The emergence and development of knowledge intensive mining service suppliers in the late 20th century

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Declaration:

I hereby declare that this thesis has not been and will not be, submitted in whole or in part to another University for the award of any other degree.

Signature:……………………………………….

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Abstract:

During the late 20th Century the mining industry went through an important technological rejuvenation that drove high rates of innovation, productivity growth and organisational change. This process included the emergence of knowledge-intensive mining services (KIMS) suppliers, who performed functions outsourced by mining companies, gradually strengthening their capabilities, enlarging their geographical scope and becoming a globally organised sector. But this was uneven across different mining economies. For instance, while numerous Australian KIMS suppliers emerged and achieved international competitiveness, few did this in Chile.

Focusing on Chile, this thesis explores the reasons for the limited development of KIMS suppliers in a developing mining economy. It examines the technological learning that shaped the KIMS sector evolution in Chile by contrasting it with the Australian experience, using a two level learning model that integrates: (1) the interaction between industry-level factors that shaped the potential for learning at the micro-level; and (2) the interaction at the micro-level between accumulated capabilities and learning efforts by firms to exploit the potential for learning.

KIMS learning is examined over four stages: (i) Gestation (1940s - early 1970s); (ii) Emergence and Development (mid-1970s to early 1980s); (iii) Internationalisation (late 1980s to late 1990s); and (iv) Consolidation (early 2000s and still going on). Over these stages, KIMS sector learning was much more limited in Chile than Australia, either because there was a lower learning potential and/or because firms carried out limited learning efforts to exploit the potential. At the first stage mining companies in Chile played a weak role as incubators of KIMS capabilities. Consequently, during the second stage there were few KIMS suppliers capable of profiting from the rejuvenation being experienced by the global industry. Also, with limited stimuli from the growth of mining in Chile, suppliers undertook limited learning efforts. So, the third stage found Chilean KIMS suppliers unprepared to exploit the learning potential that came with internationalisation; and the learning opportunities inherent in the significant expansion of Chilean mining production were captured by foreign KIMS suppliers, including Australians. Accordingly, Chilean KIMS suppliers started the Consolidation Stage without the capabilities to overcome the increasing barriers to participation in the industry’s continuing high learning potential.

CHAPTER 1

INTRODUCTION

1.1 The Thesis at a Glance

Many authors argue that at least over the last two centuries the mining industry has been a source of development for many countries, supporting their industrialisation and technological capability accumulation processes (Wright, 2001; Ramos, 1998; De Ferranti *et al*., 2002; Lima and Meller, 2003). Nevertheless, little attention has been given to how and under what circumstances this industry has supported such processes, especially in the context of developing mining economies.

The economic and technological development level achieved by countries with a considerable and long-lasting mining tradition has been significantly uneven, and so has been the success of technological development processes supported or leveraged by the mining industry. On the one hand, there are examples of nations whose industrial and technological development was supported and encouraged by their mining industry, the US, Canada, Australia, UK, Sweden, Finland are a few examples (Ericsson and Noras, 2005; Maloney, 2001; Wright, 1997). On the other hand, there are also examples of countries, such as Chile and South Africa, whose economies have relied on mining activity for over a century. These countries have had significant periods of economic growth (Power, 2002; Segal, 2000), also experiencing important technological development, but have not been able to maintain a process to become an economically and technologically developed country. In addition, there are several minerals producer countries – for example Gambia, Mauritania, Ivory Coast and Bolivia – that have shown small, none, or even negative economic growth over extended periods. This has raised questions about whether the mining industry can support sustained economic development (Sachs and Warner, 1999, 2001).

Strangely, despite the uncertainty about how the mining industry can sustain and promote a long term economic and technological development process, there is a general consensus that mining activities provide developing countries with opportunities, which in some cases have been used wisely and in other instances have been misused (Davis and Tilton, 2002; De Ferranti *et al*., 2002).

Obviously, abundant minerals endowments alone are not enough to stimulate long-term sustainable economic development, and several factors should be taken into account in seeking to understand the reasons behind the significantly uneven economic and technological performance of different mining economies. In particular, if, as is widely accepted, technological capabilities played a key role in underpinning long-term and sustainable development (Scott-Kemmis, 2004; Johnson, 1997; Bell and Pavitt, 1993; Lall, 1993; Lundvall, 1992), then understanding how and under what circumstances the mining industry encourages and leverages technological development is a central issue that should be addressed.

Despite the existence of a vast literature addressing and questioning natural resource based development processes, in particular regarding the mining industry, there has been little analysis about how mining and related activities support and encourage the creation and accumulation of technological capabilities or about the underlying learning processes. The research reported in this thesis aims to contribute to filling this gap by analysing technological capability accumulation processes in the mining industry, especially in the context of developing countries.

Specifically, this study analyses how technological learning processes take place in the mining industry, in particular with regard to the supplier sector to the industry. More precisely, this research aims to understand the structure and dynamics of the technological learning process that shaped and supported the emergence and development of a wide and specialised group of knowledge-based suppliers, such as engineering consulting, exploration consultant services, mine planning services, equipment designers, metallurgical process designers, environmental services and blasting engineering services. This group of suppliers is here referred to as Knowledge-intensive Mining Services (KIMS) suppliers.

The process by which KIMS suppliers emerged and developed has been part of a significant transformation of the mining industry over recent decades (Urzúa, 2003). Since the late 1970s and early 1980s the mining industry has shown high rates of innovation and productivity growth, and several functions formerly performed within mining companies, have been outsourced to independent suppliers. As a consequence, an important 'new knowledge-based industry' has emerged and developed. Especially important has been the emergence and development of the KIMS supplier sector. Many KIMS firms have gradually become international players, creating a new knowledge-based and globally organised activity. Additionally, these suppliers have played an important role in underpinning the mining industry's competitiveness (Dodgson and Vandermark, 2000a). They have also been a key element in the development of knowledge-intensive 'clusters' based on the mining industry.

The emergence and development of these suppliers has been uneven across mining economies. On the one hand, an important number of KIMS suppliers – from mining countries such as Australia, Canada and South Africa – have emerged and participated in the fertile technological rejuvenation that has been taken place in the global mining industry over recent decades, and have also gradually achieved international competitiveness (Urzúa, 2003). In contrast, in Chile, also an important mining economy, where mining has been probably the main engine of the economy over the last century and where mining has been experiencing a significant growth over the last two decades, only a weak growth of locally-owned KIMS firms has taken place. Chilean KIMS firms have developed some strength in the local market, but were weak in developing international competitiveness. Accordingly, a major share of the significant growth of the demand for KIMS derived from the rapidly expanding Chilean mining industry – mostly with regard to the copper mining sector – has been met by international KIMS suppliers.

The specific subject addressed in this research project is about this comparatively weak development of the Chilean KIMS sector. More specifically, it is about the differences in the technological learning process that shaped the emergence and development of internationally competitive KIMS suppliers. By questioning how technological learning take place with respect to the emergence and development of KIMS suppliers, this research seeks to contribute to understand both, the technological development processes led by the mining industry and more specifically the comparatively weak development of the Chilean KIMS sector.

This research has pursued an exploratory historical case study approach, taking into account several variables and processes and their interactions over a long period of time. It analyses mainly the emergence and development of the Chilean and Australian KIMS sectors, which have contrasting experiences in terms of their technological capability and international competitiveness levels. Other mining economies such as South Africa have also been examined but in much less detail.

Specifically, the study analyses the long-term evolution and interaction of two key processes which, it is claimed, are key shapers of KIMS supplier sector learning process and the related level of technological capabilities accumulated:

Process 1: The process of interaction between industry-level features that shapes the potential for learning and innovation at the micro-level.

Process 2: The process of interaction at the micro-level between accumulated capabilities and learning and innovation efforts carried out by firms to exploit the learning potential (the output of *Process 1*).

These key processes were identified from literature review and deepened during exploratory interviews and during the fieldwork. They are considered core elements of KIMS supplier sector learning process, and determine to a significant extend the potential for carrying out an effective and high-impact technological learning process that might lead to catch up the technological frontier.

Based on these key processes a Learning Dynamic Model (or Learning Driving Forces Model) for the KIMS supplier sector has been developed. This is used to analyse the Chilean and Australian experiences, taking into account the interaction between each of the key processes and the long-term evolution of technological capabilities.

The evolution of each key process is traced by analysing variables reflecting several specific features.

At the industry level the features are:

i. The scale and growth rate of mining production;
ii. The complexities and challenges of mining production; and
iii. The structure and organisation of the mining industry.

At the micro-level the features are:

i. R&D and engineering efforts by local mining companies and supplier firms;
ii. Efforts to develop the capabilities of KIMS experts;
iii. KIMS suppliers' interaction as source of learning; and
iv. The dynamic interaction between accumulated capability levels and the learning and innovation efforts in (i), (ii) and (iii).

The data gathering method was based on semi-structured interviews with executives working in a sample of Chilean and Australian KIMS supplier firms. Also secondary data and literature were used as sources of information. Information about the key processes was collected at three levels: i) KIMS supplier firms; ii) KIMS interactions, especially regarding the interaction with mining companies, and iii) the level of the national mining industry and its wider global context.

The next section (1.2) presents the structure of the thesis. Section 1.3 raises questions about the mining industry as a source of technological development and learning. Section 1.4 describes the specific research context, i.e., the Chilean mining industry and the emergence and development of KIMS suppliers in Chile.

1.2 The Structure of the Thesis

Chapter 2 reviews the increase of technological innovation and organisational change that the global mining industry has been going through over, at least, the last three decades. This process is identified as the 'technological rejuvenation' of the mining industry. The emergence and development of KIMS suppliers is a key part of this process, and different mining economies have participated unevenly in it, which has led to different levels of emergence and development of KIMS suppliers. This chapter also reviews the evolution of mining industry production in terms of geographical location and rate of production growth. These are two key factors that shape the innovation and learning opportunities.

Chapter 3 presents the literature review, which was used as the basis for the development of a technological learning dynamic model for KIMS suppliers. This model integrates the effect of industry level and firm level factors, and is the conceptual framework used for analysing and contrasting KIMS development experiences in Chile and Australia. Additionally, the research questions are presented in this chapter.

Chapter 4 explains the methodology pursued, including the overall research design, the operationalisation of concepts, and the systems for data collection and analysis.

Chapter 5 presents a general outline of the whole mining industry supply sector in order to show the blurry borderline between KIMS and non-KIMS suppliers. Additionally, this chapter shows the general historical stages in the development process of the international KIMS supplier sector, and a general overview of the historical evolution of the Chilean and Australian mining sectors.

Chapters 6 and 7 present and contrast the evolution in Chile and Australia of the two key processes that comprises the learning model used in this thesis and that shaped the emergence and development of the KIMS supplier sector. Chapter 6 focuses on the factors at the industry level that shaped the potential for learning and innovation at the micro-level, and Chapter 7 focuses on the factors at the firm level regarding the interaction between accumulated capabilities and learning and innovation efforts.

Chapter 8 concludes by presenting an integrated view of the learning and innovation dynamic generated by the interaction of industry-level and micro-level processes examined in Chapters 6 and 7. It is argued that this interaction goes a long way towards explaining the different degrees of success achieved by Australia and Chile in developing an internationally competitive KIMS supplier sector. These empirical findings are then related to the research questions and the main contribution of the thesis is summarised. General policy recommendations are presented, together with ideas about further research areas.

1.3 The Mining Industry as a Source of Development and Technological Learning

Several studies show that the mining industry has been a source of development, in particular stimulating and supporting technological development and the associated learning process. For instance, Wright and Czelusta (2002) describe how part of North American industrialisation and its economic development were based on natural resources. They stress that what mattered most was not the quality of the resources, but the nature of the learning process through which the economic potential of these resources was achieved. They emphasise that the North American case was essentially a process of continuous technological change and collective learning, embodied in intellectual networks linking world-class mining universities, government and private research, together with large-scale investment in exploration, transportation, geological knowledge, and the technologies of mineral extraction, refining and utilisation. They also identify three main conditions that encouraged this development process:

i. An accommodating legal environment, including open access for exploration, exclusive rights to mine a specific site upon proof of discovery, and the need to use the mine or lose it;

ii. Investment in publicly accessible knowledge; and

iii. Significant effort in education in mining, minerals, and metallurgy.

The case of Australia constitutes another prominent successful example. Some of Australia's development was based on the discovery of new deposits and the generation and export of mining-related knowledge (such as mineral detection, environmentally sound mining practices, and processing technology), based on a massive educational and research infrastructure (Maloney, 2001). It is highlighted that a network of universities and private and public think-tanks played a key role in achieving a high rate of productivity growth and innovation.

Another successful story is the case of the oil industry in California, where the total income of the state nearly doubled as a consequence of this development. In this case, research organisations played a basic role in generating process innovations such as hydro forming, fluid flex coking, and fluid catalytic cracking. Oil-using industries spread around the world under American influence, despite the fact that the US was not particularly well endowed with petroleum. An additional example regarding the oil industry is Norway, where the industry learnt to produce deepwater drilling platforms, extending the quantity of Norway's petroleum reserves (Wright and Czelusta, 2002; David and Wright, 2002).

De Ferranti *et al*. (2002), based on the cases of Australia, Canada, the US, Finland and Sweden, show that the mining industry can be a knowledge-based industry, able to sustain long term development processes that lead to the gradual development of a high-tech industry. They highlight that the most important element is not what is produced, but how it is produced.

Overall, the literature (Wright and Czelusta, 2002; De Ferranti *et al*., 2002; David and Wright, 2002; Maloney, 2001; Ramos, 1998) shows that the mining industry can be a source of technological development, and it stresses the key role of the learning process. However, there is no deep analysis of the long-term 'structure' of these particular learning processes, specifically in the context of developing mining countries.

Questions along the following lines therefore arise:

- What are the key factors that shape technological learning processes based on mining activity and how do these factors interact?
- How can technological learning in the mining sector lead to the emergence and development of knowledge intensive businesses?
- How can a developing mining economy participate in the learning opportunities opened-up in the mining sector?

Such key questions have been barely addressed, and they need to be analysed in order to inform natural resource-based technological development policies.

1.4 The Specific Context: The Particular Case of the Chilean Mining Industry and KIMS suppliers

1.4.1 Size and growth of Chilean mining production

At least since the late 19th century, mining has been the main engine of growth of the Chilean economy and the key link to the international economy through the export of minerals, especially copper (Gana, 1990; Meller, 1991; Wright and Czelusta, 2002).

Nowadays, mining remains one of the main economic activities in Chile and it is also a key link to the international economy. In fact, over the period 1996 – 2005 mining accounted for 7.6 per cent of Chilean GDP (gross domestic product) and for 45.6 per cent of its exports. Additionally, mining production value grew at a higher rate than the country's GDP. Copper production has been the main mining activity with a share of 86.6 per cent in terms of value. Moreover, over this period copper exports reached 38.4 per cent of the total exports, representing 84.2 per cent of total minerals exports. Chile became the largest copper producer in the world, accounting for 35.5 per cent of the world copper output in 2005 (Cochilco, 2006b).

Besides being the top producer of copper, Chile also ranks first in lithium (39.3 per cent of world production in 2005), first in iodine (61.8 per cent of world production in 2005), first in rhenium (44.7 per cent of world production in 2005), third in molybdenum (26.8 per cent of world production in 2005), fifth in silver (7.2 per cent of world production in 2005), and thirteenth in gold production (1.9 per cent of world production in 2005).

Chile also exports iron ore, ferromolybdenum, potash, and zinc. In addition, Chile produce arsenic trioxide, lead, manganese, barite, natural borates, bentonite, kaolin, clay, diatomite, dolomite, feldspar, gypsum, lapis lazuli, hydraulic lime, phosphate rock, pigments, pyrite, potassium chloride, pozzolan, pumice, quartz, salt, sodium compounds, sand and gravel, limestone, marble, sulphur, and talc.

Despite the diversity of minerals produced in Chile, only a few account for most of the export value. In fact, in 2005 copper contributed 79.3 per cent of Chile's mineral export total value. Table 1.1 shows the share of other minerals in the total value of Chilean mining industry exports in 2005.

Table 1.1: Share of the Export Value of the Chilean Mining Industry (2005)

	Copper	Molybdenum	Gold	Iron ore	Iodine	All others
% Exports	79.3	14.6	1.6	1.4	1.1	2.0

Source: Cochilco, 2006b; US Geological Survey Minerals Yearbook, 2005; www.nationsencyclopedia.com/ Americas/Chile-MINING.html.

In terms of the whole range of metallic mining[1], in 2005 Chile's production value accounted for around 7 per cent of world production value (source: own estimation based on Ericsson and Noras, 2005 and Cochilco, 2006b).

The future of Chilean mining production looks promising, despite an important decrease in the grade of the ore body of Chilean minerals, the significant pipeline of investment projects allows one to believe that Chilean mining production growth will remain high for at least the next decade. (Cochilco, 2002, 2006; Olivares and Valenzuela, 2006; Capurro, 2006; Bande and Silva, 2003; CIPMA and IDRC, 2002).

[1] Metallic mining comprises minerals such as gold, iron ore, copper, nickel, platinum group metals and bauxite and represents approximately 35 per cent world mining production excluding oil and gas

1.4.2 Suppliers to the mining industry in Chile

Over the last three decades the demand for products as inputs to the Chilean mining industry has grown rapidly. In 2005 it reached about US$ 6.5 billion and it is expected to keep growing at a rate of 5 to 10 per cent over the next decade (Cochilco, 2006a; Capurro, 2006).

