of the FTSE100 (FTSE, 2013). Seven years earlier, the share was six per cent.

The structure of the global mining industry today is the product of a long and complex history. The largest and most publicly visible companies are the so-called 'global diversified miners', or mining 'majors'. These are, by any standards, large companies, operating across many geographies and minerals. Following a period of consolidation during the first decade of the century, this group currently comprises BHP Billiton, Vale, Rio Tinto, Anglo American and Xstrata.[2] The market capitalisation of the world's largest mining companies is shown in Table 2.1. The country indicated is the country of the company's primary stock market listing. The table, it should be noted, excludes aluminium companies, this because most of the value of aluminium, like steel, is created through metallurgical processing rather than through mining.

At the next level down in terms of scale, companies tend to be more focused with respect to either commodity or country. Freeport McMoRan, Grupo Mexico and Antofagasta, for example, are focused on copper, while Barrick Gold, Goldcorp and AngloGold Ashanti are, as their names suggest, focused on the production of gold. Companies which produce a variety of products, but which operate predominantly in one country, include several from the former Soviet Bloc, most notably Norilsk Nickel, but also Kazakhmys and ENRC (Eurasian Natural Resources Corp.) which fall just outside the top twenty companies listed.

Most of the world's largest miners, and all of those in Table 2.1, are public companies, quoted on stock markets (from which their market capitalisations are derived). There are, in addition, a few mining companies comparable in the scale of their mineral output to those listed in the table which are either wholly or predominantly owned by the state. These include the world's largest copper producer, Codelco, which is owned by the state of Chile, and a handful of Chinese companies such as China Shenhua, Yanzhou Coal, China Minmetals Corporation (Minmetals), Chinalco, Metallurgical Corporation of China, (MCC) China Nonferrous Metal Mining Corp. (CNMC) and the Jinchuan Group. Although production from state-owned enterprises is significant and growing, the extent of state ownership in mining is still very much less than is the case with oil and gas.

Beyond the larger and mid-sized mining companies, there are huge numbers of smaller miners, ranging from quoted companies with two or three mines to small family enterprises. Some produce for international markets and some just for local markets. The nature of the mineral product and the form of its occurrence play an important part in determining what products such producers focus on. Small miners do not generally try to compete in mineral markets where producers need scale economies and correspondingly large capital outlays, like iron ore. They can, however, operate in markets where demand is small or where ore deposits can be worked on a relatively small scale, like precious metals or semi-precious stones. At the extreme end of this part of the industry are the artisanal miners. These are very small, maybe even part-time, operators, recovering minerals that can be easily mined near surface (such as alluvial gold, tin, tantalum and diamonds) using very little capital. Such production activity is commonly lightly regulated or indeed wholly unregulated, with miners operating under very basic, and often unsafe and environmentally unsound, conditions. Artisanal mines do, nonetheless make a significant, if not always terribly reliable, contribution to the supply of several critical minerals.

The other key players in the mineral supply equation are exploration companies. This is the entrepreneurial end of the business – the equivalent of technology start-ups – the end where small companies go out to find mineral deposits in the hope either of being able to mine them themselves or else (and more often) sell them on at a good profit to a larger company for development. Since exploration can create enormous value for shareholders, turning what might otherwise be a fairly worthless piece of land into a profitable business opportunity, exploration companies have a strong pioneering quality. The highest rewards typically go to those with innovative ideas about ore genesis (an example might be those which uncovered significant diamond resources in Canada) or which are prepared to go looking in remote and difficult places. By the same token, exploration is also an extremely high-risk activity, and much exploration ends in failure and in investors losing their money.

Accordingly, exploration companies have their own particular economics and their own specialist investors. Banks, which might well be interested in helping a mining company with proven mineral reserves to finance the construction of a mine, are not generally interested in financing exploration. Exploration companies therefore tend to have to rely on equity (i.e. stock market) financing for their activities or on the support of large private

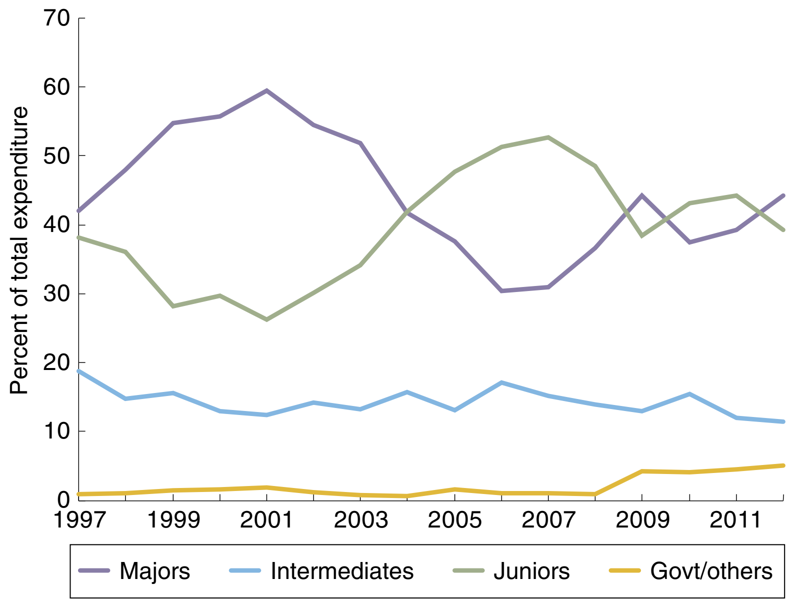

Figure 2.1 Worldwide exploration by company type: per cent shares, 1997–2012. (Data from MEG, 2012.)

investors. Some stock markets specialise in the provision of this sort of financing, notably the Toronto stock exchange (TSX) the Australian stock exchange (ASX) and the alternative investment market (AIM) of the London stock exchange (LSE). Because of the nature of its activities and of its financing, this is much the most responsive part of the mining industry and the part that is quickest to adjust to changes in market perceptions.

Metals Economics Group (MEG) has, for many years, compiled data on global exploration spending. For 2012, it estimated that expenditure was at a record level of US$21.5 billion (MEG 2012). Figure 2.1 shows the distribution of exploration expenditure in recent years split between that undertaken by mining majors, by intermediates, by juniors and by government or other organisations. Two points are apparent from this figure. First, spending by the juniors was much more responsive to rising prices during the course of the metal price boom in 2004–2007 and more responsive also to the falling off of prices in 2008–2009. Secondly, despite the small size of the companies in this sector, the juniors collectively account for a very large proportion of total exploration, this share rising to over 50 per cent of total spend in 2006 and 2007. A high proportion of exploration spending by juniors is accounted for by gold, the small scale of many gold deposits combined with the easy saleability of the product making this metal the target of choice for many juniors. A final point to note is that MEG data is focused on private-sector exploration and accordingly does not take full account of exploration by state companies and other state organisations. In light of the fast growth of state-funded exploration in countries such as Russia, India and, above all, China, in recent years, Raw Materials Group of Sweden considers that MEG's data understate the total exploration spend (Ericsson, 2011a).

Industry dynamics

The larger mining companies do not generally give much thought to a mineral's perceived criticality when evaluating an investment. Their role is to produce minerals for which there is a proven market and to make a profit by so doing.

It is certainly the case that part of the assessment of whether something can be mined profitably resides in a miner's judgement about the strength of demand for the mineral in question and the price that consumers will be prepared to pay for it. However, for the most part these cannot be very accurately determined. Mineral demand and mineral prices are functions of the economic cycle, the forecasting of which is a very inexact science. Moreover, proving up resources and bringing them into production is a process that can take several years and a lot can change in the condition of markets during that time. Thus, while a miner must have some general level of confidence that a market will exist for the product to be produced and that prices will be sufficient to generate a positive return on capital, detailed projections of demand growth are not normally the primary factor behind a decision to invest. Mining companies cannot realistically lay claim to any particular comparative advantage in the art of economic forecasting and will generally, and rightly, be sceptical about the claims which appear in the popular press from time to time about the glittering prospects of this or that exotic-sounding mineral.