Imports meet a significant share of this demand, but local suppliers have been gaining market share over time. Indeed, during the 1950s most of the products required by the Chilean mining industry were imported. Gradually local suppliers have been gaining a larger share of the local demand compared to imports. For instance, during the 1950s, suppliers in the local market provided less than 25 per cent of the equipment and inputs required by the mining industry, but this share increased to 60 per cent during the 1990s (Meller, 2002; Ramos, 1998). However only 40 per cent of the equipment and input provided locally was supplied by locally owned producers and the remaining 60 per cent was provided by locally based dealers or representatives of international companies.

Additionally, locally owned suppliers to the mining industry are predominantly focused on the domestic market, and exports have not shown a sustained and significant expansion. In fact, in 2006 only 7.5 per cent of the sales of Chilean suppliers to the mining industry were exports[2].

1.4.3 Emergence and evolution of KIMS in Chile

Before the 1970s the mining industry was highly vertically integrated; most KIMS were provided internally by specialised units within mining firms (Urzúa, 2003). At that time, Chilean mineral production was controlled by US companies, whose KIMS units were based in their home country. Therefore, most of the KIMS required in Chile were provided by specialised units based in

[2] This estimation is based on a survey carried out by the Mining Centre of the Catholic University of Chile. The survey was applied to a representative sample of 134 suppliers, selected randomly of a universe of about 4,000 locally based suppliers to the Chilean mining industry (Lagos et al, 2007).

the US. For instance, at the late 1960s just 5 per cent of engineering services required by local investment projects were carried out in Chile (Morales, 2001).

In the early 1970s, through the Nationalisation of the Chilean mining industry, foreign mining firms operating in Chile were expropriated and the National Chilean Copper Corporation (Codelco) was created as a state-owned company responsible for managing mining production (Gana, 1990). Codelco relied significantly on resources and skills available locally. This encouraged the development of some Chilean engineering and KIMS suppliers. Thus, in the late 1980s between 70 per cent and 90 per cent of project engineering was provided by locally owned supplier firms (Morales, 2001).

Since the late 1980s and especially during the 1990s Chilean mineral production increased at a high rate. Indeed, during the 1990s the yearly average growth of mineral production was 11 per cent (Chilean Mining Compendium, 2003). This process was driven by a significant amount of foreign direct investment (FDI) led by big multinational mining companies, and the share of multinational mining companies of Chilean mineral production grew from about 20 per cent in 1990 to around 70 per cent in 1999 (Cochilco, 2002).

In the 1990s following international mining companies, many international engineering and KIMS suppliers arrived in Chile crowding out locally owned KIMS and engineering firms, whose share of the local KIMS market fell. Consequently, mining companies gradually contracted most of their required engineering consulting services to large multinational firms (Katz *et al*., 2000).

In addition, in terms of exports, the success of Chilean engineering services and KIMS suppliers has been fairly weak. There are isolated cases, but there is not any clear trend that could suggest the development of an internationally competitive Chilean KIMS sector.

Why, in contrast to other major mining economies, has an internationally competitive, locally owned KIMS supplier sector not emerged and developed in Chile?

The research reported in this thesis addressed this question by analysing the structure and evolution of the technological learning process that accompanied KIMS emergence and development.

CHAPTER 2

KEY FEATURES IN THE EVOLUTION OF THE MINING INDUSTRY IN THE 20TH CENTURY

2.1 Introduction

The aim of this chapter is to review key features of the deep changes that the global mining industry went through during the later 20th century. These features constitute an important set of common background conditions facing both the Australian and Chilean mining industries during that period. In principle, these conditions provided favourable global conditions for the emergence and development of specialised knowledge-intensive mining services (KIMS) suppliers in association with the development of mining industries in many countries. However, this emergence and development of KIMS suppliers has been uneven across mining economies. In particular, as noted briefly in the previous chapter, the KIMS supplier industry in Chile responded to these conditions less successfully than in Australia, Canada and South Africa.

Three key features are highlighted. First, the combination of industry growth, international relocation and innovation transformed the global industry (Section 2.2). The share of industry output accounted for by long established mining industries in the advanced economies declined, and industries in Asia and Latin America grew rapidly to take globally leading positions. But the location of the industry's innovative activity, as well as the production of its equipment and knowledge-intensive services, shifted much less significantly.

Second, after a slow down in the rate of innovation during the first half of the century, a major technological rejuvenation of the mining industry gradually took place over the second half (Section 2.3), providing innovation opportunities to be captured by new entrants. This process was fertile in several mining economies like South Africa and Australia, and weaker in others like Chile.

Third, associated with the technological rejuvenation of the industry, there was a phase of rapid change in the organisation of production (Section 2.4). In particular there was a major change in the division of labour between mining companies and specialised suppliers as several functions formerly performed within mining companies were outsourced to independent suppliers.

Some of this outsourcing involved KIMS suppliers. Section 2.5 briefly outlines key characteristics of the emergence and development of an internationally competitive KIMS supplier sector. Also, although the point is elaborated later in Chapter 5, this section highlights the particular case of the Chilean KIMS sector and its weaker development within the broader context of the global rejuvenation and re-organisation of the industry.

2.2 The Transformation of the Global Mining Industry in the late 20th Century

This section outlines four broad features of the transformation of the mining industry during the late 20th century:

i. Global relocation of mining production;
ii. Global output growth;
iii. Interaction between growth and innovation;
iv. Global location of the mining industry's innovative activity.

(i) The global relocation of mining production:

Over the last two centuries the geographical location of mining activity, in particular metallic mining, has been changing. During the early 19th century Europe was the leading producer of metals. For instance, in 1836 Britain was the world largest copper producer, with 45 per cent of world output. Gradually, during the second half of the 19th century the action moved to North America, in particular to the US, and by the end of the century the US became the world's largest metal mining producer. For instance, the US produced 60 per cent of world's mined copper (Ayres, Ayres and Råde, 2002).

Over most of the 20th century the US kept its leadership as mineral producer. However after the Second World War its share of world mineral production began to drop, and by the end of the century the geographical location of mining production showed a completely different picture compared to 100 years earlier as new mining regions emerged (Figure 2.1). For instance, South America and Asia became the new leaders in metallic mineral production followed by Australia and Canada, with the USA lagging behind.

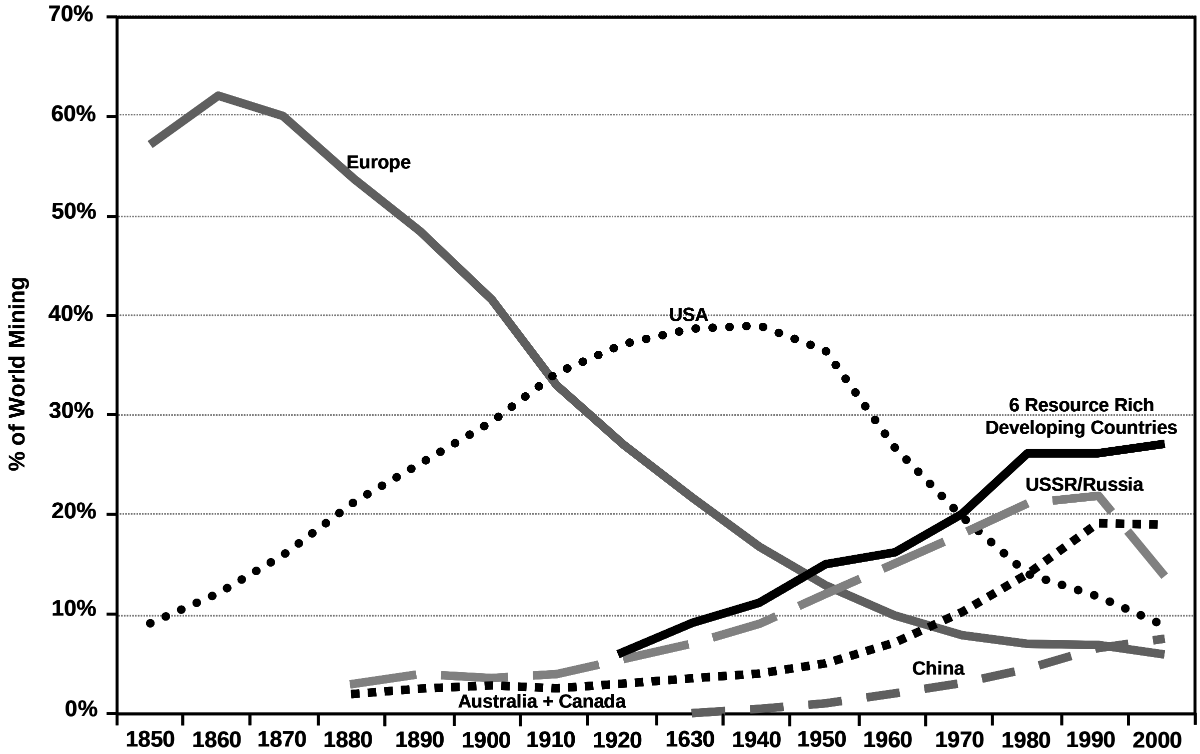

Figure 2.1: Historical Evolution of Geographical Location of Mining: 1850-2000

Source: Brett and Ericsson (2006).

Although mining activity is now more evenly distributed over different regions than a century ago, most of the activity is still concentrated in a small number of countries. Around 80 per cent of metallic mining production takes place in only 12 countries and the remaining 20 per cent is produced in around 90 countries (find more details in Appendix 2: Figures A2.11 to A2.18 and Tables A2.2 to A2.18).

(ii) Global output growth:

After the Second World War, the changing geographical distribution of global mining production was accompanied by an important increase in the rate of growth of production. Figure 2.2 shows the evolution of production level (in volume) of eight major metallic minerals (copper, iron ore, gold, nickel, zinc, silver, lead and bauxite) over the entire 20th century. For these metals, production grew at a steady but slow pace during the first half of the 20th century. Over the same period the value of mineral production, showed only a very slight growth (Figure 2.3).

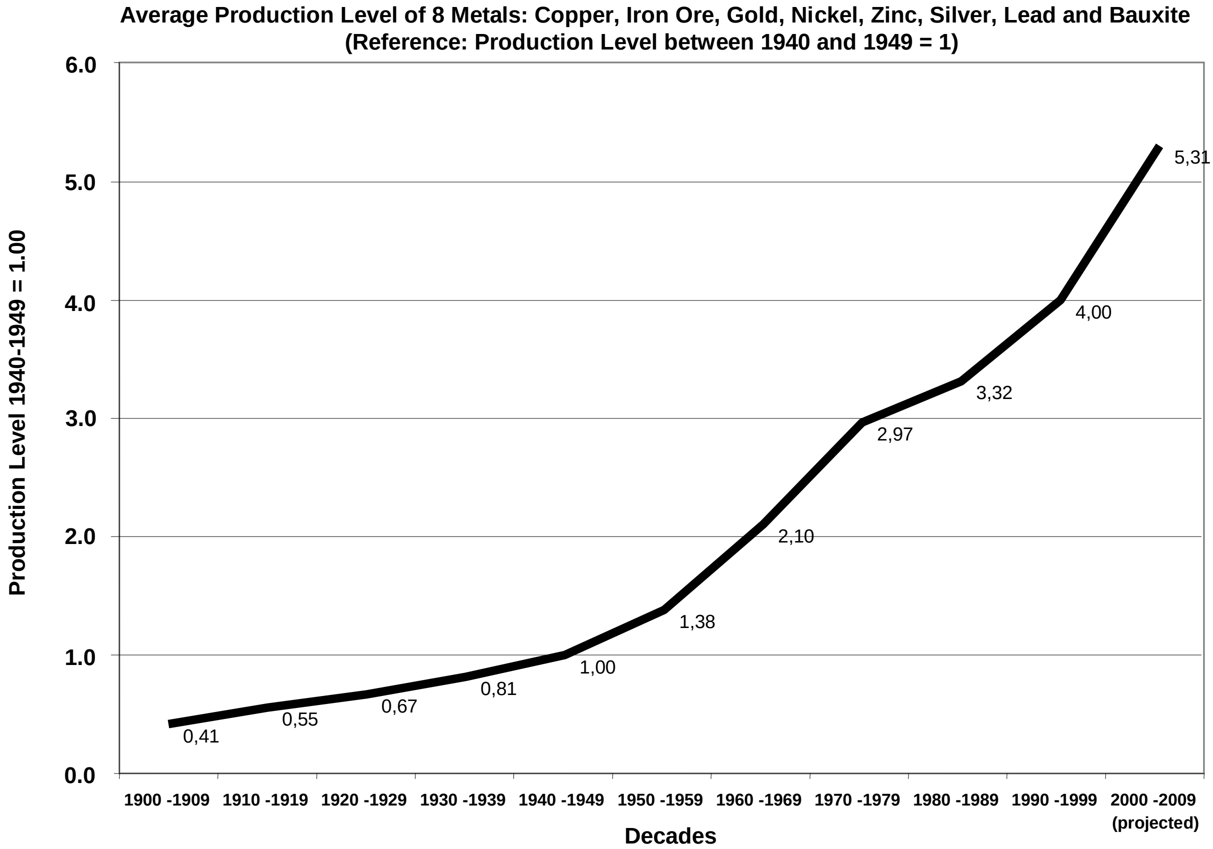

Figure 2.2: Evolution of World Mine Production Level over the 20th Century

Source: Compiled by the author from data in Appendix 2, Table A 2.1

Over the second half of the century a major change took place. Metallic minerals production (in volume) grew on average 3.3 times faster than during the first half, and in terms of value, production also grew very rapidly. Two different sub-periods can be recognised within this period, particularly with respect to the value of output. Over the three decades that followed the Second World War, the value of metallic mining production experienced a dramatic increase, and then during the two subsequent decades it experienced a drop. Very rapid growth resumed over the early years of the 21st century, and, as indicated later, it is expected that high growth will continue over at least another decade[3].

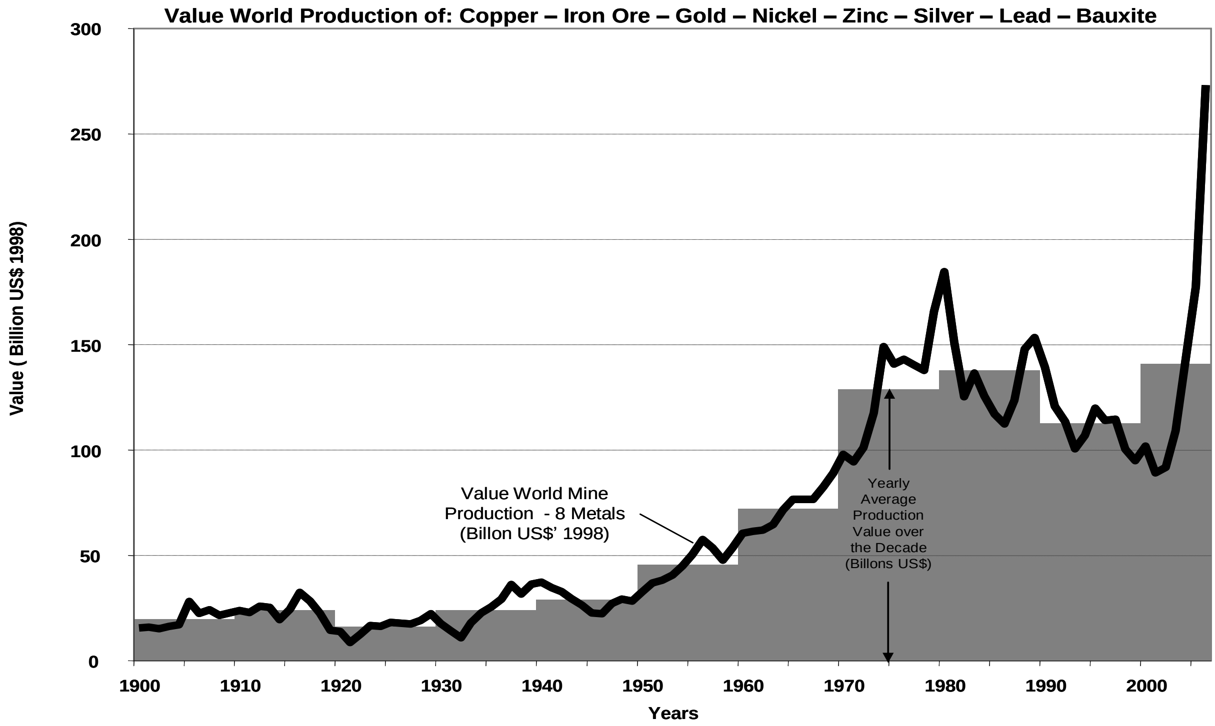

Figure 2.3: Value of World Mine Production Eight Metals 1990-2006

Source: Own elaboration based on data shown in Appendix 2.

(iii) The interaction between growth and innovation:

Historically, the industry has faced major challenges to maintain satisfactory levels of cost and productivity required to meet important increases of mineral demand under scenarios of decreasing ore grade and increasing mineralogical complexity. In more recent periods further challenges have been added in terms of requirements to address environmental, health and safety issues. These challenges have been key driving forces of innovation and learning, which in turn supported further production growth.

The innovations involved in this interaction have involved the development of mining technology in areas such as safe use of dynamite for fragmentation, continuous mining machinery, open-pit mining technology for massive mining in low-grade deposits, monitoring technologies for maintenance and increasing the operational life of equipment and mining system, and a pervasive array of

[3] Further detail about metal production growth can be found in Appendix 2.

computer systems for engineering and geology (Yudelman, 2006; National Academy of Sciences, 2002). Each of these innovations has been part of continuous process in which mining production requirements have generated the demand for learning and innovation efforts that supported production growth.

The US copper mining industry provides an illustrative example of how mining production growth and innovation generated a mutually reinforcing interaction. Despite having low grade ore bodies, which were decreasing more rapidly compared to other mining countries, the US was able to keep its leading position in copper production over most of the 20th century primarily due to its innovation capabilities and learning efforts. As shown in Figure 2.4, the ore grade in US copper mines has been decreasing rapidly since the late 19th century. This led to the development of open pit mining technologies, which permitted the use of very large equipment, generating economies of scale that enabled the exploitation of large deposits with lower ore grade. Additionally the introduction of flotation concentration techniques raised the recovery rate over 90 per cent.

The innovation and learning efforts behind the growth of the US copper mining industry covered every aspect of the whole mining process, from the exploration stage, to the mining and mineral processing stages. This included technologies such as explosives, drilling, earth moving, lighting and ventilation, crushing, processing, metallurgy, power, transportation, communications and information, remote sensing and mapping, health and safety, effluent treatment and environmental management, and robotics (International Institute for Sustainable Development, 2002).

The strong growth of mineral production, in particular since the Second World War, has involved the scaling up of equipment and plants for mining and metallurgical processes, as well as the generation of new technologies. This progress has made it feasible to exploit low-grade deposits, while increasing production and reducing the costs of mineral extraction (Yachir, 1988).

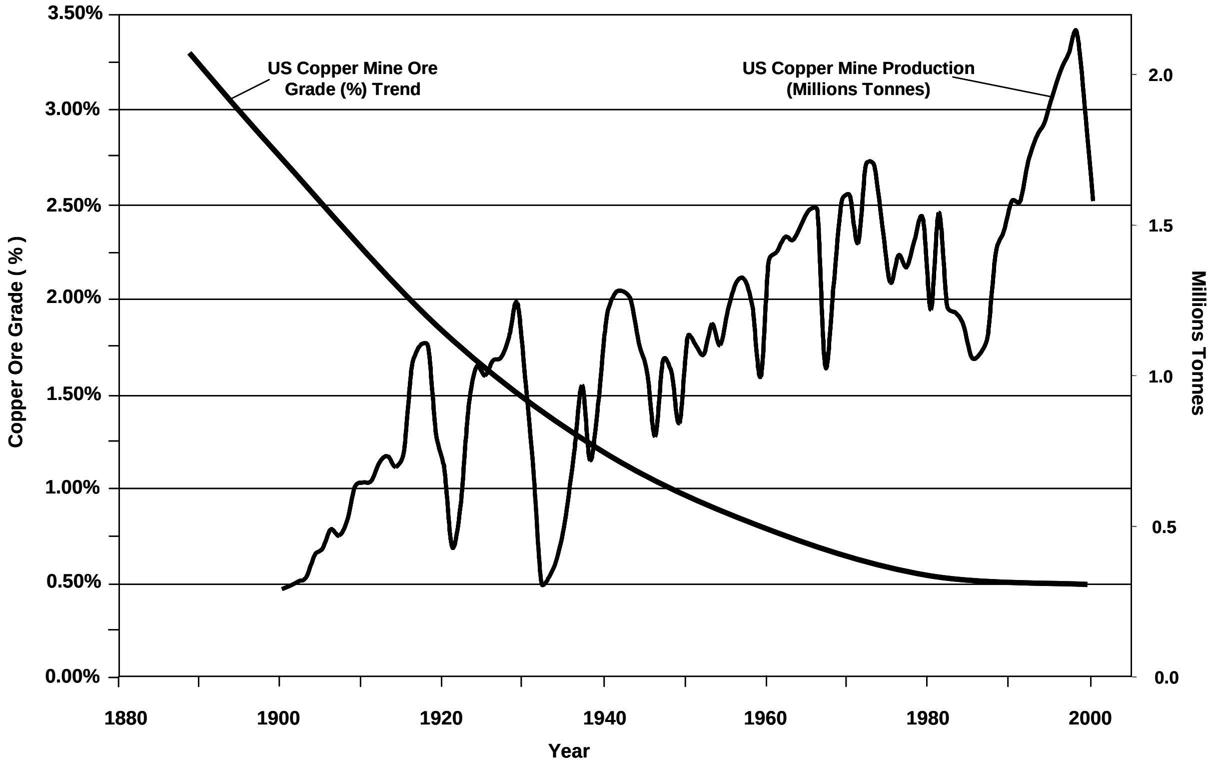

Figure 2.4: US Copper Mine 1880-2000: Ore Grade and Production Level

Source: Ayres, Ayres and Råde (2002); US Geological Survey.

(iv) The global location of the mining industry's innovative activity:

During the late 19th and early 20th centuries most of the mining industry's innovation and knowledge requirements were provided by countries that were also the geographical location of most mining activity: Britain, the US, the Soviet Union, Japan, Germany, and France. Later, during the second half of the 20th century, ten countries accounted for 90 per cent of the equipment and inputs required by the mining industry, but in the case of the more specialised products there were as few as five (Lemieux, 2000, p.20). Over this period, the US was the leading supplier of mining machinery and equipment and specialised products. Although the rank varies somewhat depending on the specific product provided, the UK, Germany, Canada and Australia were among the other leading suppliers. Other important suppliers were Sweden, Finland, South Africa, Japan and France (Lemieux, 2000).

The US kept its position as leading supplier of machinery, equipment and other inputs to the mining industry, together with keeping an important share of world mining production. Several European countries, in particular Germany and the

UK and to a lesser extent Sweden, Finland and France, also kept a leading role as suppliers despite having a much diminished share of world mining production. Two countries, Canada and Australia, emerged as key mining producers and as new suppliers to the mining industry. South Africa, another important mineral producing country, experienced also an important emergence of suppliers.

As demonstrated later in Chapter 5, these countries developed significant innovative activity and accounted for a dominant share of the supply of the industry’s technology embodied in equipment and knowledge-intensive services. South America and Asia show a major contrast. These two regions have emerged as leading minerals producers, but they have not become major producers and suppliers of machinery, equipment and knowledge-intensive services and inputs to the industry.

2.3 Technological Rejuvenation in the Global Mining Industry

> *“Existing mature industries neither remain unchanged nor passively coexist with the new industries. Each technological revolution brings generic and all pervasive technologies, together with new organisational practices, which significantly increase the potential productivity of most existing activities…. The result is the gradual rejuvenation of the whole productive structure, so that updated mature industries can again behave like new industries in terms of dynamism, productivity and profitability”.* (Pérez, 2001, p. 117)

Chapter 3 (Section 3.4) reviews the cyclical nature of such rejuvenation processes and some of their broader aspects across industries. This section concentrates on outlining the specific rejuvenation phase that the mining industry went through during the later decades of the 20th century.

Numerous studies have highlighted the technological aspects of that rejuvenation, indicating that a large number of technological innovations and improvements in exploration, mining and mineral processing have been driving the development of the industry. For instance, satellite imaging methods have reduced the costs of geological exploration, and geographical information systems make it possible to accurately map geological parameters for exploration purposes at a dramatically reduced cost (Granville, 2001). These advances produced a radical change in exploration processes. For example, currently the first stage in the exploration process is gathering information through the use of satellites supplemented by information gathered from aircraft and only after this, is exploratory drilling required (Segal, 2000).

Significant progress has also been achieved by the use of biotechnology, chemistry and mechanical engineering, increasing the efficiency of the mineral extraction process. These improvements have been large enough to change the financial viability of many investment projects. For example, bioleaching used at mines around the world, has improved the feasibility of many projects.

Such advances in exploration and processing technologies have had a major impact on profitability (see the examples in Box 2.1). Innovation in exploration technologies has made it easier to explore large and remote regions, at the same time as successive improvements in metallurgy have enabled the extraction of minerals from previously uneconomic deposits (Segal, 2000).

Cutting across and underpinning most of the innovation in particular areas of mining activity during the later decades of the 20th century was the emergence and development of information technology (IT). IT acted as a pervasive driving force for innovation in almost all mineral production processes by allowing the use of vastly larger amounts of data to predict, design, plan and control operations and installations (Granville, 2001). The biggest impacts of IT were obtained when a connection was made between critical technologies. For example: (i) IT integrated with global positioning systems, airborne geophysics and low-impact seismic methods that are environmentally friendly re-shaped exploration in important ways; (ii) Applying IT in extracting and processing minerals (including robotics, remote operations, and improvements in mine design and automated handling systems) has reduced producing cost, making ore bodies valuable that previously were not cost-effective; and (iii) IT has been integrated with procurement systems so that supply-chain time cycle and inventories have been reduced (Mining Association of Canada, 2001).

Box 2.1: Examples of the Economic Impacts of New Technologies

Example 1: Airborne electromagnetic exploration technology.

Noranda, after adapting airborne electromagnetic exploration technology, discovered the Perseverance deposit in the spring of 2000 near Matagami, Quebec. Traditional exploration methods had not revealed the presence of the deposit, which contains around 5.1 million tonnes of ore worth approximately $1.5 billion.

Example 2: Supporting bolts for seismic activity.

New anchor bolts for effective ground support prevents the walls from caving in during seismic activity. This innovation safely prolongs mining activity, as the anchor bolt absorbs two times the energy the regular bolt does. That allowed maintaining access to two years worth of reserves at the Brunswick mine, valued at approximately $440 million.

Source: Gagnon, 2001.

In addition, IT has supported the integration of operations, from exploration to mining, processing, marketing and sales. In these cases organisational changes are also vital for the integration to succeed. Favourably, organisational change has also shaped the process of innovation itself. For example, Dodgson and Vandermark (2000b) argue that over the 1990s several developments in the mining industry transformed the organisation of production and increased research networking, which helped to accelerate the innovation process.

The overall result of these changes was a transformation of the mining industry from a sector considered in the 1970s to be mature and low-innovating into one that 30 years later is perceived as an innovation- and R&D intensive industry. In Australia in the late 1990s, for example, 42 per cent of Australian minerals businesses undertook technological innovations, compared with 26 per cent of manufacturing businesses, and the large mining companies BHP and Rio Tinto were among the top ten Australian business investors in R&D (Tedesco et al., 2002). Similarly, in Canada 4 per cent of total R&D in 1999 was spent in the mining and mineral industry and five of the “top 50” R&D companies belonged to this sector (Schaan, 2002).

Several authors have sought to identify the driving forces lying behind this phase of accelerating innovation. For example, Peterson et al. (2001) highlighted the following:

i. The long-running decrease in the price of minerals, and the consequent pressure for cost reduction and productivity enhancement;

ii. Continuous new requirements in areas such as health, safety, the environment and land use; and

iii. The processes of globalisation.

Such underlying drivers of the rising innovation-intensity of the industry are not explored further here. Only a brief outline of some of the main consequences is summarised in Table 2.1 and further elaborated below.

Table 2.1: Some Consequences of Rising Innovation-Intensity and Technological Rejuvenation

Features	Description
1. Innovation-led productivity growth	The sectors that are part of the 'rejuvenated industry' and use the new technologies show high productivity growth, pushing up the productivity of all the industry. The use, adoption and adaptation of the new technology requires low investment in infrastructure, by taking advantage of the infrastructure that already exists in the 'rejuvenated industry'.
2. Market growth of innovative sectors	High market growth is experienced by sectors that are part of the overall 'rejuvenated industry' and use the new technologies.
3. Demand for qualified human capital	The 'rejuvenated industry' makes increasing use of highly qualified and skilled personnel.

Source: Based on Pérez, 2001; Pérez and Soete, 1988.

(1) Innovation-led productivity growth: Innovations have been reducing production costs, increasing mineral resources, and improving productivity and safety. Innovations have maintained or extended the viability of mining for a number of commodities and slowed the decline of others (Malherbe and Segal, 2001).

There are several examples of the impact of innovations on the productivity of the Mining Industry. For instance, better prediction of seismic disturbances has improved safety and productivity in mines (Granville, 2001; Committee on Seismic Signals from Mining Activities, National Research Council, 1998; Greenhalgh et al, 2000), and the use of IT has contributed to the mining industry's remarkable productivity performance (Mining Association of Canada, 2001).

Over the period from 1984 to 1998, mining and primary metals were amongst the top ten leading industries in terms of total factor productivity growth in Canada, the sector's productivity exceeding the Canadian average (Schaan, 2002). According to a report elaborated by Global Economics (2001), total factor productivity grew by 3.1 per cent in the Canadian mining sector between 1984 and 1998, almost three times faster than Canada's overall productivity growth, and the primary metals sector had the highest overall ranking in Canada for use of advanced technologies between 1989 and 1998.

According to Davies and Vandermark (2003) Australian mining R&D is world-class, and advances in research and continuous innovation have significantly improved productivity in the industry. For instance, over the 1980s and 1990s the Australian mining industry experienced higher labor productivity growth than the average of all industries (Gruen, 2001, p. 63).

(2) Market growth of innovative sectors: Alongside the continuous expansion of production capacity in the mining industry itself during the 1990s, there has been similarly rapid growth in the production of inputs for the industry – especially technology-intensive machinery and equipment and knowledge-intensive services in the ancillary supplier industries. As elaborated in Sections 2.4 and 2.5, much of this growth in the supply of inputs has been associated with the rapid expansion of specialised KIMS suppliers.

The point stressed here is that the more innovative of these suppliers, especially of knowledge-based services concerned with areas such as exploration, automation, monitoring of mining processes, and environmental management, were more able to capture rapidly growing sales, usually involving a very high level of exports to the global mining industry. In effect, the overall mining industry became a knowledge-exporting industry as much as an exporter of commodities (Dodgson and Vandermark, 2000a). For example, not only did Canadian suppliers of new environmental technologies grow at rates between 5 and 10 per cent per year during the late 1990s, but also 40 per cent of the products were exported, and almost 40 per cent of Canadian suppliers had some kind of foreign representation abroad to market their products (Mining Association of Canada, 2001).

(3) Demand for qualified human capital: The rising intensity of innovation has brought with it a change in the quality of labour force employed in the mining industry. The industry shifted from a high intensity of unskilled workers to the employment of workers with higher technical abilities and education (Malherbe and Segal, 2001). In part this was directly because of the demand for skilled personnel to undertake the innovation activities themselves. But it also reflected a more pervasive demand across the increasingly knowledge-intensive operational areas of the industry. For example, according to the Department of Industry, Tourism and Resources of Australia (2002), individual operators of mining processes are required to have higher technical skills and be more flexible, in order to be able to operate in an environment characterised by multi-disciplinary employment roles and emerging technologies. In Canada also, the mining Industry has created a rising number of high-tech jobs requiring a large percentage of workers to have post-secondary education. According to the Mining Association of Canada (2001), the mining sector employs highly skilled and high-technology workers who are among the highest wage earners in Canada. Additionally, mining-related small and medium firms create thousands of high-tech service jobs. Almost one quarter of the employees in suppliers of specialised mining products are engineers, geologists, geophysicists, geochemists or graduates of related disciplines (Lemieux, 2000).

In order to maintain the availability of highly skilled and educated workers, mining companies have initiated education and training programmes, in association with other companies and universities. They also support post-doctoral research at universities to build knowledge while training future employees (Mining Association of Canada, 2001; Katz *et al*., 2000).

2.4 Change in the Organisation of Production in the Mining Industry

A key part of mining industry's rejuvenation process consisted of changes in the organisation of production and innovation. Key features of this re-organisation are described below and summarised in Table 2.2.

(1) Vertical disintegration and internationalisation of large mining companies: Before the 1980s large mining companies provided internally a significant share of goods and services they required. Additionally, most of the specialised services, such as engineering services, were provided centrally due to their significant economies of scale (Segal, 2000). Later, mining corporations started to reassess their businesses, identifying those activities in which they excelled and made superior returns. Several functions, operations and services formerly performed internally were outsourced to independent specialised firms, and a wide range of specialised suppliers that compete internationally emerged. During the 1990s mining companies sold their non-mining subsidiaries and scaled down the capacity of their centrally run specialised units. Some resources were reassigned to operational functions and many services were outsourced to external service providers (Granville, 2001). As a consequence, highly specialised suppliers firms emerged. Nevertheless, mining companies kept some strong key technological capabilities considered strategic and required for the proper evaluation and control of projects (Segal, 2000).

Additionally, before the 1980s, the minerals industry was essentially domestically based. Most mining companies operated primarily within their home country, with a relatively small number of overseas operations. However, during the late 1980s a dramatic shift occurred. As mentioned earlier in this chapter, mining activities moved from Europe and the US to mining nations such as Australia, Canada, South Africa, Brazil, Chile, and Peru. Mining companies acquired foreign interests, and they became global players running large deposits spread widely across the globe. The requirements for scale then led to the consolidation of few large international mining companies. For instance, the share of world copper production of the five largest mining companies rose from about 40 per cent in 1985 to over 55 per cent in 1999 (Meller, 2002).

(2) Transformation of the innovation process into a network activity: As many processes and functions spread out from the mining firm, the innovation process became a network phenomenon driven by the interaction and collaboration of specialised supplier firms and mining companies (Dodgson and Vandemark, 2000a). This change speeded-up the innovation process and enhanced the development of knowledge-based services.