The situation with junior miners and exploration companies is a little different. As already noted, these companies are generally dependent on equity markets for their financing. Their survival thus depends on their ability to spark and to sustain interest amongst investors. Accordingly, they tend to be rather more sensitive to market perceptions about the desirability of different minerals than are large mining companies and will often creatively talk up the prospects for the products which they are hoping to find and to mine.

This being the case, exploration companies and junior miners are that much more likely than larger, well-established, mining companies to be responsive to the notion of a mineral's criticality. A project becomes easier to promote if the product it is expected to recover is viewed as having an exciting growth prospect, or is used in new and exotic applications; especially when this is reflected in strongly rising prices. It may not be that the mineral in question is suffering from insufficient investment, or even that there is a realistic prospect of getting a mine into operation in time to relieve any shortage, it is simply that funding is more readily available at such times. The identification of rare earth elements and lithium as critical minerals in recent years has helped generate huge interest in exploration for these minerals. There are believed to be some three hundred rare earth deposits under evaluation (Chegwidden and Kingsnorth, 2011) and over one hundred lithium projects (Mining Journal, 2011). This gold rush mentality – wherein high levels of exploration feed expectations about the demand prospects for a mineral, and vice versa – is an age-old feature of the mining industry.

Only a very few of the many thousands of mineral prospects that are explored ever actually make it through to production. And when it comes to the determination of whether a mineral deposit is to be developed, then judgements about the outlook for demand may well take second place to judgements about the economics of production. After all, if too many companies are pursuing the same growth segment for a given mineral, then there is always the risk that the market will at some point tip over into serious oversupply, at which point the relative competitiveness of producers becomes rather important. Many large mining companies, it might be noted, talk about their strategic objective as being to secure and operate low-cost, long-life, mines without reference to any particular mineral or its demand outlook.

In order for a prospect to be developed, a mining company will generally want to be sure that the resource is of a scale, quality and consistency to support production long enough to permit the recovery of the initial capital investment. It will need to be sure that the conditions of the rock are such as to permit safe and efficient mining. It will need to be sure that power and water are available to the project and that transport exists to get the product to market. In essence, what this will all ultimately boil down to is that the company will want to be confident, or as confident as it is possible in business to be, that it will be able to produce at costs which will make it profitable over the long term. This will, of course, depend in part on its assessment of the long-run price of the product to be produced. However, because of the uncertainties attaching to forecasting long-run commodity prices, the mining company will also be seeking the comfort of knowing that its costs are competitive relative to those of others in the industry.

Such comparative cost assessments play an absolutely vital part in mining company decision making. Having low production costs is not in itself sufficient to justify investment in a project. The object of the exercise, after all, is to make money, and while low operating costs are clearly better than high operating costs, if low production costs can only be achieved through very high levels of spending on capital, it may still be that a project does not merit development. However, comparative assessments of operating costs remain important to miners for several reasons. They permit companies to benchmark themselves against others in the industry and to determine how efficiently they are producing. They provide information about where prices might trend longer term, in as far as prices in a competitive market tend towards the cost of the marginal producer; that is, the highest cost producer required in production to meet prevailing demand. And, by the same token, they will provide information about which companies are likely to be making positive cash returns throughout the cycle, something in which those financing a mine's development, be they shareholders or banks, will be particularly interested.

For the most part, the mining industry has been successful in responding to the changing requirements of the market, and indeed it is organised and incentivised so to do. Rising prices provide a signal of actual or impending shortage and companies accordingly respond by increasing output from existing operations and by instigating searches for new resources. Rising prices also have a stimulus effect on financial markets and facilitate the raising of debt and equity funding by miners and explorers. Reflecting these factors, global mining investment in 2011 soared to US$175 billion, the highest level ever recorded (UBS, 2011) and investment in 2012 is believed to have been higher still. For minerals currently deemed critical, and whose demand is expected to grow rapidly in coming years, there is no reason in principle why the industry should not be able to respond to the challenge and to match increases in demand.

Aside from encouraging the development of known high-quality deposits, higher mineral prices have the effect of converting what were once marginally economic resources into mineable reserves, and may similarly convert waste dumps from earlier workings into sources of recoverable product. Sustained interest in these minerals will also likely stimulate an interest in investing in, and improving the technologies used for, the recovery of these minerals. It is interesting to note that Molycorp Minerals's Mountain Pass rare earths mine in California, which has re-opened in response to higher rare earth element prices, has been wholly reconfigured since it was closed in 1995 following a thorough review of all aspects of its technical and environmental performance. The new mine will have process recoveries of 95 per cent as against 60–65 per cent at the old mine, will use 30 per cent less reagents and only four per cent of the fresh water. Accordingly, it will be able to produce rare earth elements at much lower costs than it could when it operated previously.

Mining is, however, a capital-intensive industry with long lead times from discovery to production and its responses are necessarily lagged. For new mine production to flow, mining companies have to be convinced that they have a viable project and then secure funding for it. Combined with the need to assess the environmental impacts of a mine, to acquire permits to mine and, frequently, forge agreements with local communities, this process can take several years. And then there is the not insignificant matter of building the mine itself. This will require ground preparation, the construction of plant, the acquisition of specialised equipment and the creation of facilities for mine waste. Not uncommonly, it will also require the building of railways, ports and power stations.

Accordingly, while it may be the case that eventually miners will catch up with imbalances in supply and demand for minerals, there can

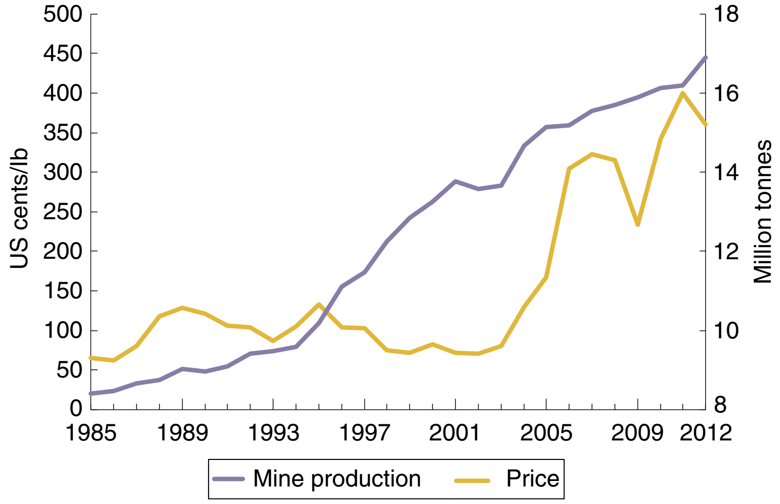

Figure 2.2 Copper prices and mine production, 1985–2012. (Price data are annual averages calculated from London Metal Exchange monthly averages; production data compiled from World Metal Statistics Yearbook, published annually by World Bureau of Metal Statistics.)

nonetheless be periods of shortage while they are bringing on new supply, these periods potentially lasting several years. Such long lags are one of the defining characteristics of the mining industry and the basis of its sticky supply responses. The point can be illustrated at a high level with the example of copper. Figure 2.2 shows a plot of world mine production against the world copper price. A close examination of this figure reveals that there was an eight-year gap between the uptick in prices which took place in 1987 and the acceleration of mine production growth in 1995. A similar delayed supply response is evident in the cyclical downswing. The decline in prices which occurred following the price peak of 1995 did not result in a visible reduction in global production until 2002. In the most recent cyclical upswing, the price increases which began in 2004 finally resulted in an acceleration in mine production in 2012. Like the proverbial oil tanker, mineral production can take a long time to turn around.