Table 2.2: Changes in Organisation of Production of the Mining Industry

Early 1980s backwards	The 1990s onwards
Vertically integrated and diversified mining companies, mostly locally based. Technological capabilities are mostly within large mining companies. Technological resources and expert advice are provided centrally.	Vertical disintegrated mining corporation with global presence. Technological capabilities are spread amongst many actors, which include mining companies and specialised suppliers
Innovation occurs in-house, within large mining companies	Innovation is performed in network as a collaborative effort of specialised supplier firms and users.

2.5 Emergence and Development of an Internationally Competitive KIMS Supplier Sector

Within the process of vertical disintegration described in the previous section, a particularly important component was the emergence and growth of an international KIMS sector. Table 2.3 shows a segmentation of four broad categories within the whole array of suppliers to the mining industry. As illustrated by the examples of the products provided under this heading, the term KIMS is introduced here to refer to a wide range of services and products supplied either to mining investment projects and/or operations.

Table 2.3: Categories of Suppliers to the Mining Industry

	Categories of Suppliers and Examples of Product and Services			
	Knowledge-intensive services (KIMS) Consultants	**Specialised Services Contractors**	**Capital Goods and Equipment Suppliers**	**Consumable Inputs Suppliers**
Services and goods mainly for investment projects	- Exploration services - Investment project management - Engineering and consulting services	- Development and construction services - Tunnelling services - Shaft sinking	- Heavy machinery and equipments such as: mills, crushers, and smelting equipment	
Services and goods mainly for ongoing production operations	- Mine automation & optimisation - Blasting engineering - Equipment design and adapting - Geological testing - Metallurgical analysis	- Drilling services - Shaft sinking - Education & training - Mineral processing - Tailing dam operating	- Light machinery and equipment - Conveyors - Ventilation equipment - Engines and generators - Trucks	- Explosives and blasting accessories - Chemical products - Abrasives - Drill bits - Tyres

KIMS are not just provided by ‘pure’ knowledge-intensive services suppliers, such as engineering consulting firms. Equipment and input providers have also been gradually integrating KIMS within their range of products. For instance, Orica (from Australia), the world largest explosive supplier, offers explosives, initiating systems and explosive accessories, and alongside these inputs it also provides blast-based services, which include important blasting engineering and research activities.

In addition, some contractors of specialised services are also looking to include KIMS as part of their offer. For example, Aker Kvaerner (from Norway) is a leading global provider that executes project development studies, followed by engineering, procurement & construction management (EPCM), direct hire construction, commissioning & start-up, and services for operating plants.

One consequence of the combined growth of the industry and the vertical disintegration of KIMS production was a rapid growth in terms of sales in this specialised services sector. Table 2.4 shows an illustrative example of this growth for Australian suppliers of specialised services to the Mining Industry in the late 1990s.

Table 2.4: Australian Suppliers of Specialised Services to the Mining Industry

Type of Specialised Supplier	**Sales Growth 1995-2000**
Scientific research services	550 %
Technical services	116 %
Computer services	53 %

Source: Department of Industry, Tourism and Resources of Australia (2002).

Although the emergence of KIMS suppliers has been a worldwide process, internationally competitive firms have emerged from a limited number of economies. A considerable number of new suppliers emerged in countries such as US, Australia, Canada and South Africa where substantial domestic mining industries underpinned the growth of their respective KIMS supplier sectors. In general KIMS suppliers in these countries have developed their initial technological and managerial capabilities based on their home-country activities, often within larger mining companies that served, in effect, as ‘incubators’ of the necessary capabilities before vertical disintegration and outsourcing processes took place. Then, they expanded their operations abroad, following the increasing internationalisation of their customer mining companies. As will be stressed later, this international experience was an important factor that enabled them to sustain an active learning process.

In contrast, despite the existence of a substantial mineral industry in Chile, the Chilean KIMS supplier sector is less developed in terms of becoming internationally competitive (Ramos, 1998). Chilean KIMS suppliers, despite accumulating higher capabilities did not reach the level that enabled them to achieve international competitiveness standards. Furthermore, when international mining companies arrived in Chile, so did their more experienced and innovative suppliers, and this crowded out the less experienced and innovative local KIMS supplier firms from the new market opportunities.

This thesis focuses on this problem. It elaborates on the process of emergence and development of the KIMS sector in Chile, contrasting it with the Australian experience, focusing on how technological learning influenced KIMS sector development. Although it is not presumed that learning is the sole influence on

KIMS emergence and development, the analysis suggests that it is an important one.

CHAPTER 3

CONCEPTUAL FRAMEWORK, DEVELOPMENT CONTEXT AND RESEARCH QUESTIONS

3.1 Introduction

This thesis aims to contribute to understanding the process by which KIMS suppliers emerged and developed in the context of a developing mining economy, Chile. More specifically it seeks to contribute to explaining the sector's relatively weak path of development in Chile compared with other important mining economies. In particular a contrast is drawn with Australia, and the analysis of Chilean experience is illuminated by comparison with experience in Australia. This focus is set within the context of an interest in understanding the wider issue of natural resource-based development in the late 20th and early 21st centuries, especially in Latin America.

It is important to emphasize, however, that the thesis does not seek to develop a comprehensive account of all the explanatory factors contributing to the path of KIMS sector development in Chile. Instead it focuses the search for explanation in the area of issues concerned with technological learning.

The underlying argument starts from the view that technological learning processes constitute one of the main drivers sustaining economic development (Viotti, 2002), and this applies as much to natural resource-based industries like mining as it does to others that have been more frequently studied, like the electronics or automobile industries. The process of learning is therefore the focus of this research. Specifically, it analyses the evolution of the technological learning that leads to a gradual accumulation of higher level of KIMS technological capabilities, fostering the development of an internationally competitive KIMS supplier sector.

In general terms, learning is seen here as a gradual increase in the reliance on knowledge-based assets, to a large extent embodied in skilled labour, in the course of continuous technological change (Amsden, 2001; Kim, 2001; Pack and Westphal, 1986; Viotti, 2002). However, most of the literature that has examined learning processes in the context of developing economies has taken only a micro-economic perspective. That is, it focuses on how learning and innovation takes place within the firm (e.g. Bell and Albu, 1999; Caniels and Romijn, 2003) and less attention has been given to issues at the industrial level. It is in this respect that the thesis aims to develop a large part of its original contribution by extending the analysis beyond the micro level to encompass its wider industry-level context.

Most of the analysis of contextual or meso-level factors refers to the institutional setting that shapes learning within a firm. However, there are other key factors that have been only broadly analysed, in particular questions about how the potential for learning and innovation at the micro-level is shaped by key features at the industry level. These include the scale and growth rate of the industry, the complexities and technological challenges it faces, and its structure and organisation. With a particular focus on the mining industry and on knowledge-intensive mining services, this study aims to contribute to filling this gap.

Usually, the learning literature has taken only a micro-economic perspective. That is, it focuses on how learning and innovation takes place within the firm (e.g. Bell and Albu, 1999; Caniels and Romijn, 2003) and less attention has been given to issues at the industrial level. Most of the analysis of contextual or meso-level factors refers to the institutional setting that shapes learning within a firm. However, there are other key factors that have been only broadly analysed, in particular questions about how the potential for learning and innovation at the micro-level is shaped by key features at the industry level. These include the scale and growth rate of the industry, the complexities and technological challenges it faces, and its structure and organisation. With a particular focus on the mining industry and on knowledge-intensive mining services, this study aims to contribute to filling this gap.

This chapter develops the conceptual framework used to analyse the long-term learning process that shaped the emergence and development of KIMS suppliers in Chile. Sections 3.2 to 3.5 review four main literatures:

i. Learning and technological capability accumulation in developing countries (Section 3.2);

ii. Innovation and learning in knowledge intensive services sectors (Section 3.3);

iii. Technological change, rejuvenation and barriers to entry (Section 3.4);

iv. Natural resource-based development and the 'natural resource curse' hypothesis (Section 3.5).

The conceptual framework itself is developed in Section 3.6. This framework is the 'lens' used to analyse the path of technological learning followed by KIMS suppliers in Chile and its contrast with Australian experience. The framework shapes the development of the research questions that drive the examination of the long-term learning processes in the two countries. This covers the complete period of emergence and development of the KIMS sectors, starting from around the early 1970s to the early 2000s. These questions are set out in Section 3.7, with their bounded scope re-emphasised. Finally, Section 3.8 opens up one aspect of that bounded scope, the focus on learning-related explanations for the path of |KIMS development in Chile. As contextual background for the core analysis of learning-related issues, it sketches some of the other factors that might have to be considered in a more comprehensive analysis.

3.2 Learning and the Accumulation of Technological Capabilities in Developing Countries

This section reviews a number of questions about technological learning and capabilities. These issues are addressed under two headings: one concerned with key concepts and definitions (Section 3.2.1), the other with key factors that play an important role in shaping technological learning (Section 3.2.2).

3.2.1 Technological learning and capabilities: key concepts and definitions

(a) Technological capability:

Technological capability is a key concept in the learning literature. It is defined as the resources, skills, knowledge and experience in an organisation that enable it to carry out production activities and to generate and manage technological change. In other words, technological capability comprises the ability to make effective use of technological knowledge in production and innovation activities in order to sustain or improve competitiveness.

Technological capabilities are embodied in individuals as well as in organisational systems and their level defines the ability to make effective use of technological knowledge either to produce or to innovate (Bell, 1982; Bell and Pavitt, 1992, 1993, 1995; Enos, 1991; Lall, 1993; Pack, 1987; Scott-Kemmis, 1988; Westphal, Kim, and Dahlman, 1984). Consequently, the technological capability level of a firm might lie somewhere on a scale ranging from doing simple routine production activities, through technology adaptation and duplication activities, to more original innovation and technology creation activities (Lall, 1992, 1993; Viotti, 2002).

Different authors (Amsden, 2001; Bell, 1982; Bell and Pavitt, 1992, 1993; Figueiredo 2005; Kim, 1999) stress that technological capabilities comprise different types of resources, which can be grouped in the following two broad categories:

i. *Production capabilities* consist of the resources (especially knowledge, skills and organisation) needed to operate and maintain existing production systems at a given level of efficiency with a ‘given’ technology.

ii. *Innovation capabilities* are used when an organisation embraces some form of technical change, and they consist of the knowledge, skills and organisational arrangements required to be able to improve, adapt, and innovate.

(b) Technological learning:

The concept of 'technological learning' has been used in several different senses. On the one hand, some of the mainstream economic literature uses the term to refer to improvements in production performance, such as productivity growth, that are associated with the accumulation of skills and knowledge. This association is often represented by a learning curve showing the relationship between performance improvement and the growth of production experience over time. In this framework learning is envisaged almost as a by-product from growing production experience, without taking explicitly into account the various processes by which performance-raising skills and knowledge are acquired by individuals and organisations in the first place, or the levels of effort and cost required to do so (Bell, 1984).

On the other hand, the term technological learning is used to refer to those processes by which technical skills and knowledge are acquired by individuals and through them by organisations (Bell, 1984). Within this sense two different meanings of the concept can be distinguished (Figueiredo, 1999; Dutrénit, 2000). Specifically:

i. *Learning in 'frontier' organisations* that already have high levels of technological capability. Technological learning refers here to the various processes by which an organisation can renew, and integrate capabilities needed to remain as a 'frontier' organisation and sustain its existing innovation capability level. There is no concern about the initial creation of those innovative technological capabilities or about how firms arrive at the technological 'frontier' – because the organisation is already there. The key concern is about how to avoid falling behind.

ii. *Learning in 'developing' organisations* with levels of technological capability that are clearly below the 'frontier' level. Technological learning refers here to the various processes by which an organisation acquires additional technical skill and knowledge to raise its technological capability level above basic production capabilities towards gradually higher levels of innovative capability.

In this thesis the term technological learning is used in the second sense concerned with learning in developing organisations.

Learning processes aim at mastering new knowledge, either related to new technology or to higher level of technological capabilities. In order to pursue this, a wide and diverse range of different learning means can be used (Bell, 1984; Bell and Pavitt, 1992, 1993; Figueiredo, 2005; Kim, 1999, 2001). For instance, in some cases learning activities seek to incorporate existing technology in the capabilities of an organisation. In others, learning seeks to build up the capabilities to generate improvement in the vicinity of technologies already available, and sometimes learning seeks to acquire the highest level innovation capabilities required to create new and original technologies.

Despite the existence of a vast literature about such learning processes in developing countries, and their importance for industrialisation and technological development, there are few examinations of how learning takes place in knowledge based service sectors, and these are usually only rather general discussions. There are even fewer studies about these issues with respect to knowledge services for the mining industry in the context of developing countries. This study aims to help fill that gap.

(c) Technological learning efforts:

The learning literature stresses that effective technological learning is far from being a costless and passive process. It requires delivered, conscious, purposive and significantly systematic efforts, which involve explicit investment in the acquisition of technological capabilities. Furthermore, because the technological change process is continuously moving the technological frontier, even to avoid diverging from the technological frontier requires a high level of effort and commitment (Kim, 1998).

Moreover, even if the source of learning is external, significant efforts are required. The mere exposure of a firm to relevant external knowledge is insufficient unless an effort is made to internalise it (Kim, 1998; UNIDO, 2003). For instance, the simple access to foreign technologies does not imply gaining mastery over it. Accurate implementation of new technologies usually demands some adaptation that requires some degree of tacit knowledge. This is not a costless process that occurs just as a by-product of buying or using new technologies. On the contrary, it is time consuming and requires significant effort to assimilate and internalise, as well as the effort required for adapting, and improving the technology if required (Dahlman, Ross-Larson and Westphal, 1987; Lin, 2003).

Learning comprises a vast array of different types of activity, which seek different goals. For instance, some learning activities aim to access and absorb new technology to be applied at the production level. On other occasions, learning aims to acquire the capabilities to adapt technologies to local conditions, which might involve design and engineering activities. Learning might also aim to accumulate technological capabilities to improve technologies or to innovate (Bell, Scott-Kemmis and Satyarakwit, 1982; Bell, 1984; Katz, 1976; Lall, 1982, 1987, 1993; UNIDO, 2003).

Technological capabilities are cumulative, that is, the ability to utilise new knowledge is a function of the prior level of related knowledge. Consequently, the range of learning possibilities depends on the prior level of technological capability accumulated. A high level of accumulated technological capability increases the ability to comprehend, to assimilate and use new knowledge, so widening the range of effective learning activities (Kim, 1998, 1999, 2001).

Learning efforts gradually evolve as an organisation succeeds in accumulating higher levels of technological capability. Technological capability accumulation proceeds from simpler to more complex learning efforts, from mastering production capacities to achieving higher levels of technological capability (Dahlman, Ross-Larson and Westphal, 1987; Lall, 1992, 1994; Katz, 1985; Viotti, 2002). Learning becomes increasingly difficult as higher technological capabilities are accumulated. The higher the technological capability accumulated, the higher the learning difficulty, cost, investment and effort (Kim, 2001; UNIDO, 2003).

As the development of technological capabilities progresses, new learning mechanisms might need to be added to the set of learning efforts pursued by a firm. For instance, at early stages there might be a high focus on monitoring and acquiring knowledge related to mastering technology or production systems. Later, learning efforts centred on acquiring the capabilities to adapt technology might be added. In advanced technological development stages, when interest centres on the acquisition of capabilities to create products and processes and to achieve original innovation, capabilities based on R&D might became important. The higher the level of technological capabilities accumulated the more diverse the learning mechanisms and efforts. The literature stresses that research is not the unique and almost never the core activity in technological learning and innovation. Innovation also requires mastering the technology, designing, construction and testing prototype products and pilot process plants, engineering activities, and others (Bell, 1984; Bell and Pavitt, 1992, 1993; Figueiredo, 1999; Kim, 2001; UNIDO, 2003).

The literature makes almost no reference to what kind of learning efforts are pursued by knowledge intensive services suppliers over their development process. This research aims to contribute in that respect, in particular with regard to KIMS suppliers learning.

Different literatures highlight that innovation and learning is technology-specific, and that technologies differ in their learning requirements (Bell and Pavitt, 1992; UNIDO, 2003). For instances, heavy process industries have patterns of learning, innovation and assimilation that differ from those in other manufacturing sectors (Bell and Van Dijk, 2003). Furthermore, innovation and learning are also firm-specific because they rely on firms' tacit knowledge. Consequently the nature of their learning processes may differ (Figueiredo, 1999; Lall, 1992, 1994; Lin, 2003). In addition, industries and sectors learn in different ways that are shaped by the particular kinds of evolving challenge and complexity that emerge from their development and production activities (Bell and Pavitt, 1992; UNIDO, 2003).

As a consequence firms move along particular and individual historical learning paths that reinforce their knowledge bases and expertise (Bell and Pavitt, 1992, 1993; Lall, 1993; Nelson and Winter, 1982). Given these unique features of learning processes, this research does not aim to identify a deterministic step-by-step model of the evolving learning process of individual KIMS firms' learning. Instead, it aims to identify (i) general industry level conditions that open-up or close-down the potential for learning and innovation and (ii) how the general firm level learning and innovation efforts change as technological development and industry level factors evolve.

3.2.2 Factors shaping technological learning

(a) Learning and individuals:

Individuals are the leading actors in technological learning. Independently of whether learning refers to the use, adaptation, imitation or creation of technology, it takes place first at the individual level and then at the organisational level. However, learning by the firm is not just an aggregation of individual learning. It comprises at least the processes of knowledge assimilation and distribution across the organisation, and its integration into the strategy and management of the organisation. Individual learning is an indispensable condition for learning by firms, but cannot be the sufficient condition (Kim, 1998; Figueiredo, 1999).

In particular, knowledge intensive services firms rely heavily on expert knowledge (Salter and Tether, 2006). Hence understanding how these experts acquire and upgrade their knowledge bases and experience as part of developing their career paths is a key element for understanding the development of KIMS firms. This feature is barely addressed in the literature but is examined in this research.

(b) The role of key events in shifting learning orientation:

The literature recognises the importance of key events that, if used proactively, can significantly increase the intensity of learning, shifting its orientation from one level or stage of technological capability to another. These events can be the consequence of deliberately created internal crises that are generated by management as a means to intensify learning efforts and orientations (Kim, 1995, 1997, 1998). Alternatively, they may arise more 'naturally' in the course of a firms operations and growth. In either form they can be used as important learning opportunities that may lead to important shifts in the level of technological capabilities accumulated. For instance, investment projects are particularly important in this way in the heavy process industries such as the mining industry. During the execution of such projects important learning opportunities can emerge (Bell and Van Dijk, 2003). In addition investment projects also open up significant training opportunities centred on acquiring the capabilities to manage complex projects. Consequently the higher the frequency of investment projects the more opportunities there are to sustain and speed up learning, and differences in the rate of growth of industries may have important implications for the rate of learning that is possible.

This research aims to contribute to understanding the types of event used as learning opportunities by KIMS firms, with a particular emphasis on the role of investment projects. But that is an issue about only the opportunities for learning. The key issue is about the intensity with which those opportunities are actively exploited by firms. Hence the question about opportunities and the rate or learning actually achieved also involves the issue discussed earlier – the intensity of firms' learning efforts.

(c) User-producer interaction:

The literature also recognises that learning is a network phenomenon; it does not take place in isolation, but in a web of relationships and interactions between suppliers, customers, experts, technology centres and educational institutes (Lall, 1993). In particular, in the services sector there might be a high level of interaction since the delivery of services in general requires that producers and buyers meet physically (Henten and Vad, 2003).

However, not all interactions have the same level of impact on learning and innovation. For instance, market-based interactions, which are concerned basically with market transactions of goods and services may on their own have lower impacts on learning, than knowledge-based interactions involving knowledge flows between the parties or collaborative processes of knowledge creation (Ariffin, 2000).

The interaction between large users and smaller knowledge-intensive services suppliers became a significant component for the development of the KIMS supply sector (Segal, 2000). However, there have not been studies about how this interaction evolves over time as KIMS suppliers become more complex organisations with higher levels of technological capability accumulated.

(d) External incentives and supports:

As stressed earlier in Section 3.2.1, the intensity of learning achieved by firms depends on a deliberate and strong commitment together with a significant effort and investment. However, firms require a setting that provides incentives and supporting mechanisms to overcome the constraints of risk and cost on learning, in particular the risk of imperfect appropriability of the returns to investment in knowledge assets – both those that are disembodied and those that are embodied in mobile human capital. These features of the context for learning are likely to be particularly important in shaping the extent to which firms engage in long-term learning and innovation arrangements in order to precede with stable and strong processes of technological capability upgrading and accumulation (Humphrey and Schmitz, 2002; Lall, 1993, 1994; Viotti, 2002).

Commonly discussed incentive and support systems for innovation and learning include: i) adequate access to technological information and infrastructure; ii) availability of skilled labour; iii) tax incentives or financial support for training and, R&D investment; iv) trade and investment attraction regimes; and v) supports and encouragements to user firms to allow suppliers to test new or adapted products and services in their operation.

Given that the level of technological capabilities in developing countries is lower than in developed ones, the nature of learning and innovation challenges differs from the first group of countries to the latter. Accordingly, the incentives and support system in developing countries might be focused on supporting learning processes that lead to building higher level of technological capabilities, rather than on stimulating original innovation activities (Viotti, 2002).

(e) Industry structure and organisation:

Learning paths are influenced by the structure and organisation of industry (Lall, 1987). In particular the geographical spread of firms' operations and investment, and the functional integration between internationally dispersed activities, shape the extent to which firms actually use opportunities for learning and innovation that are opened up by the growth of industries and the challenges generated by the expansion of their production.

As commonly stressed, the progress of globalisation has brought an increase in the flow of worldwide investment by multinational firms. This has two implications for learning. On the one hand, these foreign investments can stimulate learning and innovation through supplier-client linkages and knowledge and technology spill over. But on the other hand, they can also crowd out local actors through mergers and acquisitions; they may strip proprietary knowledge from local firms; and they may generate market-distorting practices with negative effects for local technological development. In addition, factors like the required volume of purchases, knowledge barriers and the long term and global nature of contracts may become huge barriers to entry for potential newcomers and for the survival of local independent suppliers (Mytelka, 1999).

As outlined earlier, major changes in the degree of vertical integration of the industry had important implications for the development of a distinct KIMS supplier sector and its learning-related linkages. But learning opportunities for supplier firms in global industries may also be influenced by trends in the degree and form of horizontal integration. This may be particularly important in heavy process industries, perhaps especially for their knowledge-intensive services sectors for which increased horizontal integration may increase barriers to entry for newcomers and the risks faced by small local suppliers. For instance, engineering services for large-scale projects in many process industries have become highly concentrated in a small number of large companies operating on a global basis. This global concentration of the supply industry may restrict access to project-based learning opportunities, particularly because major supplier firms typically incorporate in their project implementation networks large numbers of established suppliers of equipment and services with which they operate o a global basis (Bell and Van Dijk, 2003).

Thus, as often stressed in the literature, globalisation goes beyond the mere geographic spread of economic activities – the phenomenon of, internationalisation that has been important since at least the 17th century. It also involves functional integration between internationally dispersed activities, creating a growing level of interconnectedness, which shapes the way firms learn, innovate and compete (Dicken, 1998). In particular, knowledge intensive services are increasingly acquiring a global knowledge network organisational structure (Salter and Tether, 2006). Consequently, analysing the factors that shape the learning dynamics of competitive services suppliers requires going beyond national boundaries.

This research contributes to understanding how changes on the structure and globalisation of the mining industry have shaped the way knowledge based services firms have been able to participate in learning and innovation opportunities that have been opened-up by the global mining industry over recent decades.

3.3 Innovation and Learning in Knowledge-Intensive Services Sectors

Over recent decades services have become a key component in the economic development of both developed and developing countries. The services sector has become a self propelling sector that develops new products that both condition the competitiveness and productivity of other economic activities and become part of the export base of local economies (Daniels, 1995; De Bandt, 1995). There is therefore a growing literature on the services sector, and this has recently come to include a number of studies that address issues about learning and innovation in the service industry (Miozzo and Miles, 2002; Salter and Tether, 2006; Sundbot, 1997). However, very little of that literature has addressed issues about learning and innovation that are important in this research – issues about: (i) the accumulation of individual competences needed to undertake innovation, (ii) the accumulation of innovation capabilities in service industry enterprises in developing countries, and (iii) the influence of service sector globalisation on those two learning processes This section reviews key features of the services literature, highlighting these gaps that are addressed by this thesis.

Service firms were traditionally assumed to be simply adopters and users of existing technologies rather than producers of new technology (Pavitt, 1984). Although the need to question this perception was noted a considerable time ago (Robson, et al., 1988), change has been quite slow, and extensive studies about the innovation and learning processes of knowledge-based services suppliers are fairly recent and are far from being conclusive (Muller and Doloreux, 2007; Salter and Tether, 2006). In the particular case of KIMS, there is a very limited literature that refers to KIMS development, which is analysed in a rather general way and without addressing explicitly technological learning (Dodgson and Vandermark, 2000b; Katz, Cáceres and Cárdenas, 2000; Lemieaux, 2000; Segal, 2000).

One of the obstacles to systematically tackling different aspects of the development of the knowledge-based services sector is the limited effort that has been devoted to an exact definition of the concept (Toivonen and Tuominen, 2006). For instance, different authors have defined categories of services in different ways:

i. *Supplier-dominated services*: this group includes public services or collective goods (e.g. education, and health care), personal services (e.g. hotels, restaurants, food and drinks, repair business, hairdressers and domestic services) and some distributive services (e.g. retail trade) (Soete and Miozzo, 1989; Miozzo and Soete, 2001).

ii. *Production-intensive services*: this group covers two groups: a) scale-intensive services that involving large scale back-office administrative tasks (e.g. client service, information processing, etc.); and b) services dependent on physical networks (e.g., transport and travel services, and wholesale trade and distribution) or on information networks (e.g., banks, insurance, telecommunications, and broadcasting services). Public utilities such as electricity, water and gas supply may also be included in this group. Usually, these services play an important role in defining and specifying innovations and new technologies, and users are therefore to an extent 'service dependent' (Soete and Miozzo, 1989; Miozzo and Soete, 2001).

iii. *Technology-users services*: this group conforms to what was described above as the 'traditional' view of service firms (Pavitt, 1984), with a low level of innovation activities being mostly 'supplier dominated' (e.g. waste, land and sea transportation, security, cleaning, legal services, travel services and retail). These firms rely on technologies bought in from external sources, usually the manufacturing and/or IT sectors. This category accounted for about 80% of all service firms and more than half of employment. The firms in this group tend to be small (Evangelista, 2000).

iv. *Interactive Services*: The activities in this classification included advertising, banks, insurance, hotels and restaurants. In this group innovation is achieved through close interaction with clients, rather than through internal R&D or technological acquisition. A heavy reliance is placed on developing software and/or acquiring know-how (Evangelista, 2000).

v. *Specialised technology suppliers and science-based services*: These are services produced by firms which have innovation activities of their own, or which use and develop new technologies (e.g. software, and specialised business services, including technical and design services). Innovation and new technology are often developed in close co-operation with particular users. (Soete and Miozzo, 1989; Miozzo and Soete, 2001).

vi. *Science and technology based services*: The activities included in this group are R&D services, engineering and computer and software services. These firms are important creators of new knowledge, which they diffuse to manufacturers and other services. Innovation activities are carried out on the basis of close interactions with research institutions. In the case of Italy, this group accounted for less than 5% of employment in services. However it contributed 30% of service firms' total expenditures on innovation (Evangelista, 2000).

vii. *Technology consultancy services:* These combine characteristics of the science and technology-based services and the interactive services. They carry out internal innovation activities but draw heavily on clients' knowledge. This group's main function is the provision of solutions to meet the specific needs of their clients. Consequently, user's problem-solving is the main driver of innovation and learning (Evangelista, 2000).

A more general category of knowledge-based services, consisting of most of the activities under categories (v) to (vii) above have commonly been called knowledge intensive services (KIS), or, almost interchangeably, knowledge-intensive business services (KIBS). This research adopts the acronym, KIS, and approaches KIMS as a particular form of KIS.

KIS production is based on user-producer interaction as one of the main sources to find a solution to users' problems by utilising knowledge – either scientific, or technological and professional knowledge – as the most important and critical resource (TEKES, 2002). KIS comprise 'pure' services suppliers as well as production integrated services. The latter refers to manufacturing companies that offer service solutions together with their manufactured product or artefact; generally the value of the knowledge content is many times that of the physical good itself.

The literature stresses that manufacturing and services are complementary sectors and infrastructure in both sectors may be needed for development and growth. Hence, the debate about international comparative advantages in services versus manufacturing can be a misleading approach (Ietto-Gillies, 2003). Additionally, services are delivered by manufacturing firms and vice-versa; hence a strict separating line between manufacturing and services sector cannot be drawn (Henten and Vad, 2003). Furthermore, there is no simple way to separate services and manufacturing modes of innovation. Many manufacturers seek to compete through the provision and development of services and many services look to manufacturing for means of generating efficiencies in their activities (Salter and Tether, 2006).

KIS used to be considered mostly adopters of new technologies, which played a central role in technological diffusion and transfer, both diffusion within specific industry clusters, and between different ones (Barras, 1986; Salter and Tether, 2006). Nowadays it is acknowledge that besides dissemination or technology transfer activities, KIS also comprises knowledge accumulation and creation activities aiming to develop a customised service or product that satisfies user's needs (Bettencourt *et al*., 2002; Miles *et al*., 1995; Salter and Tether, 2006).

Some authors highlight that it is uncommon for services firms to have R&D departments, and that innovation generally is an unsystematic search-and-learn process (Sundbot, 1997). Innovations often emerge in the process of service provision and on the basis of clients' needs identification based on user-producer interaction. Additionally, a significant part of the innovation emerges as the product of a close interaction between the skilled and experienced staff of users and producers, and other partners (den Hertog, 2000; Salter and Tether, 2006; Turner and Keegan, 1999). Frequently, innovations are recognised as such only later on (Toivonen and Tuominen, 2006).

In user-producer interactions there are usually significant knowledge flows in both directions. The knowledge base of the user is enriched by confrontation with the knowledge base of the KIS firm. Suppliers play a double role, firstly they can provide new knowledge or technology, and secondly they may also speed-up learning acting as catalysts that help internal communication and knowledge conversion in user firms and other related organisation (den Hertog, 2000). Additionally, user-producer interactions may generate knowledge networks that operates across the economy supporting innovation and learning (Muller and Zenker, 2001; Wong and He, 2005). KIS innovation activities tend to be open and networked, rather than closed and undertaken within a single firm (Salter and Tether, 2006).

Some authors have stressed that the role or importance of services in innovation has been growing over time and also its share in R&D activities, which may imply more formal innovation units or department (Salter and Tether, 2006).

KIMS suppliers rely heavily on professional knowledge or expertise associated with a specific discipline or functional domain (Miles *et al*., 1995; Salter and Tether, 2006; Windrum and Tomlinson, 1999; den Hertog, 2000; Toivonen, 2006). This knowledge includes a high degree of intangible or tacit knowledge from suppliers, users and other actors involved in projects (Windrum and Tomlinson, 1999; den Hertog, 2000). For instance, professional engineering services have typically been produced by sourcing human resources with specialist and experience-based knowledge, combined and extended in highly complex project-based networks, and adapted to local environments and constraints through interaction with users, contractors, regulatory agencies and other organisations (Baark, 2002). In KIS, it is the human capital assets that are invaluable and are the source of competitive advantage, because they are unique, rare and difficult to imitate. The key assets are experience-based knowledge, gained through practicing a technical skill over time, and in a variety of different situations (Salter and Tether, 2006).

However, despite these emphases on the importance of these various kinds of people-embodied knowledge and experience, as a base of KIS capabilities, there have only been rather vague studies of how individuals accumulate and upgrade such expert knowledge. In other words, the career development path pursued by a KIS expert to sustain and increase KIS competitiveness is a largely unknown process. This aspect of learning processes in the KIMS sector is therefore a gap in current understanding that is explored in this research. But that exploration of learning at the individual level is closely linked to the examination of two other neglected issues.

First, although much of the literature reviewed above addresses issues about learning at the organisational level in the KIS sector, a pervasive feature is that it has examined such learning only in the context of developed countries. The dynamic that drives KIS development in developing countries, and the factors that shape the sector's learning processes, have not been analysed. This research aims to help fill that gap with particular reference to knowledge based services and the mining industry – i.e. KIMS.

Second, the existing literature recognises that globalisation has also come to the services sector, and notes such issues as: (i) the internationalisation profile of KIS firms has been growing, (ii) the sector's organisation has been restructured by creating major international services networks that are coordinated by holding companies (Daniels, 1995); and (iii) this process has been supported by the introduction of ICT, in particular from the 1980s onwards (Ietto-Gillies, 2003). However, little attention has been given to understanding ways in which these trends affect learning at both individual and organisational levels in KIS industries in developing countries, and that gap is also explored in this study.

3.4 Technological Change Cycles, Rejuvenation and Barriers to Entry

Every significant technology evolves within its own life cycle and, it has been argued, the opportunities for learning by firms located behind the technological frontier vary through different stages of these cycles (Pérez and Soete, 1988; Perez, 2001). The cycles typically start with a 'radical' innovation – a significant new product or process such as the light bulb, the vacuum tube, rayon, nylon, penicillin, television, nuclear power, the contraceptive pill, the semi-conductor or the automatic transmission. This initial and radical innovation can drive the emergence of a new product or process and, depending on the level of innovativeness and on the socio-economic context it may generate a new industry.

The initial stage of the lifecycles of such technologies is characterised by innovation and optimisation until the new product or process gains acceptance in the market – though frequently this involves the introduction of several variants of the technology. This is typically followed by a stage where market interactions shape the direction of improvements via more incremental types of innovation, and during this process a dominant design is usually defined. After that, successive incremental innovations improve quality, productivity and producers' market positions. Finally, the cycle culminates with technological maturity, when investment in innovation begins to have diminishing returns, and the possibilities of increasing productivity by further innovation are diminished. Across different products and industries the whole process can last a few years or a number of decades (Pérez, 2001).