During these lengthy periods of supply adjustment, prices are required to take the strain of forcing supply and demand into alignment by rising to levels which choke off the portion of demand which cannot be satisfied. This is sometimes referred to as demand rationing or demand destruction.

Demand rationing works in several ways. First and foremost, high prices encourage consumers to use less of a product or to use it more efficiently. Thus, high copper prices have resulted in the thin-walling of copper pipes and in gauge reduction. High prices of nickel have encouraged a shift towards the production of stainless steels which use less, or indeed, no, nickel. High prices also encourage consumers who can do so to switch to using cheaper alternative materials. Thus, high platinum prices have led jewellers to substitute white gold and palladium for platinum, while high copper prices have encouraged the substitution of plastic plumbing pipe for brass pipe. Finally, high prices result in a reduced call on mined materials by encouraging recycling (see Chapter 3). A key element in the economics of recycling is played by the cost of collection and separation. Although the effects tend to be highly mineral specific, as mineral prices rise so generally they provide an incentive for the collection of old scrap and an increase in the rate of recycling.

These effects of higher prices are part of the normal mechanism of adjustment in mineral markets. Indeed, some of the changes brought about by price-induced changes in demand have beneficial long-run effects in terms of increasing the efficiency of materials use and promoting advances in technology. Although it is not so hard to point to examples where mineral markets have suffered sustained shortfalls in supply – the shortages of cobalt arising from civil war in Zaire in the late 1970s, for example – it is quite difficult to think of peacetime examples where shortages of minerals have had serious adverse long-run effects on an economy. Normally, markets adjust in the short term through price-induced demand rationing and in the longer run through increased supply.

Constraints on mineral supply response

While it may generally be the case that properly functioning markets will provide solutions to mineral shortages, there is a variety of natural, economic and institutional factors which in practice can inhibit the responses of miners and explorers to shortages and thereby prolong the period of supply adjustment. These are important in assessing the likely future availability of critical minerals. The next three sections look at these factors in turn.

Natural constraints

One of the defining characteristics of the minerals industry is that mineral resources are depleted through exploitation. (For a fuller discussion on resource definitions and related issues, see Chapter 1.) This gives rise to a common perception that physical availability may become a constraint on future mineral supplies. In point of fact, physical availability of minerals in the ground is scarcely, if ever, a constraint on mineral supply. While some minerals are inevitably easier to find and develop than others, most minerals mined commercially are available in quantities which are adequate for very many years to come.

A simple way of looking at the adequacy of mineral reserves is to divide through the reported reserves of a mineral by annual production to get a 'static life index'; that is, an estimate of the expected life of the remaining reserves expressed in years. Such estimates are, unfortunately, commonly subject to misrepresentation in that casual users of these data have a tendency to overlook the fact that reserves is a dynamic concept. For many of the most commercially important minerals, including copper, nickel, lead, tin and zinc, reserves life tends to fall into a range of twenty to fifty years (USGS, 2012). However, it should be noted that these reserves lives have not much changed in many years (Crowson, 2011). As production has risen, so reserves have gone up. The commercial incentives simply do not exist for companies to go out and prove up reserves which will be required more than fifty years out. Moreover, it should also not be forgotten that most mineral materials are not destroyed by use and that in addition to reserves in the ground there are substantial amounts of above-ground materials available for re-use and recycling.

For the minor metals which are the focus of concern in the debate on critical minerals, the picture on reserves life is more varied. Some, such as the rare earths, lithium and tantalum, have reported reserves which are very large indeed relative to current levels of production, stretching out in the case of the first two to several hundred years. For others, because they are recovered as by-products, there are no meaningful estimates of reserves so a calculation of reserves life cannot be made.

If the physical availability of minerals is not a major constraint on the supply response of the minerals industry, the geographic concentration of mineral resources can be. Such a concentration exists in the case of the platinum group metals (PGMs).[3] (A more detailed discussion on the PGMs is to be found in Chapter 12.) According to the US Geological Survey, some 95 per cent of the world's reserves of PGMs are located in South Africa, in the Bushveld Complex (USGS, 2012). Such concentration of reserves does not in itself represent a constraint on supply, but it does make supply more susceptible to constraint.

Thus, while South Africa's reserves are sufficient to supply world markets with PGMs for many years to come, several factors have restricted access to the reserves.

A large part of the better reserves are tied up by one of the existing major producers and are therefore not available to industry newcomers. Those that are available often present serious challenges with respect to mining conditions, permitting and access to smelting and refining facilities. Meanwhile, all mining companies operating in South Africa, including the majors, face tough challenges associated with ownership requirements (including the strictures of black economic empowerment (BEE)), health and safety standards, power availability, rising labour costs and a strong Rand. It is largely for these reasons that, despite the existence of strong demand for platinum over the past decade, driven by demand for autocatalysts, investment in the industry has been constrained and production has grown scarcely at all (see Figure 12.5), forcing up prices and, as noted above, resulting in a substantial displacement of jewellery demand for platinum.

Other cases where a high concentration of reserves represents a potential constraint on supply are phosphates in Morocco and cobalt in DR Congo. In the case of Morocco, which accounts for three-quarters of the world's reserves of phosphate rock (USGS, 2012), access to the industry is restricted by the fact that the industry is wholly state-owned. With respect to cobalt, the DR Congo accounts for around half the world's reserves of cobalt and around half its production (USGS, 2012). The challenging investment climate in DR Congo, and the reluctance of large international companies to operate there, has long made this a matter of concern for consuming nations. The invasion of the Katanga province in DR Congo in the 1970s (or the Shaba province and Zaire as they were respectively known at the time), and the disruptions to supply that this caused, were a key event in triggering the 'resource war' concerns of the 1980s. In addition to the concentration of reserves by country, corporate concentration can sometimes be an issue in supply vulnerability as the case of the PGMs also illustrated. Examples of minerals where corporate concentration of production is unusually high are niobium (where CBMM is the dominant producer) and tantalum (Talison Minerals).

Another natural constraint on the ability of the mining industry to respond to shortages is the fact that some metals are produced predominantly as by-products of other, economically more important, metals. (For more on the subject, see Chapter 1.) This is not to say that they cannot be recovered in their own right, only that the cost of doing so will be very much higher, perhaps prohibitively so. Thus, cobalt is produced largely as a by-product of copper and nickel. Cadmium, indium and germanium are produced as by-products of zinc production. Germanium is also recovered from coal fly ash. Gallium is produced as a by-product of bauxite. Molybdenum, rhenium, selenium and tellurium are all produced as by-products of copper.

The problem for these metals is that their supply is largely dependent on the production economics of the metal of which they are a by-product. If production of the principal metal ceases to be economically viable then the by-product will cease to be recovered too. It is for this reason that the supply of by-products tends to be insensitive to changes in the level of demand and why the prices of mineral recovered as by-products can fluctuate wildly. The price of molybdenum (Figure 2.3) shows a fairly classic by-product profile, which is to say, long periods of low and stable prices (reflecting times when markets are well supplied) interspersed by explosive price peaks (reflecting times when supply is unable to respond to increased demand). Rhenium, another by-product of copper which is discussed in Chapter 14, shows a similar price pattern to molybdenum. Quite a few of the minerals deemed critical in the US and the EU fall into this by-product category and accordingly display the rather erratic supply and price behaviour of such metals.