One feature of these cycles is that the economic characteristics of the technological change. For example, as noted above, the space for productivity growth via further incremental innovation falls, and the investment cost for new production facilities rises as minimum efficient scale increases – see the top half of Table 3.1. But another important issue also changes over the cycle – the barriers facing new entrants to the industry. As argued by Perez and Soete (1988) and Perez (2001), various aspects of the knowledge, skills and experience required in the industry constitute an important influence on these barriers. As shown in the bottom half of Table 3.1, these typically change over the cycle. For example, the importance of unskilled labour rises with growing technological maturity, along with the importance of other static comparative advantages, while the importance of mastering the underlying scientific knowledge falls, along with the importance of other dynamic comparative advantages. The consequence is that these knowledge-related conditions come to be increasingly compatible with entry by firms in developing countries – but at the same time as investment costs rise and the potential growth of markets and productivity falls. The argument is, therefore, that there are windows of opportunity for entry at relatively early and much more dynamic stages of the cycle, provided firms and their contexts have the necessary mastery of knowledge and skills.

Table 3.1: Changing Barriers to Entry and Innovation Potential over the Technology Cycle

	Phases of the Technological Cycle		
	Introduction	***Growth***	***Maturity***
Types of economic potential of technologies over their life-cycle	**Levels of economic potential over the technology/product life-cycle**		
Space for productivity improvement	High	Medium-High	Low
Potential for market growth	High	Medium	Low
Profit making capacity	High	Medium	Low
Investment cost (e.g. production facilities)	Low	Medium	High
Type of barrier to entry	**Level of the type of barrier**		
Requirement of mastering scientific knowledge	High	Medium	Low
Experience & know-how requirement	Low	Medium-High	Medium
Capacity to use unskilled labour	Low	Medium	High
Relative importance of dynamic advantages	High	High	Low
Relative importance of comparative (static) advantages	Low-Medium	Low-Medium	High

Source: Based on Pérez and Soete (1988).

Thus, it is argued, the cyclical process of radical innovation followed by growing technological maturity in particular technologies, products and markets creates a moving set of development opportunities based on a highly interactive and interconnected dynamic that comprises the disappearance of old windows of opportunity and their replacement by new ones. Consequently, sustained technological development depends on taking advantage of different and successive windows of opportunity. To take such advantage it is central to recognise the nature of each successive opportunity, to set-up appropriate learning processes, and to foster innovation capacities. So, whether a developing country takes advantage of the “windows of opportunity” opened up by global patterns of technological change depends partly on the level of technology absorbed from the more advanced countries and on the learning efforts to adopt, adapt, modify and gradually master the technical know-how involved.

However, two other factors cut across this analysis. One is about changes in the power structures that govern particular industries; the other is about phases of technological transformation that pervasively influence all sectors of the economy rather than just the development of individual products and industries. These merit a little elaboration as they are potentially important in the case of the mining sector and the emergence of the KIMS supplier sector over recent decades.

3.4.1 Industry power structures

Associated with cycles of technological change in particular products and industries there are also changes in the patterns of competition and the organisational structures of power. These changes, and not just changes in knowledge-related conditions, contribute to shaping the barriers to entry and consequently the possibility of actually taking advantage of any learning opportunities that are opened up. As technology evolves to maturity there is a tendency towards growing industry concentration at the global level. Thus the cyclical nature of technological development interacts with the process of industry consolidation and the consequent combination of financial power and market control becomes an important entry barrier. In addition the weakest firms disappear or are absorbed by larger market controlling organisations (Pérez, 2001, 2003).

The value chain literature provides a supplementary illustrative view of the way these factors interact to shape barriers to entry. It highlights how the interaction between technological development paths and the process of globalisation have been shaping the industry power structure and influencing barriers to entry (Kaplinsky and Morris, 2002). The full range of activities required to bring a product or service from conception, through the different phase of production, delivery and final disposal are increasingly spread worldwide and some firms acquire greater control over this process by setting the parameters under which others firms operate. This control refers to the whole spectrum of production activities, which can include elements such as the technology to be used, quality systems, labour standards and environmental standards (Humphrey and Schmitz, 2002). These forms of inter-firm relationship and control are generating new kinds of organisation, driven by the combined forces of technological development and globalisation.

Box 3.1: General features of how globalisation shapes the Automotive Industry

Assemblers:

- Increasing scale is required to spread costs of vehicle design and branding.
- Innovation and design capabilities remain critical as first movers in new markets segments can gain important rents while other companies catch up.
- Some companies believe that core competences lie more in branding and finance, and they are outsourcing parts of manufacturing. Others maintain an emphasis on manufacturing excellence and competence.
- Require significant financial resources.

Global mega suppliers (' Tier 0.5'):

- Closer to the assemblers than the first-tier suppliers (see below) and supply major systems to the assemblers.
- Require global coverage, in order to follow their customers to various locations around the world.
- Design and innovation capabilities are required in order to provide "black box" solutions (solutions created by the suppliers using their own technology) to meet the performance and interface requirements set by assemblers.
- Require considerable financial resources.

First-tier suppliers:

- Supply direct to the assemblers.
- Some of these suppliers have evolved into global mega suppliers.
- Require design and innovation capabilities, but their global scope may be more limited.

Second-tier suppliers:

- Often work to designs provided by assemblers or global mega suppliers.
- Require process engineering skills in order to meet cost and flexibility requirements.
- Require ability to meet quality requirements and obtain quality certification.
- May supply just one market, but there is some evidence of increasing internationalisation.

Third-tier suppliers:

- Supply very basic products.
- In most cases, only very rudimentary engineering skills are required.
- The competences required are much less, but the returns are also much lower.
- At this point in the chain, firms compete predominantly on price.

After market (and market for replacement parts):

- Many firms in developing countries first moved into this sector, even before local assembly sectors were developed.
- There is an international trade in after market products.
- Competition is predominantly on price.
- Access to cheaper raw materials and process engineering skills are important.
- Innovation is not required, because designs are copied from the existing components, but reverse engineering capability and competence to translate designs into detail drawings are important.

Source: Humphrey (2001), Humphrey and Memedovic (2003).

An illustrative example of this process is the automotive industry. In this case, as summarised in Box 3.1, the web of relationships between assemblers, component and subcomponent fabricators, services and inputs suppliers that is emerging forces one to think about the organisation of production on a global basis (Humphrey, 2001). In this industry, design activities have shifted from assemblers to suppliers and the coordination between the two parties is enhanced. The assembler provides the overall performance specifications and information about the interface with the rest of the car, and then the supplier designs a solution using its own technology. Additionally suppliers have to provide complete systems or modules rather than individual components. Therefore, first-tier suppliers become responsible not only for the assembly of parts into complete units, but also for the management of the second-tier suppliers. The assemblers develop more the specification of the production and improve quality systems of their suppliers. In this context locally owned firms have to find new abilities to prosper within the globally organised industry.

Elements of similar patterns have been emerging in the mining industry, and this thesis explores their implications for the development of KIMS suppliers.

3.4.2 Phases of pervasive technological transformation

Since the 1980s considerable attention has been given, not so much to individual radical innovations such as those discussed above, but to the clustering of innovations in particular periods of history. Such clusters or ‘constellations’ of innovation typically have radical innovations at their heart – sometimes the driver is a single innovation like the steam engine or electrical power, and at others it consists of small combinations of radical innovations like the automobile plus associated radical innovations in petroleum and petrochemical technologies or the semi-conductor combined with the computer and radical telecommunication innovations. But these radical core innovations are combined with a host of associated incremental innovations, and the whole complex has pervasive effects across all (or at least very many) sectors of the economy. These were originally distinguished from individual radical innovation by the term ‘new technology systems’ (Freeman et al., 1982; Perez, 1983), and other terms have also been developed (e.g. new ‘constellations’) and, when associated institutional and economic dimensions are also included, wider terms are used like ‘new techno-economic paradigm’ (Perez, 1985). Freeman and Louçã (2001, pp. 139-151) provide a recent integrating review of these ideas in the context of their discussion of ‘technological revolutions’ in ‘long waves’ of economic development.

The emergence of such constellations of innovation gives rise to great surges of growth by the creation of a double opportunity. First, it generates the emergence and expansion of a core of one or more new high-tech industries (e.g. the automobile, petroleum and petrochemical industries with their main innovation origins in the early years of the last century and their phase of rapid growth – at least in the advanced economies – from around the 1940s to 1970s; or the semiconductor, computer, and telecommunication industries with their initial radical innovations in the 1960s and their rapid growth in the ‘IT revolution’ or ‘paradigm’ since then). Second, the technologies at the heart of such constellations are also pervasively applied across other industries that are at various stages in their own ‘internal’ product and technology life cycles. Consequently, this pervasive character of such constellations may ‘rejuvenate’ even mature existing industries (Perez, 2001). It is argued that this rejuvenation may once again create conditions in and around an existing industry that are similar to those that existed earlier in its emerging phase. In particular opportunities for higher rates of productivity and profitability may open up, and at the same time barriers to entry may fall and new opportunities for learning by latecomer firms may emerge.

However, the extent to which specific industries in developing countries are actually be able to exploit the learning and entry opportunities opened up by such technological rejuvenation has scarcely been addressed in the literature. More specifically the question has not been raised with respect to the mining industry. This research aims to contribute to filling that gap. But it takes quite a focused perspective. Rather than attempting to assess the implications of rejuvenation for the core mining industry itself, it examines how the industry’s technological rejuvenation associated with the electronic/IT revolution over recent decades may have influenced opportunities for entry and learning by firms in the industry’s emerging knowledge-intensive services supplier sector.

This focus of the research needs to be set in the context of broader perspectives on the mining industry. The emphasis on technological rejuvenation of this industry and on the possible opportunities it may open up for learning and entry by firms in developing countries seems inconsistent with common arguments about the inherent developmental limitations of natural resource-based industries – the so-called resource-curse hypothesis. This issue is reviewed below.

3.5 Natural Resources-Based Development and the "Curse" of Natural-Resource Abundance

A widely held view is that an abundant endowment of natural resources is 'a curse' for developing economies. This resource-curse hypothesis argues that there is an inverse association between resource abundance and relative economic growth (Auty, 1994; Gylfason, 2001; Sachs and Warner, 2001). With differing emphases between authors, this literature has argued that economies that are richly endowed with natural resources have to deal with several problems such as economic volatility, vulnerability to corruption, deterioration in the terms of trade, and the development of passive rent-seeking behaviour instead of more active entrepreneurial activities. In some arguments, the last of these views is linked to ideas about the technological maturity of natural resource based industries and the limited opportunities for active innovating and knowledge producing activities and associated technologically dynamic forms of development.

More recently, however, a number of studies have drawn attention to the earlier experience of countries such as the United States, Canada, Sweden and Finland that have used natural resource-intensive industries as central components of dynamic development paths, including their role as platforms to support the development of highly-skilled, knowledge-intensive and export-oriented activities (Walker and Jourdan, 2003; De Ferranti *et al*., 2002). But the technology- and learning-related dimensions of these arguments are usually somewhat marginal to the debate. Thus, the main arguments about the resource curse centre around six issues, only some of which relate to questions about technology and learning.

3.5.1 The main arguments within the resource curse hypothesis

As noted above, six central arguments are outlined below, with contrasting views summarised in each case.

1. The finite character of natural resources: This argument states that primary production based on non-renewable resources – as in the mining industry – cannot contribute to sustainable long-run economic growth because of the finite nature of the natural resource base on which production depends.

However, it has been argued that the exploitation of non-renewable resources can be progressively extended through exploration, technological progress and investments in appropriate knowledge. This has been the case for the mining industry in the US, Canada, Norway, Chile and Australia among others (Meller, 2002; Ramos, 1998; Wright and Czelusta, 2002).

2. Deteriorating terms of trade: This argument, states that resource-abundant economies face continuing declines in their terms of trade (Prebisch, 1959). This means that the price of primary products relative to manufactures in international markets appears to have been on a long-run decline. The explanation of this trend can be summarised as follow: It is assumed that demand for primary products is income and price inelastic. If there is productivity growth that shifts out the supply curves then a rise in income resulting from that productivity growth will shift out the global demand curve, but less so for primary products whose demand is less income elastic. As a consequence, economies with a comparative advantage in primary products would grow less rapidly than other economies. For the relative price decline of primary products not to occur, given the differences in income elasticity, the slower growth in the global demand for primary products would need to be matched by slower growth in their global supply. But even then, resource-rich economies, and specifically those whose primary sectors are relatively dominant, would still be growing slower than others because of slower aggregate output growth. The relative price of primary products would decline even more if there was relatively faster growth in their supply, for example because of faster productivity growth in primary sectors. In that case the lower price elasticity of demand for primary products would contribute too. This greater price decline means that real incomes of resource-rich economies still grow more slowly than those of resource-poor economies, despite the greater output of primary products.

This argument has been contested by showing that the supposed decline of commodity prices over the early part of the 20th century (the case used by Prebisch) was probably misleading (Maloney, 2007). It was rapidly decreasing transport costs that made commodities appear relatively cheaper in London, where they were usually measured. The reverse trend would have been observed if prices had been measured at the port of origin. In addition, the demand curve for commodities in the first half of the 20th century was significantly different from that in the second half (US Geological Survey Minerals Yearbook, 1998). Additionally, over the past decade, mainly driven by the entry of China into the global market, the pattern of relative prices between commodities and manufacturing has been changing. The prices of some commodities have been increasing and the prices of many manufactures have been falling. These price changes may reverse the decline in the terms of trade of commodity producers (Kaplinsky, 2006).

3. The Dutch disease: According to this argument, the large exports of commodities or raw materials can generate increases in the real exchange rate of the currency, which can lead to both an increase in manufacturing costs and increases in the sector's wages, attracting labour from other industries and raising wages. Furthermore, repeated booms and busts of raw materials prices tend to increase exchange rate volatility, thus reducing investment in the tradable sector (Gylfason, 2001).

However, despite the possible difficulties generated by the Dutch disease, some countries have used their mining activity as a basis for the development of a mining equipment manufacturing sector, the growth of which was export-oriented. Different countries have shown different trajectories of mining equipment sector development. This can be illustrated by Figure 3.1. This shows the level of mining equipment exports from seven countries in 1987 and those countries' metallic mining production level with respect to the eight most important metals (copper, iron ore, gold, nickel, zinc, silver, lead, bauxite).

Behind this cross sectional comparison three different development trajectories can be identified.

The first trajectory lies behind the observations for Canada and the US. These countries had developed a mining equipment exporting sector along with the expansion of their metals production. It is argued that the growth of mining interacted with the development of a mining equipment industry and its export growth (Duhart, 1993). Australia might also be considered in this group, although in the period up to the 1980s the development of the mining machinery industry and exports was not as closely linked to the scale and growth of the mining industry as in the other two countries.

The second trajectory was associated with the three countries in the top left-hand quadrant of Figure 3.1 – Japan, Sweden and Finland. These are countries that in earlier years had followed paths like the US and Canada, evolving a symbiotic relationship between their mining and mining equipment industries. However, by the 1980s their domestic mining industries had declined substantially, leaving the legacy of strong, internationally competitive mining equipment industries.

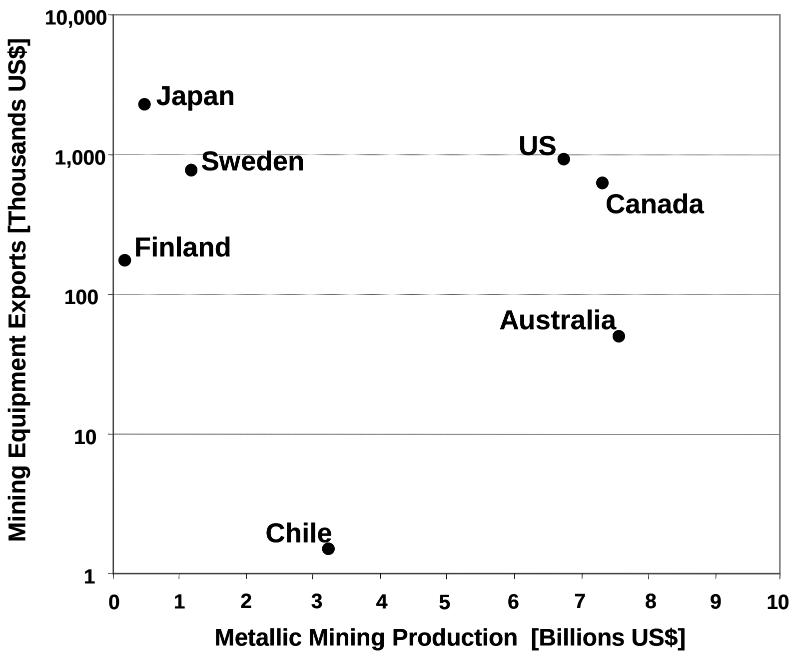

Figure 3.1: Metallic Mining Production and Mining Equipment Export in Seven Countries (1987)

Source: Based on Duhart (1993) and USGS (2008).

The third type of trajectory is illustrated by the Chilean case. Here there was a significant level of mineral production but almost no development of mining equipment exports. In other words, the growth of the mining industry, with Chile becoming the world largest copper producer during the late 1980s, had not been linked to a corresponding development of the mining equipment industry (see the discussion of capital goods exports in Section 3.8)

This raises interesting questions about why Chile appears to demonstrate a different pattern from the other two groups. In particular, had the historical conditions associated with the symbiotic relationship in the case of the first two groups changed by the time of the growth of the mining industry in Chile? For example, is the process of technological learning that is now needed for effective entry to the equipment industry now much more complex and demanding than it was earlier? Are there now much greater barriers to entry? Alternatively, is there a key issue about the absolute scale of the mining industry needed to stimulate the emergence of an equipment supply sector? Also, since this focuses on the services sector, not equipment production, how do these issues apply in the case of the development of an internationally competitive services industry in association with the growth of a domestic mining industry?