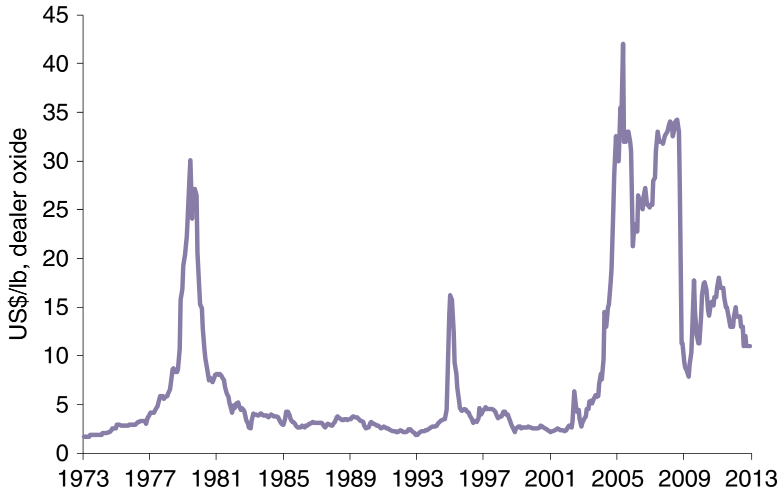

Figure 2.3 Molybdenum price, 1973–2012. (Price data are quarterly averages from Metal Bulletin.)

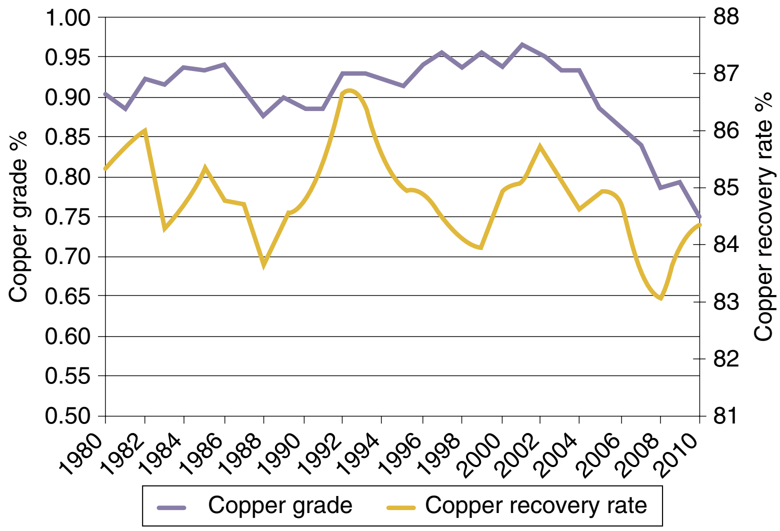

Figure 2.4 Copper mine grades and recoveries, 1980–2010. (After Citi, 2011b.)

Economic constraints

A second set of constraints on mineral development – referred to here as economic constraints – are a product of the fact that the quality of mineral resources has a tendency to deteriorate over time. Ores become lower in grade or more difficult to treat, while ore deposits are found at greater depth or in more difficult locations. As an illustration of this, Figure 2.4 shows the recent declining trend in copper ore grades and in recoveries from those ores.

To some degree, the upward pressure on industry costs which results from these trends can be offset – or even more than offset – by cost-reducing improvements in technology, and historically this has been the general experience of the industry. However, there is no law which says that this has to be the case and, for a number of mineral commodities, it would appear that the declining quality of reserves, combined with other factors such as higher energy prices, water availability and tougher environmental requirements,

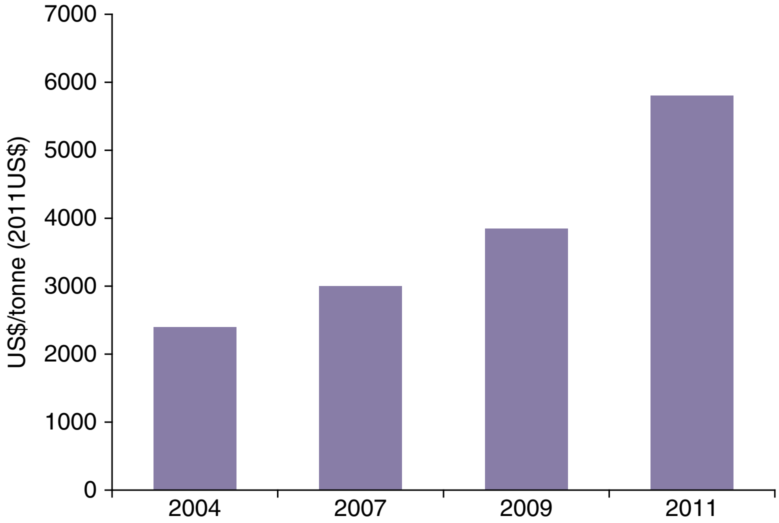

Figure 2.5 Long-run marginal cost of copper production. (Adapted from Robinson, 2011.)

are pushing up net production costs, notwithstanding continuing technological progress.

Sticking with copper, Figure 2.5 shows an analysis by the consultants CRU of what their database is telling them has happened to the long-run marginal cost of producing copper. (These are notionally the operating costs of the last (i.e. highest cost) producer required in production to balance the market. For practical reasons, they are more usually derived by mechanically taking a reading off the industry cost curve at fixed point, for example, the 90th or 95th percentile.) These costs leapt from around US$2400 per tonne in 2004 to some US$5800 per tonne in 2011; a real terms increase of 13 per cent a year over the period. Considering that industry operating costs declined for the twenty-five years prior to this the increase is extraordinary. Partly, of course, the effects are cyclical, but it seems probable that, underlying these cyclical influences, a structural shift is taking place. Moreover, this experience is not exclusive to copper. Similar evidence of deteriorating quality of ore resources and rising production costs can be adduced for nickel, PGMs and gold. At the same time, it should be noted, evidence of declining ore quality is less evident in other cases, for example, in iron ore, coal and bauxite.

What applies to operating costs applies also to capital costs. As mines become deeper and more remote from infrastructure, and as the environmental and political challenges of mining mount, so the cost of building mines has escalated too. Figure 2.6 shows estimates of the capital costs of some large greenfield copper mines currently in development or undergoing evaluation. The capital costs of these mines typically fall in the range US$10,000–20,000 per tonne of annual mine capacity. Capital costs historically have generally been below US$7500 per tonne of capacity, with US$5000 per tonne for a long time being used by the industry as a rough rule of thumb.

In principle, higher costs of production should eventually result in higher prices, which should in turn contribute towards bringing forward the necessary investment to balance the market. However, there are lags in the system. The long-run prices used by companies in the evaluation of their projects have been rising, but companies, and the banks providing them with finance, have to be absolutely convinced that prices are going to stay substantially higher on a sustainable basis before risking a commitment to large long-life projects. It also might be noted that exchange rates can be as important as mineral prices in determining a mining project's viability. The emergence of an increasingly multi-polar global economy, and the associated decline in the role of the US dollar, is likely to bring with it