4. Lower opportunities for technological progress: Adam Smith (1776) first argued that, compared with primary production, manufacturing industries produce more externalities or spillovers that reinforce economic growth. Also Marshall (1890) suggested that there are lower possibilities for technological progress in primary industries, because manufacturing is subject to increasing returns while primary production faces decreasing returns. More recently, some authors have argued that manufacturing industry leads to more learning effects, which result in higher productivity growth in the economy as a whole, and therefore an economy specialised in primary products would benefit less from externalities inherent in manufacturing production (Sachs and Warner, 2001).

Other authors argue that the important issue is not what is produced, but how (Anderson, 1997; Lederman and Maloney, 2007). Particularly important, it is suggested, is whether primary production is embedded in an enabling environment for adopting technologies, producing knowledge and commercialising knowledge-based products over the long term. Much of the discussion of that issue has focused on developing new industries 'downstream' from natural resources. The research reported here focuses on 'upstream' industries and on knowledge-intensive services in particular.

5. Rent seeking behaviour: The argument on this point states that significant natural-resource rents, under conditions of badly defined property rights, imperfect markets and lax legal structures, may create opportunities for rent-seeking behaviour, distracting resources away from more socially fruitful economic activity. Such behaviour can lead to corruption in business and government, therefore distorting the allocation of resources and reducing both economic efficiency and social equity (Auty, 1994).

These types of rent are called 'exogenous rents' and are a consequence of having access to particular endowments (e.g. abundant natural resources) that arise from barriers to entry created by parties external to the value chain. In other words, the barriers are generated outside the firm, and the firms that profit from them do not make any significant entrepreneurial effort or investment, and the rents are available only to a selected group of producers (Kaplinsky, 2001, 2005).

But rents do not arise only from having privileged access to natural resource endowments. They may arise from having other resources such as capability, knowledge or some form of endowment that others do not possess. In particular, sustained growth requires rents that arise from the command over production processes and product technology, which enables firms to build barriers to entry (Kaplinsky, 2001, 2005). These more developmentally constructive types of rent are called 'endogenous rents' and they include the following:

- *Technology rents*: producers command scarce technological capabilities with regard to processes and products;
- *Human resources rent*: producers have a relatively more skilled labour force than their competitors;

- *Organisational rents*: producers have particular organisational and managerial skills, which create superior command over organisation and logistics;

- *Marketing rents*: producers possess better marketing capabilities and/or establish brand name prominence in major markets;

- *Relational rents*: producers have inter-firm relationships that may involve the management of production linkages with other firms, the development of strategic alliances, or the management of relations with clusters of small and medium sized enterprises.

In principle, these types of rent can be created in and around natural resource-based industries like mining. However, in order to profit from endogenous rents firms need to maintain a deliberate effort and investment in acquiring the capabilities that are the sources of these rents. In addition, endogenous rents are dynamic, the barriers to entry can diminish and others may have access to the resources or capabilities that generate the rents, which also push to keep a continuous deliberated effort to upgrade the capabilities these rents are based on.

6. Distortions at home: Abundant natural resources may create a sense of security, which leads governments to lose awareness of what is needed to encourage economic growth, including free trade, bureaucratic efficiency, institutional quality and sustainable development (Gylfason, 2001).

It is possible to take an alternative perspective on these six arguments, one that puts technological learning at the centre of the debate. An outline of this learning-centred perspective is presented below.

3.5.2 An overview of alternative arguments: steps towards a learning-centred perspective

A lthough some evidence shows a correlation between slower economic growth and intensive dependence on resource-based industries (Sachs and Warner, 1999), and although some of the factors described above may be correlated with natural resource abundance, there is no conclusive evidence that slower economic growth and resource-based industrial development are unavoidably linked. Indeed it can be argued that the evidence underpinning these arguments that rich natural resource endowments lead to distortions in the domestic economy are taken from an unrepresentative period, namely the 1970s and 1980s. In contrast, in the period from 1913 to 1950, for example, it was the resource-rich countries that grew faster than the then-industrialised countries (Maddison, 1994). Moreover, in the case of Latin America, the period of the Sachs-Warner analysis includes the “lost decade” of the 1980s, which resulted from the over-borrowing of the 1970s, the traumatic demise of the protectionist model of development, and the transitions to more open economies (De Ferranti *et al*., 2002).

Also, as noted earlier, in contrast to the argument for the ‘curse’ of natural-resource abundance, there are successful cases of development based on natural resources exploitation. For instance, a successful case of resource-based development emerges from the US mining industry before the 1920s. Indeed, North American industrialisation and its economic development were supported by natural resources based industries. It has been argued that, what mattered most in the US case was not the quality of the national resources, but the nature of the learning process through which the economic potential of these resources was achieved (Wright and Czelusta, 2002). Three main factors have been identified as conditions underpinning the development of the American minerals industry:

i. An accommodating legal environment, including open access for exploration, exclusive rights to mine specific sites upon proof of discovery, and the need to use the mine or lose it;

ii. Investment in publicly accessible knowledge;

iii. Education in mining, minerals, and metallurgy.

The American case was essentially a form of collective learning, a return on large-scale investment in exploration, transportation, geological knowledge, and in the development of technologies of mineral extraction, refining, and utilisation. It was a process of continuous technological change and learning, embodied in intellectual networks linking world-class mining universities, government and private research. The US success resulted from a gradual transition to resource-intensive manufacturing industries, and later to more knowledge-intensive industries (Wright and Czelusta, 2002).

The case of Australian mining development is another prominent example of development based on mining. Some of Australia's development was based on the discovery of new deposits and the generation and export of mining-related knowledge (mineral detection, environmentally sound mining practices, and processing). This process was based on a massive educational and research infrastructure (Maloney, 2007). In this case, clusters of universities and private and public think tanks were key factors to further productivity growth and development of new products.

In these successful cases, natural resource industries were the starting point for the development of many firms. Nevertheless, those successful strategies were not exclusively based on the extraction of natural resources. They were also complemented with investments in human capital, technological knowledge, and infrastructure. Only part of the rents of natural resources-based industry might refer to having access to an important endowment of natural resources. However that is not enough, and to sustain a successful development trajectory other sources of rents should emerge or grow.

Figure 3.2 below summarises these contrasting views between the negative perspective on resource-based development (the resource curse perspective) and more developmentally positive perspectives. Essentially, these two perspectives take different views about the role of knowledge, innovation, and learning and associated capability accumulation at the centre of the resources-based development process. In simple terms, the resource curse hypothesis (represented in the left side of Figure 3.2) argues that an abundance of resources leads to slower growth because it generates exogenous rent seeking behaviour that leads to corruption, which has a negative effect on sustainable growth. In addition, abundant resources lead to the destruction of technological capabilities and trade development, which further weaken a sustainable growth process.

On the other hand, the more positive resource-based development hypothesis (represented in the right side of Figure 3.2) argues that having abundant natural resource may support sustainable growth. First, the exploitation of natural resources may lead to the accumulation of higher level technological capabilities, which in turn increase natural resources endowment generating a mutually reinforcing process. Second, this perspective recognises the existence of exogenous rents, but over a natural resources-based development process, the balance between exogenous and endogenous rent is progressively changing so that the relative importance of exogenous rents gradually decreases. Over this process, exogenous rents may support the development of the capabilities that are the sources of endogenous rents, especially while the level of endogenous rents is not enough to sustain a competitive position. Third, natural resources also support trade development as commodity trade and production can create a direct link with the international economy. Additionally, mining technology and knowledge developed over time may achieve exportable standards, which may lead to an increase in international trade by exporting mining technologies and services to the world mining industry and to other industries where the same technology and knowledge may be applied, so widening learning possibilities.

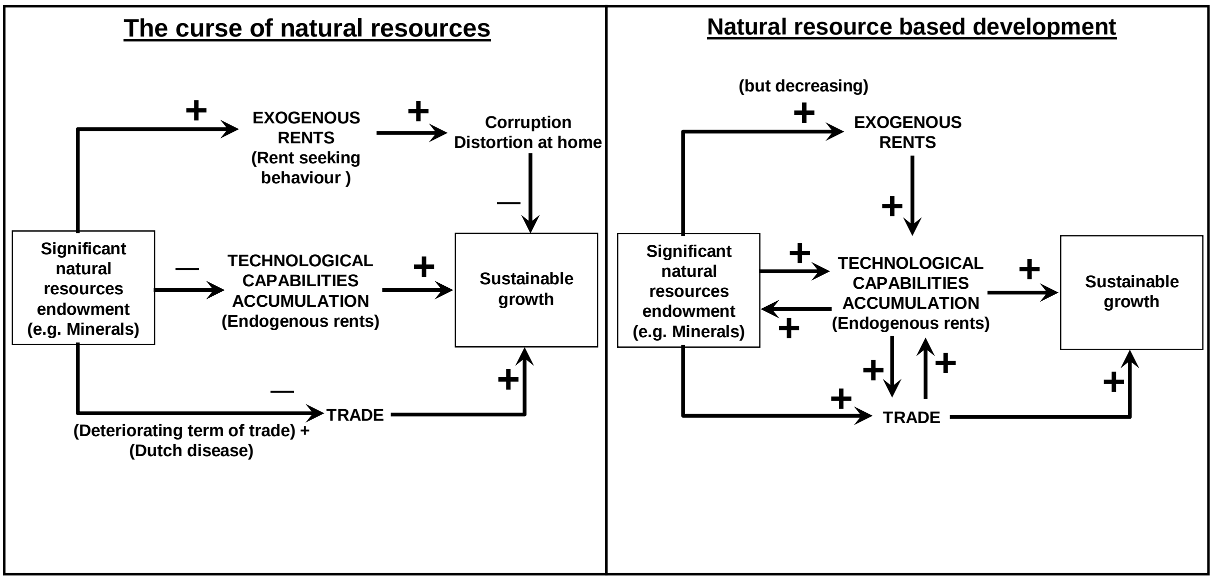

Figure 3.2: Comparing the Rationale Behind 'The Curse of Natural Resources' and 'Natural Resources Based Development'

The key difference between these two perspectives is that the resource curse hypothesis argues that abundant natural resources crowd-out activities that drive long-term growth, in particular technological capability accumulation or learning and innovation activities. On the other hand, the more positive resource-based development hypothesis states the opposite, abundant natural resources may support activities that drive growth, in particular activities concerned with technological capability accumulation, learning and innovation.

However, there exist neither detailed analyses of how technological learning takes place in and around natural resource-based industries in developing countries nor studies of circumstances under which abundant resources can support an active learning process that drives a sustained growth trajectory. This is precisely the focus of the research reported in this thesis. Specifically, how does the technological learning process work in the mining industry, focusing on the learning process that shapes the emergence and development of KIMS suppliers?

3.6 Conceptual Framework: A Dynamic Model of KIMS Learning

This section draws on the concepts and arguments reviewed in Sections 3.2-3.5 and present the conceptual framework used to analyse the evolution of the technological learning pursued by KIMS suppliers in Chile and Australia during the 40-year emergence and development of the KIMS sectors.

It is important to stress that the focus here is on the development of KIMS suppliers at the level of national economies, and that the scope for such development, especially in an industry like mining, is strongly influenced by forces at the global level. Two issues are particularly important:

i. Trends in global demand for mining products and the rate of growth of the global industry have an important influence on the opportunities and incentives for learning and KIMS sector development in particular countries;

ii. Those opportunities and incentives are also strongly influenced by trends in technological change at the global level, and especially phases of technological rejuvenation and associated organisational change, as outlined in Chapter 2 and also in Section 3.4 above. As well as posing new demands for learning in new areas of technology, phases of rejuvenation open up opportunities for the development of knowledge-intensive firms as entry barriers are relatively low at early stages of the technological cycles in such phases.

What is under consideration here is the effectiveness of learning and innovation and KIMS sector development in two countries within the global context influenced by such factors. In effect, the issue here is about the way in which firms and industries at the national level responded to, and exploited, the incentives and opportunities available in that global context for the development of internationally competitive KIMS supplier sectors. The basic argument advanced is that, at the level of the individual countries, that development was shaped by two key intertwined processes; and the broad proposition explored in later chapters is that differences between the countries in the characteristics of these two processes played a major part in accounting for the difference between them in KIMS sector development through the late 20th century.

The main features of these two key processes within the conceptual framework that is developed here have been identified through an iterative exercise that combined selecting ideas and concepts from the literature reviewed in previous sections and testing and refining them during the exploratory stages of the field work.

The two key processes are:

Process 1: The broad historical process by which key features at the industry level shape the potential for learning and innovation at the micro-level.

***Process 2*:** The micro-level learning and innovation efforts carried out by firms to exploit the learning potential to generate particular paths of capability accumulation.

The interaction of these two processes constitutes what is described in this thesis as an overall ‘KIMS learning dynamic model’, which determines the level of technological capability accumulated through particular periods of time. The two processes and their interaction in the overall dynamic model are outlined below in more detail.

Process 1: **Shaping the potential for learning and innovation**

The potential for learning and innovation that is available at the level of individual economies is strongly influenced by the following three industry-level factors:

i. The scale and growth rate of mining production activity;

ii. The complexities and challenges faced in mining production activities;

iii. The structure and organisation of the mining industry, which comprises mining companies and suppliers.

The state of each of these factors and their interactions are key determinants of whether there is a suitable environment for developing active and sustained learning and innovation efforts at the level of individual firms. They may interact to create negative effects by constraining the learning and innovation potential (or opportunities for learning and innovation). Alternatively they may operate positively opening up wider potential and greater opportunities. Figure 3.3 illustrates the two kinds of relationships involved in this part of the overall learning model: (a) the interaction between these factors themselves; and (b) the influence of them on the potential for innovation and learning.

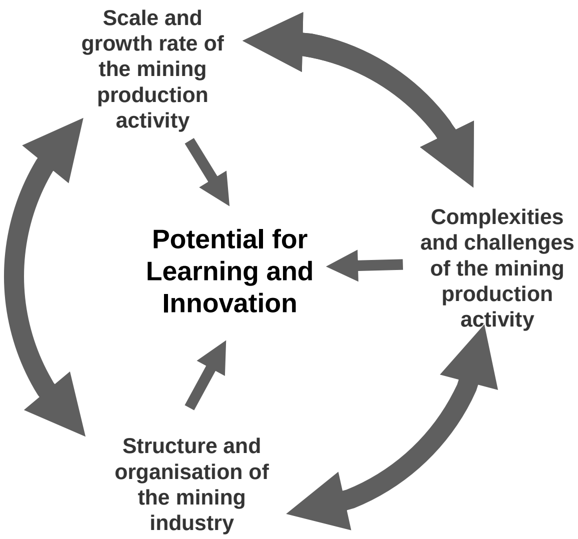

Figure 3.3: Factors Shaping the Potential for Learning and Innovation

The three factors and their influence on the learning potential are elaborated further below.

1. *The scale and growth rate of mining production activity*: This factor refers to the scale and growth rate of mining production that KIMS suppliers may be linked to. Scale and growth rate shape the potential for learning and innovation because the demand for technology, learning and innovation is derived from it. Both on-going production and investment projects for expansion need to access continuously new technologies, to improve the technology mastery level and to innovate in order to keep production aligned with competitive and sustainable standards. In addition, mining production activity shapes the scope of available learning activities since investment projects and production operations can be used as opportunities for learning. For instance, periods with a high frequency of investment projects can be used strategically to develop learning programmes, such as training programmes, based on participating in a sequence of increasingly challenging tasks. Moreover, the learning opportunities associated with the scale and growth of mining production are not necessarily limited to mining production within national boundaries. Indeed, the scope of internationally competitive KIMS suppliers is the international mining industry.

2. Complexities and challenges of the mining production activity: The potential for learning and innovation that is inherent in the production scale and growth rate is also shaped by the technical and organisational complexities and challenges associated with the particular kinds of mining activity involved in both ongoing operations and new expansion projects. For instance, if the growth of mining production is based on using standard technological solutions that do not require significant capability building efforts, adaptations and innovations, then the potential for learning and innovation is more limited than in the case of a production growth trajectory that faces greater complexity and other challenges.

As with the previous factor, the range of complexities and challenges is not limited to those arising only in connection with local mining activity. For instance, frequently globally organised KIMS suppliers are “chasing” projects of high complexity to sustain and activate their learning and innovation processes, and also to become a world reference in their area of technological expertise.

3. The structure and organisation of the mining industry: The structure and organisation of the industry influence the barriers to participation in production activity and consequently in potential learning and innovation activities. As the industry’s structure changes so do the barriers to participation in such learning and innovation possibilities associated with any particular level of mining activity. It is important to bear in mind also that the mining industry comprises mining companies as well as their suppliers. Therefore changes in the structure and organisation of the industry consider both type of actors and their interactions. The structure and organisation of the industry can be characterised by degrees of vertical integration, specialisation, horizontal integration and globalisation.