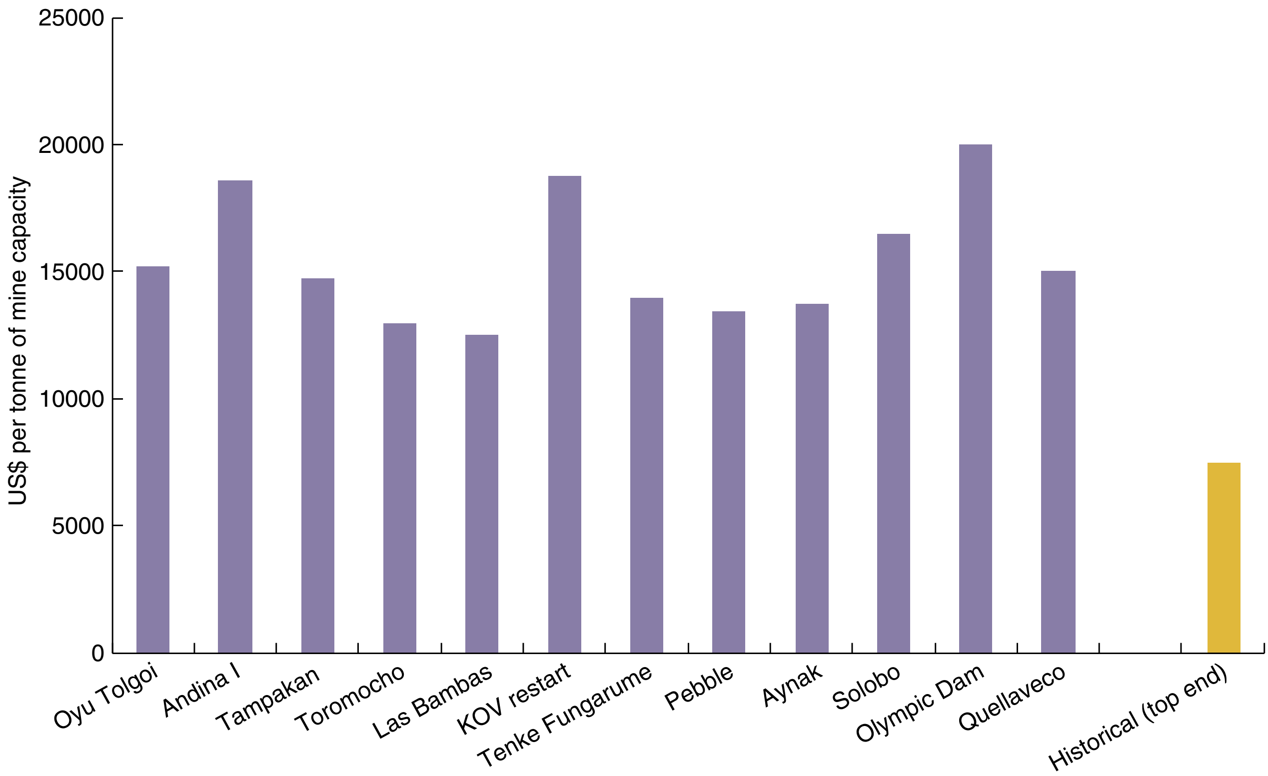

Figure 2.6 Capital cost of green-field copper mines. (Data from various industry sources.)

increased currency instability, adding a further layer of complexity and risk to mine project evaluation. In short, while companies may be investing heavily in new capacity, they are having to overcome higher economic barriers, and assume greater exposure to risk, to do so.

Institutional constraints

A third set of constraints on mineral supply involve institutional factors. For the purposes of the section, these are taken to include the laws and taxes to which mining companies are subject wherever they operate, through to intermittent geopolitical interventions in the industry.

Although a widespread perception exists in the more economically developed countries that issues of institutional risk is largely a matter for emerging and developing nations, this is far from the case where the mining industry is concerned. Pressures on land for housing, agriculture and leisure use, and concerns about impacts of mining on the environment and on local communities, make many developed countries highly ambivalent about the industry. On one level, this simply reflects the widespread perception that mining is a dirty and unsightly business and the fact that developed countries have large numbers of articulate people with the leisure to fight mineral projects. Such opposition to mining activities is often underpinned by the view that developed countries can make their living in other, cleaner, ways and import the mineral raw materials they want from elsewhere.

While many mining companies will want to persist with mining in the more developed countries because of the political stability and legal protections which such countries typically offer, mineral projects in developed countries often confront extremely demanding and lengthy permitting procedures and very tight restrictions on emissions, noise, visibility, effluents and transportation. Moreover, these restrictions are getting tougher with time. Although the provisions in themselves may be entirely reasonable, their cumulative effect can sometimes render a project marginal and encourage miners to go where they feel more appreciated and the wealth and employment they create are more highly valued. It does, however, leave developed countries more heavily dependent on imports than they might otherwise be and in a morally weak position to demand that others supply them with products they are demonstrably reluctant to produce themselves.

A growing impediment to the ability of miners and explorers to respond to changes in mineral demand is resource nationalism in mineral-rich countries. As was the case with the commodity boom of the 1970s, the commodity boom which started in 2004 helped stoke up a debate in mineral-producing countries over whether host nations were receiving a sufficient share of the proceeds from mining's growing success. Countries throughout the world have taken the opportunity to increase taxes and royalties on the industry. These are factors which mining companies have to take into account when assessing the likely returns to shareholders from an investment and, at the margin, can be an important factor influencing the decision whether or not to proceed with an investment. The threat of a wide-ranging Resource Super Profits Tax in Australia in the first half in 2010 resulted in many mining companies pointedly cancelling and deferring projects. (A revised Minerals Resource Rent Tax was subsequently introduced in July 2012.)

However, the concerns of resource nationalism are not confined to the distribution of income. They stretch also into the ownership and control of the industry. As noted in the introduction to this chapter, this politicisation of minerals in mineral-producing countries is a direct parallel to the securitisation of minerals in consuming nations. Minerals viewed within this broader political context become not just the basis of wealth-generating economic activity but a potential component in a project of national economic and social development, and a symbol of a country's sovereign right of self-determination. As the Washington consensus gives ground to the Beijing consensus at the level of the global economy, so the emphasis on the role of the nation and of the state is becoming more prominent within the confines of the resources sector. The forces for economic liberalism, as represented, for example, by the attempt to complete the World Trade Organisation's Doha Round, are in retreat and in international institutions like the World Trade Organisation the sovereign rights of nations over natural resources are increasingly being asserted in opposition to the principles of economic efficiency which underpin and legitimise the free trade system. Less and less, it seems, will mineral-rich countries accept the idea that other countries, or multilateral institutions, have the authority to determine how they develop their resources and how much of their mine production they must make available on international markets.

In the course of the recent minerals boom, a number of countries have come to the view that their national interests are best served by insisting that the state has a stake in mining operations on their home soil, or else that mine developments are undertaken by domestic private companies. Bolivia, for example, embarked on a programme of nationalisation for the mining industry in 2005. Mongolia has insisted on a major holding for the state in the large Oyu Tolgoi copper mine. Zimbabwe passed an Act in 2008 to promote the 51 per cent 'indigenisation' of mining companies operating within its borders. The Government of Guinea stripped Rio Tinto of some of its permits to mine iron ore in 2008, on the grounds that the company was not advancing the projects quickly enough, and now requires a substantial direct holding in all large new mining projects undertaken within the country. In DR Congo, the government in 2010 expropriated two mines belonging to TSX-quoted First Quantum Minerals.

Nor should it be supposed that such interventionism is confined to developing countries. The Australian government blocked the purchase

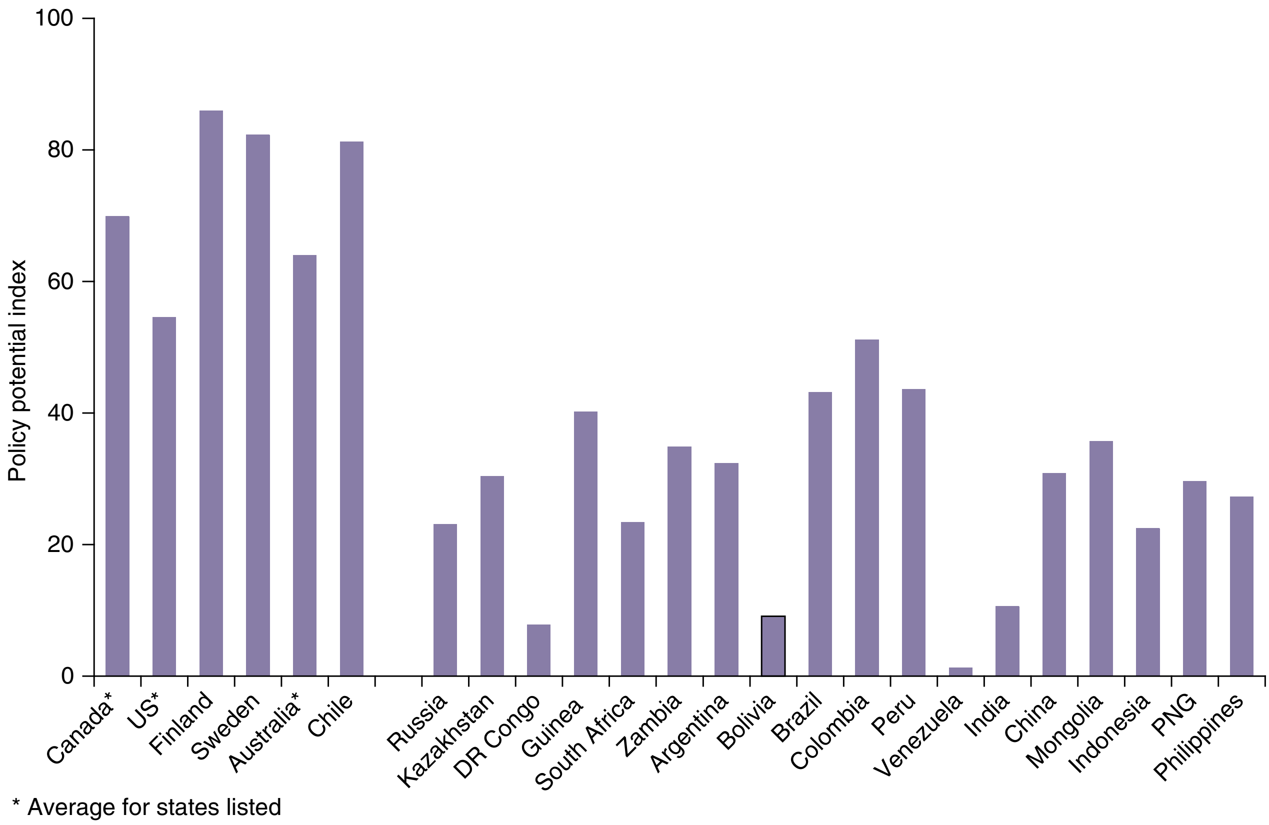

Figure 2.7 Policy attractiveness of large mining countries. (Data from Fraser Institute, 2011.)

of the Prominent Hill copper mine by China Minmetals in 2009, while the Canadian government blocked BHP Billiton's proposed take-over of the Potash Corporation of Saskatchewan in 2010 on the grounds that it was not in the national interest.

State interventionism inevitably adds another layer of uncertainty to investment decision making by mining companies. Political risk assessment is difficult and unreliable and there are only so many things that companies can do to mitigate risk. Many available strategies for risk mitigation, such as bringing in partners or buying political risk cover, result in reduced control over projects and/or increased costs. Despite this, on the basis that mining companies have to go where the minerals are found (and presumably also because mineral prices remain high), companies are continuing to commit to invest in what might be regarded as 'difficult' countries such as DR Congo, Guinea and Mongolia in the hope and expectation that they can manage the geopolitical risks involved and not become victims several years down the road of the 'obsolescing bargain' (the situation in which the investment has been made and the rules are changed). Time will tell whether this confidence is justified. The experience of the oil sector, it must be said, which is now wholly dominated by state firms, provides a somewhat discouraging example.

An objective assessment of the nature and scale of geopolitical risk across the industry poses obvious problems and, in the last resort, it is the geopolitics of the particular country in which a miner is thinking of investing which matter. However, attempts are routinely made to try and provide some comparative context for the assessment of this issue. Figure 2.7 shows the results of an investor perceptions survey carried out annually by the Fraser Institute of Canada. Amongst other things, this survey seeks to capture the mining industry's perception of the relative attractiveness of mining policy in a variety of mineral-rich countries, taking account of political risk alongside a range of other factors such as taxation, the administration, interpretation and enforcement of mining laws, and environmental regulation. While such analyses have their limitations, Figure 2.7 serves to make the point that perceptions of policy attractiveness vary significantly across different countries, with some regimes (those on the left-hand side of the chart) viewed as essentially supportive and others as effectively no-go zones. It also suggests that the perceived attractiveness of many mineral-rich countries in the developing world is considered quite low.

Critical minerals and the role of China

The specific minerals which are the object of concern for mineral-consuming countries vary through time, as also do the countries viewed as unreliable sources of supply. This in turn has implications for the producers whose role it is to seek to ensure that adequate supplies of the minerals are forthcoming.

The concerns which arose in the immediate post-WWII era over mineral supply were focused largely on the military requirements of having to fight a sustained conventional (i.e. non-nuclear) war. Efforts to address the threat in the US – which included the creation of a large materials stockpile – were therefore focused on a lot of relatively basic industrial raw materials, particularly those which were not abundant in the US, such as bauxite, manganese, zinc, lead, nickel, chromium and tin (Anderson and Anderson, 1998). With respect to the threat of nuclear confrontation, there were parallel concerns relating to the availability of uranium. The USSR, the source of the presumed threat to the USA in the context of the Cold War, would have had similar concerns, although the perception in the West at the time was that the USSR was broadly self-sufficient in minerals.

A second wave of concern over the supply of critical minerals followed (not coincidentally) the commodities boom of the 1970s. Although the Cold War was still on-going at that time, and the USSR was still perceived as a threat to the West, the primary focus of concern over mineral supplies at that time had shifted to South Africa. The policy of apartheid in South Africa had alienated many western states and there was a widespread view that the USSR was seeking to capitalise on the situation through its support for the African National Congress (ANC) and the socialist regimes of neighbouring Angola and Mozambique. The government of South Africa was, at the same time, using the threat of disruption to mineral supplies to the region to bolster its position in western capitals. The specific minerals whose supply was deemed under threat by the US, Western Europe and Japan at this time included the PGMs, manganese, chromium and vanadium, for all of which South Africa was the western world's leading supplier (House of Lords, 1982 and Maull, 1986). Because of Zaire's[4] proximity to South Africa and its dependence on South Africa's transport routes, supplies of cobalt were also considered vulnerable to unfolding events in South Africa (this quite apart from issues related to Zaire's own political instability).

The concern over mineral supplies at this time was less to do with the threat to the military capabilities of mineral consuming countries and more to do with the threat of economic disruption. Manganese, chromium, vanadium and cobalt were used in the production of high-performance steels, such as stainless steels and high-strength low-alloy (HLSA) steels, as well as superalloys, which were in turn used for the manufacture of important high-technology products such as petrochemical plant, oil pipelines and jet and gas turbines. The fear was that curtailment of supplies of these metals from South Africa would cause serious dislocation in strategically important industrial sectors, from energy production to aerospace. These concerns gave rise in a number of countries, including

Japan, the Republic of Korea and the UK, to strategic stockpiling of the threatened metals and to the adoption of schemes to incentivise mineral exploration.

In the most recent manifestation of concern over the supply of critical minerals, the focus of concern has once more shifted. With respect to the specific minerals which are deemed under threat, the focus has shifted to a range of specialised, low-volume metals used in the production of technologically advanced consumer electronics, green energy products and defence applications. Many of these are discussed in detail elsewhere in this book.

The sophisticated nature of the products in which minerals now designated as critical are used and the growing complexity of linkages between different sectors of modern economies (as well as the blurring of the distinction between commercial and military products), makes the threat which their non-supply would pose rather harder to evaluate than was the case in earlier era (Anderson and Anderson, 1998). While there is a clear sense in consuming countries that these metals are important for certain cutting-edge applications, it is evident from studies published in the US and EU that the authors of these studies have struggled with the matter of how to assess the relative importance of different end-uses of the minerals designated as critical and the likely economic impact of their non-availability (NRC, 2008 and European Commission, 2010). While the approaches adopted in the US and EU reports differ – with the US study resting more on expert judgment and the EU study adopting a more quantitative approach – both generate some rather counter-intuitive results. Thus, for example, the US study determines that the economic impact of restrictions on the supply of rhodium would be greater than those on copper, while in the EU study the economic importance of tellurium and rhenium is rated as higher than that of copper and the PGMs.

The geographic focus of concern has also shifted since the 1980s. It has shifted towards China. This follows from the facts that China is a major producer and supplier of many high-technology minerals, and that western consumers became heavily dependent on supplies from China during years when China was offering these minerals at substantially lower prices than were available from suppliers elsewhere. Of the fourteen minerals judged most critical by the European Commission – antimony, beryllium, fluorspar, gallium, germanium, graphite, indium, magnesium, rare earth elements, tungsten, niobium, PGMs, cobalt and tantalum – no less than ten (the first ten minerals listed) are sourced by the EU substantially from China (European Commission, 2010). The concern is that China's own growing domestic use of these minerals is reducing the supplies being made available for export, creating increased competition for supplies amongst other users of these minerals and putting upward pressure on prices.

Not surprisingly, given that it is the world's largest and fastest growing market for minerals, China shares many of the concerns of the US and the EU about minerals availability. In fact, because of the need for a good supply of raw materials to support the rapid industrialisation and urbanisation of the country, and because the legitimacy of China's leadership depends in no small part on its ability to sustain high growth rates, China takes the matter of mineral supplies very seriously indeed (FT.com, 2011 and Ericsson, 2011b). For those minerals which it can source internally, the Chinese government has generally encouraged local mine development. Recently, however, this objective has awkwardly become conflicted with another policy objective, namely the need to regulate the mining industry more tightly so as to improve its environmental performance and conserve resources, and led the Chinese government to seek to restrict the export of certain minerals considered important to national economic development.

There is, however, a long list of minerals which China cannot source wholly from domestic sources. As of 2010, China had to import 100 per cent of its PGMs, 85 per cent of its copper and nickel, and 70 per cent of its iron ore. For these minerals, China has had to turn to international markets and its purchases of these and many other minerals have been a major factor driving global markets and mineral investment in recent years. In addition, since 2004, and the promulgation of its 'go out' policy, the Chinese Government has been actively encouraging its companies to invest in mining overseas as a means to secure supplies for its domestic metallurgical operations. Chinese companies have been particularly active in the pursuit of iron-ore investment opportunities overseas, notably in Australia, but they have also invested in other mineral projects such as those for copper, nickel and coal. In addition to China's direct investment in foreign mining projects, Citi analysts have identified 217 M&A (mergers & acquisition) deals involving Chinese companies in recent years, totalling almost US$50 billion (Citi, 2011a). The Metallurgical Miners' Association of China (MMAC) has said it would like to see 40 per cent of imports of iron ore coming from Chinese-invested mines by 2015 (China Economic Net, 2011a). Also, as a means to secure adequate supplies of mineral, the Chinese Government operates a strategic stockpile, the State Reserves Bureau (SRB), to hold and manage supplies of metals it deems critical to its industrial development such as aluminium, copper, nickel and zinc.

The particular range of the minerals designated as critical in the US and the EU has important implications for the nature of the response from the world's miners. For the most part, these are not minerals of any great interest to the major miners. They are simply too small in terms of their market size. Minerals do not, it should be noted, attract public interest in direct proportion to the scale of their markets. Raw Materials Group of Stockholm has calculated that global mine output of metals plus diamonds and uranium was worth around US$386 billion at the mine in 2009. Its analysis is shown in Figure 2.8. (Note that it excludes coal, which would add very substantially to the total.) Two thirds of the total was accounted for by iron ore, copper and gold. By way of

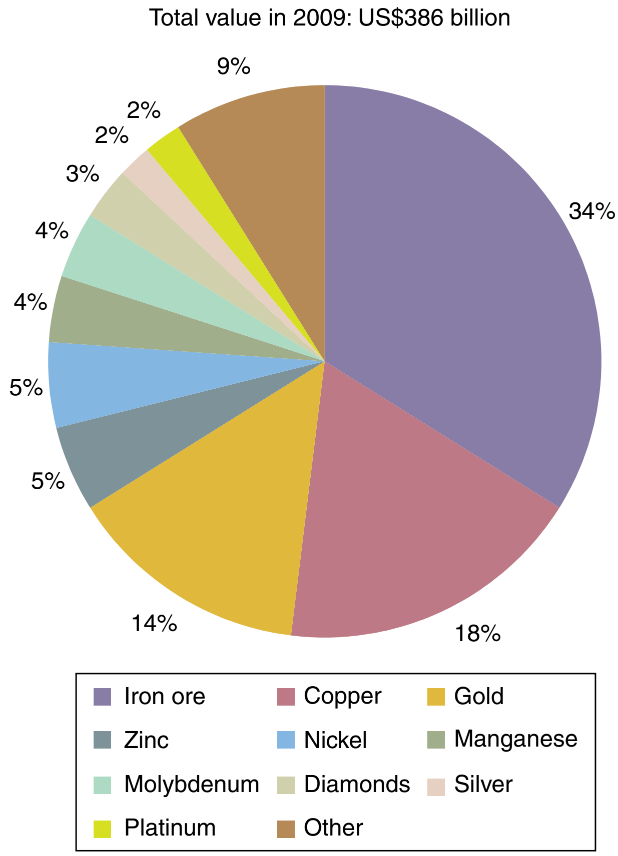

Figure 2.8 Metals value at the mine in 2009 (includes diamonds and uranium). (Data from Raw Materials Group, Stockholm, 2010.)

comparison, the value of mined cobalt in that year was around US$2 billion, the value of rare earths was around US$1 billion, the value of antimony was somewhat less than US$1 billion, while the markets for gallium, germanium, indium and tantalum combined amounted to less than US$1 billion. The value of rare earths production, it might be noted, was around one per cent the value of iron ore production, revealing a striking difference between the importance accorded these minerals by policy makers and the importance accorded them by the industry.

The large mining companies, having revenues measured in tens of billions of dollars a year, naturally like to focus their financial resources and management time on commodities which can make a material contribution to their businesses. As a result of this, the development of projects producing many of the minerals deemed critical is often left to smaller companies which, while they may be enterprising, often lack the experience, political clout and financial muscle of the big companies, making the route from discovery to production lengthier and more uncertain. These smaller companies also face the challenge that the markets for many minor metals lack transparency. The absence of exchange pricing and forward markets for these metals inevitably makes some potential financial backers nervous about investment.

That said, smaller miners have been extremely active in pursuing projects targeted on these critical minerals and on others facing declining supplies from China. Thus, for example, in the case of the rare earth elements, Molycorp Minerals has re-opened the Mountain Pass mine in California, Lynas Corporation has re-opened the Mount Weld mine in Western Australia, Great Western Minerals Group (GWMG) is re-opening the Steenkampskraal mine in South Africa's Western Cape, Toyota is planning to open a mine at Dong Pao in Vietnam with Sojitz and the Vietnamese Government, while there is a raft of other projects in Canada, Australia and elsewhere undergoing exploration and evaluation. In the case of tungsten, North American Tungsten Corp. has re-opened its Cantung Mine in the Northwest Territories of Canada and is evaluating the Mactung deposit in Yukon. There are also advanced plans in Australia to develop the King Island Scheelite mine on Tasmania and the Molyhil project in Northern Territory. Woulfe Mining Corp. is hoping to re-open the Shangdong tungsten mine in South Korea. In the UK, Wolf Minerals has conducted a feasibility study on the Hemerdon tungsten deposit in Devon and has raised funds to re-open the mine there.

Much the same goes for fluorspar, another mineral on the EU's list of critical minerals. In Mexico, there are expansions planned at Mexichem Fluor SA de CV (the world's largest producer) and at Fluorita de Mexico SA de CV, while in Mongolia, Monros is expanding its operations. In South Africa, Sephaku is expanding its operations by developing a new mine at Nokeng and ENRC is planning a mine at Doornhoek. In Canada, Canada Fluorspar is re-activating the St Lawrence fluorspar mines in Newfoundland. In the US, the Klondike II fluorspar mine in Livingston County, Kentucky, has been permitted for re-opening. In Vietnam, Dragon Capital Vietnam Resource Investments is building the Nui Phao tungsten-fluorspar project in North Vietnam while in Thailand, SC Mining Co is developing the Doi Ngom deposit in the north of the country.

All of which serves to make the point that resources of many of the minerals currently sourced from China are, at a price, available elsewhere in the world. It is just that China's preparedness in the past to supply these commodities at low prices made it uneconomic for many producers elsewhere to do so. Consumers, who themselves operate in competitive markets, were opportunistically led towards buying cheap Chinese minerals, in doing so creating a degree of dependency on China that was, in retrospect, perhaps unwise. As supplies from China have diminished and prices have increased, so miners in these other countries have been granted the opportunity to start, or re-start, production. The same applies in the case of the critical materials sourced significantly from DR Congo, namely cobalt and tantalum. Substantial resources of these metals exist outside DR Congo (for tantalum in Brazil and Australia, for example). It is just that in the past there was insufficient economic incentive for producers in these other regions to grow their output. A diminution of supply out of DR Congo, or heightened concern over political risk in the country, would provide the required incentive.

For minerals such as gallium, germanium and indium which are recovered as by-products and which are sourced from China as a result of China's rapid development as the world's largest processor of metals, there is very little the mining industry can do to relieve supply shortages.

Generally, it will not be economic for miners to pursue production of these minerals in their own right, and the issue of a supply response rests rather with metals processors outside China and on the question of whether it is profitable for them to add recovery circuits to existing plants to produce the relevant metals. In the longer term, it may depend on an ability to find new resources of these metals or to work different types of ores containing them.

With respect to large-scale, more basic mineral products, China represents a rather different challenge for western states. Certainly it is the case that China's growing demand for these products has resulted in a tightening of global supplies and increased prices, much as it has for more specialist metals. However, China's attempts to source an increasing amount of minerals from their own overseas mines – which may serve to ease the pressure on global supplies in all regions – is an additional competitive pressure on western mining companies. Just as western consumers are becoming more conscious of competition from Chinese manufacturers and purchases of minerals so western miners are feeling similar pressures in their business. As of the moment, this threat is relatively modest (Ericsson, 2011b) but it is one that is likely to increase with time. (Humphreys, 2011).

Policy issues

In the main, mineral markets work and deliver an appropriate level of supply to mineral users. Mining is a highly adaptable and enterprising industry and miners are constantly on the lookout for opportunities to make money by identifying gaps in the market and filling them. Although concerns over the availability of mineral supplies in consuming nations are understandable when markets are tight, there are few examples one can point to in history where the non-availability of mineral supplies has resulted in serious economic trauma. The shortages which have given rise to concerns over critical minerals in recent years are largely transitional and result from the lagged supply responses which are an unavoidable feature of the mining industry. High mineral prices are part of the mechanism for transition; they force supply and demand into alignment, in the short run by choking off demand and in the longer run by stimulating new supply by encouraging increased exploration and technical innovation.

Policy makers, whose time horizons, being politically determined, are generally shorter than are those of the mining industry, need to be aware of the underlying reasons why the industry suffers from lagged responses and why therefore the adjustment to imbalances in supply and demand takes time. This is normal, if frustrating. They also need to be aware of the characteristics of the individual mineral products under threat and understand better where and how they are produced, especially those which come as by-products of other minerals, or flow from the processing of imported ores. Europe, for example, is a major producer of cobalt but the cobalt it produces all comes as a by-product from the processing of imported copper and nickel ores. Without these metal processing activities in Europe, there would be no cobalt produced.

For miners and explorers to perform their functions effectively, markets must be allowed to operate. Price signals must be reliable and companies must be allowed – or, better, encouraged – to respond to these signals. The following comment, which was made at a time when governments were busy disengaging themselves from involvement in the minerals sector, still seems relevant to today's challenges.

> "Fair and efficient markets are man-made constructs. Their effective functioning depends not on the absence of policy but on a particular type of policy. They do not create or maintain themselves. Those who decide to trust to the markets for their minerals therefore need to accompany this decision with a commitment to ensure that mineral products are able to flow without undue hindrance from tariffs, subsidies or spurious environmental conditions, and that investment in the industry can similarly flow to where it can most productively be employed." (Humphreys, 1995.)

With respect to the last point relating to the free flow of investment, here there do appear to be some significant challenges facing the industry. While there are few physical impediments to investment in new mineral supply, there are some significant economic and institutional constraints and these appear to be getting more severe with time. In particular, there are the growing pressures from resource nationalism and from the growing involvement of the state in the mining sector in many countries. These are matters about which the mining industry can do relatively little but which should be of interest to policy makers.

While current and recent concerns over critical minerals naturally lead governments of consuming countries to want to do something to prevent a recurrence of supply shortages, it carries the risk of fighting the last war. As has been shown, problems of minerals supply do not always come back in the same form or apply to the same minerals. Policies such as stockpiling of critical minerals have a superficial appeal but they are cumbersome and costly and have not in the past proven very effective; in addition, the buying of minerals for a strategic stockpile always risks aggravating supply problems by pushing up prices and distorting markets.

There are, nonetheless, things that policy makers can usefully do to assist with the adjustment to supply shortages and to support future industry supply responses. However, these tend to be more long term and structural in nature. Governments of consuming countries can, for example, help consumers adjust to mineral shortages and accompanying high prices by encouraging R&D in materials technologies and facilitating recycling.

With regard to supporting future industry supply responses, governments of mineral-consuming regions can promote local mine production, where this could be viable. They could also do more to promote the development of new technologies for mining and mineral processing. Neither of these are things for which the authorities in the US and the EU have shown much enthusiasm in recent years. For minerals which cannot be supplied locally, there is a need to fight for open and competitive mineral markets both within multilateral forums and through bilateral agreements. It may be (and this would represent a departure from past and present practices) that governments should stand up more prominently for their companies where their legal rights are being flouted by host countries or where they are subject to unfair competition by state-owned enterprises. They could also support and encourage institutions which provide finance for exploration and mining, including providing guarantees for companies making investments in higher-risk countries, and provide more support for educational establishments which are training up the next generation of mining industry personnel. The best protections against sustained mineral shortages are efficiently working markets and free-flowing investment. Although the point has a tendency to get lost in the world of political cut and thrust, the US, the EU and China are all major mineral consuming and importing regions and share a common interest in healthily supplied global markets.

Notes

1. Enterprise value (EV) is calculated as market capitalisation plus debt, minority interests and preferred shares minus total cash and cash equivalents.
2. In late 2012, Glencore and Xstrata agreed terms for the merger of the two companies, to take place in 2013.
3. These comprise platinum, palladium, rhodium, ruthenium, iridium and osmium.
4. Since 1997, Zaire has become the Democratic Republic of the Congo.

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