High levels of vertical integration of mining companies foster the development of internal KIMS units over external suppliers (outsourcing) and most learning and innovation opportunities are caught by the former. In contrast, in a vertically disintegrated industry external KIMS suppliers have access to more learning and innovation opportunities. Particularly important learning and innovation opportunities for KIMS suppliers emerge when mining companies are going through a process of vertical disintegration. During this process external KIMS firms face an increase in demand driven by a higher level of participation in mining production activities, which widen the learning and innovation possibilities. Additionally, capabilities accumulated within mining companies and embodied in experts are available to be taken over by KIMS firms by hiring these experts.

Specialisation refers to whether KIMS suppliers are widening or narrowing the scope of services offered. On the one hand highly specialised KIMS suppliers might have access to important learning and innovation experiences since their unique knowledge is in high demand. On the other hand, mining companies might simplify their procurement systems by hiring specialised services through intermediate suppliers, such as a project management consultant, and then highly specialised KIMS firms become second tier suppliers and their access to operations and projects is shaped by first tier suppliers. The pattern of specialisation also refers to the range of minerals produced by mining companies and the range of stages of the mining process addressed by companies. The higher are these kinds of diversity in mining companies the wider is range of learning and innovation possibilities.

Horizontal integration refers to the extent that acquisition or merging has become a significant means for KIMS firms' growth, leading to larger firms and eventually higher level of concentration. Horizontal integration can change the governance of the supply chain. The industry might consolidate and larger firms might develop a higher degree of control over the access to mining production activity, shaping the access to learning and innovation possibilities.

The degree of globalisation represents the extent to which firms' activities and functions are spread and organised on a global basis. Globally organised firms might have access to world mining production activities, which widens the range of learning and innovation opportunities accessible to the firm.

Process 2: **Exploiting the potential for learning and innovation**

Learning and innovation are activities that take place at the micro level. It is the firm which exploits the learning and innovation potential that exists at the industry level and consequently increases or decreases its level of technological capabilities. This process is not costless. On the contrary, it requires firms to sustain significant and deliberate learning and innovation efforts, which evolve as the firms achieve higher levels of technological capability.

The process of accumulating higher levels of technological capability is represented as the outcome of a cyclical process, the learning and innovation cycle. This is identified here as having three elements:

1. The level of technological capabilities accumulated by a firm at a given period determines the type of learning and innovation activities that the firm is able to pursue. The lower the technological capability level the narrower the range of types of learning and innovation activities feasible for the firm;

2. The efficacy of the actual learning and innovation activities pursued by a firm (in terms of accumulating higher technological capability levels), which is shaped by:

   (a) Selecting a feasible set of different types of learning and innovation activities according to the firm's capability level already accumulated, which might also comprise new challenges associated with higher capability levels; and

   (b) The level of learning and innovation efforts committed by the firm;

3. If learning and innovation efforts are effective, higher technological capability levels are accumulated and the cycle starts over again, but now the range of types of learning and innovation activities that the firm is able to pursue is wider.

This cyclical dynamic is illustrated in the following figures (Figures 3.4a and 3.4b). Figure 3.4a shows that the accumulated capability level (left side) determines the scope of learning and innovation possibilities, and if effective learning and innovation efforts are carried out (right side), then capability levels will be upgraded, starting the cycle over again.

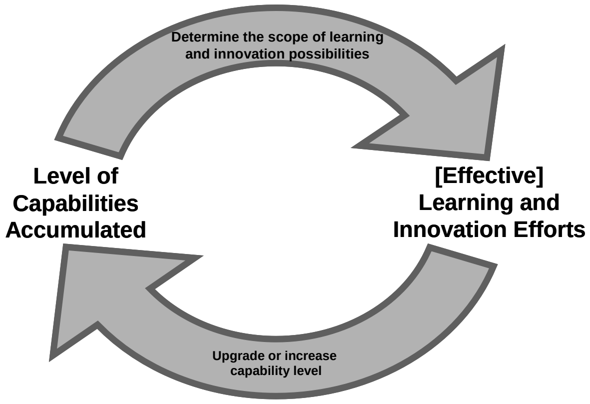

Figure 3.4a: Learning and Innovation Cycle

Figure 3.4b includes the idea of evolution over time by presenting the gradual displacement to the right (which represents progressively higher technological capability levels) of the learning and innovation cycle. The figure shows the effect of capability level increasing after an effective learning and innovation effort took place, which subsequently enables updating learning and innovation efforts given the new range of learning and innovation activities that the firm is able to cope with.

If learning and innovation efforts are effective over several cycles, then the technological capability level of KIMS firms, or the sector as a whole, will gradually increase leading to catching up with the technological frontier.

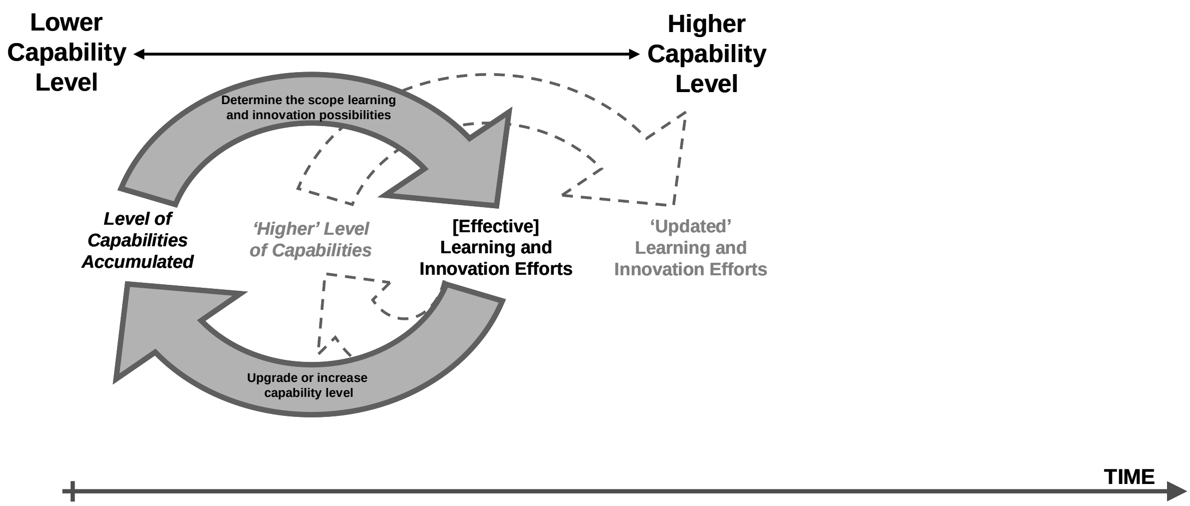

Figure 3.4b: Learning and Innovation Cycle

In order to trace the evolution of the learning and innovation cycle it is necessary to characterise both the level of capabilities accumulated and how learning and innovation efforts have been evolving.

Usually KIMS are delivered by both suppliers and mining companies, and also through their interactions. In addition, significant knowledge transfer between both may exist. Therefore, in order to get a more accurate picture of KIMS technological capability level, one should take into account the capabilities accumulated within both types of organisation.

Learning and innovation efforts comprise a vast variety of different types of activity. Identifying and tracing every type of effort is an almost endless task. Hence, to characterise the evolution of learning and innovation efforts it is necessary to be selective – taking into account that: (a) learning and innovation comprises efforts regarding different level of technological capabilities, from the most advanced research activities to the most basic production practises; (b) innovation and learning in knowledge intensive services rely heavily on the knowledge embodied in experts, therefore the career paths of KIMS experts are important elements in KIMS firms' development trajectories; and (c) interaction can be an important source of learning and innovation, especially between mining companies and KIMS suppliers.

Integrating Processes 1 and 2: Dynamic Model of KIMS Learning

The integrated effect of both processes is represented in Figure 3.5. Interacting industry level factors shape the learning and innovation potential available in the industry (right side of the figure). The firm exploits this potential learning and innovation by carrying out deliberate and active learning and innovation efforts, which are shaped by the level of capabilities already accumulated by the firm (left side of the figure). The integrated effect of the industry level factors and the firm learning and innovation efforts determine the real level of technological capabilities accumulated after a learning and innovation cycle had been completed (the very left side of the figure).

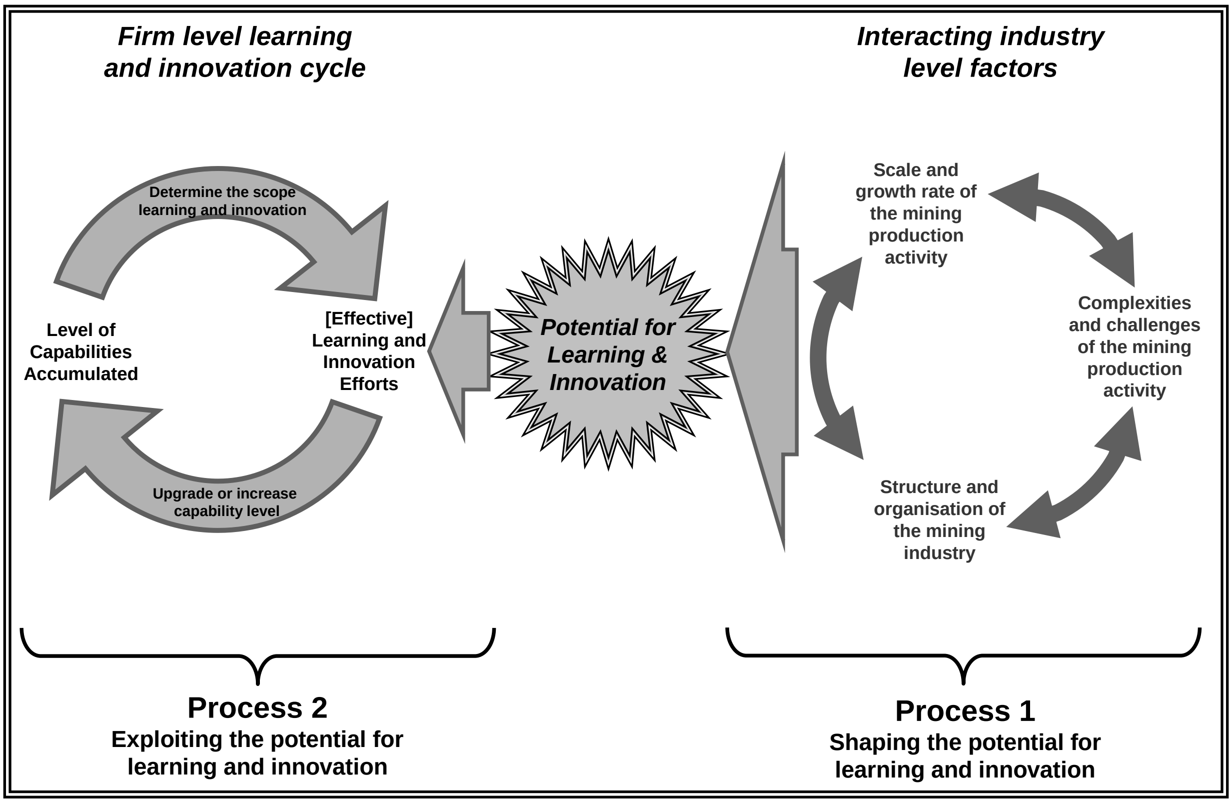

Figure 3.5: A Dynamic Model of KIMS Learning

3.7 The Research Questions

The key issue addressed in this research is the relatively weak development of the Chilean KIMS sector through the second half of the twentieth century. This section identifies the basic questions about that issue that are examined in the thesis. It does so in two steps. First, in Section 3.7.1 it sets out the questions and re-emphasises two important ways in which they are bounded – in terms of the nature of the comparative analysis involving Australian experience and the focus on explanation concerned with technological learning processes. Then in Section 3.7.2 it clarifies further the way in which the thesis addresses questions that lie outside the second of those bounds, questions about the possible explanatory role of other factors beyond those concerned with technological learning

3.7.1 Research questions

As noted earlier, in addition to the primary focus on the experience of KIMS sector development specifically in Chile, the scope of the questions addressed in the thesis is bounded in two important ways.

The first is about the comparative framework within which the questions are examined. Although the Chilean experience of KIMS sector development appears to have lagged behind that of several other mining-intensive economies, in particular the United States, Canada, South Africa and Australia, the comparative element in the analysis is limited almost entirely to drawing contrasts with Australian experience. Moreover, the scope of that comparative dimension is also bounded. The intention is not to undertake a comprehensive examination of the difference between the two sets of experience. Instead, the main purpose is to focus on selected issues where comparison with Australia can help to illuminate their significance in explaining the path of development in Chile.

The second is about the scope of the Chilean-centred analysis itself. The intention is not to undertake a comprehensive analysis of all the factors that might have contributed to influencing the particular path of KIMS sector development in Chile. Instead, the aim is to focus on the explanatory role of issues concerned with technological learning. More specifically, the research questions concerned with these issues were derived from the conceptual framework presented in the previous section and summarised as the dual-process 'dynamic model of KIMS learning' (Figure 3.5).

The research questions, bounded in these ways, were as follows.

- How have the levels of technological capabilities accumulated within KIMS suppliers in Chile changed since the 1970s, and what have been the main contrasts with experience in Australia?

- How did the key industry-level factors and the interaction between them shape the potential for learning and innovation by KIMS firms in Chile and how did this contrast with Australian experience?

- How did efforts by Chilean KIMS suppliers to exploit the potential for learning and innovation evolve over the period and shape the levels of capability actually accumulated, and how did this compare with experience in Australia?

These questions are examined successively in Chapters 5, 6 and 7, with an integrating summary in Chapter 8.

3.7.2 Other factors

The two-part process model outlined in the previous section is a complex and demanding framework for examining the core question of the thesis about learning and KIMS sector development in Chile. In particular it stretches beyond the scope of most previous studies of learning in industrializing economies by setting the analysis of micro-level learning phenomena in the context of industry-level shaping processes. It also examines these interactions within a historical perspective stretching over more than fifty years, while also setting the primary analysis of experience in one country (Chile) against a backdrop of comparative observations in another (Australia).

Nevertheless it is well recognised in this thesis that other factors beyond those outlined above would be involved in any attempt at a comprehensive explanation of Chile's apparently limited KIMS sector development through the late twentieth century. For example, one might argue that issues like the limited scale of the Chilean economy or the relatively small size of the population shaped the potential for developing knowledge-intensive sectors like KIMS. More specifically, perhaps the development of such a knowledge-intensive activity in Chile was constrained not so much by the size of the population as by its skill composition, in particular by a significantly low proportion with university level education.

It is also possible that characteristics of the general structure of industrial activities and capabilities in Chile were important in constraining the extent to which opportunities for KIMS sector development were actually grasped even if they were opened up by factors specific to the development of the mining industry as outlined above. For example, Chile might have had particular limitations in the depth and diversity of its manufacturing activities and capabilities that did not provide an environment conducive for taking advantage of any opportunities for knowledge-intensive activities like the production of KIMS. If production activities and their underlying capabilities were particularly constraining in this way, does that point to weaknesses in broad patterns of economic policy in Chile as having been the main constraint on KIMS sector development? In particular, one might argue that the country's experience of import-substituting industrial development policy encouraged the emergence of technologically 'shallow' capabilities that could not respond effectively to any opportunities for developing knowledge-intensive activities that might have been opened up by the development of the mining industry during the late twentieth century.

These may be plausible propositions, along with meaningful questions, about factors that might have impinged on the issues examined in the main body of the thesis, but it is not feasible to stretch the complexity and scope of the analysis in this thesis into yet wider areas like these. Nor is it feasible to consider such issues even superficially through the whole period examined in detail in the thesis. Nevertheless it may be useful to consider at least whether, at the start of the period (i.e. around the1950s and 1960s in the middle of what is defined later as the ‘Gestation’ stage of KIMS development), Chile faced a set of initial conditions in some of these areas that might have acted as significant constraining influences on the subsequent development of KIMS capabilities – conditions that were significantly different from those faced in Australia.

The next section therefore includes an overview of some of these issues in Chile and Australia around the middle of the twentieth century. This superficial treatment is not advanced as part of the core analysis of the thesis. But it can perhaps be used to prompt awareness of the possible role of substantial differences in some of these initial conditions that, in addition to the factors examined in the main analysis in the thesis, might have contributed to the diverging paths of KIMS development through the rest of the century.

3.8 Some ‘initial conditions’ in Chile and Australia

This section examines three aspects of the two economies:

(i) Basic features of the size and growth of the economies in the two countries in the years up to the mid-twentieth century and through the subsequent 50-60 years examined in more detail in the thesis. (Section 3.8.1)

(ii) The structure of manufacturing capabilities developed by the middle of the century in the two heavily natural resource-based economies, and the role of protectionist policies in that process of structural change. (Section 3.8.2)

(iii) Selected broad features of the human capital resources of the two economies. (Section 3.8.3)

3.8.1 The size and growth of the two economies.

Table 3.2 Provides data about population, GDP and GDP per capita in Chile and Australia at ten-year intervals between 1940 and 2000. The relative magnitudes of some of these measures in the two economies are shown in the lower rows of the table.

In terms of population the size of the two economies was very similar in 1960, with the Australian population of 10.3 million being slightly larger at 1.3 times the size of Chile's 7.7 million. The growth of the population followed broadly similar paths in the two economies over the next 50 years, and the relative magnitude remained unchanged in 2010.

However the difference in the scale of total GDP in the two economies was much more substantial, being nearly seven times larger in Australia in 1960 when measured in terms of US dollars (2000). With faster growth in Australia in the next two decades, especially in the 1960s, the gap widened. But the difference in growth rates then reversed, and the gap narrowed significantly after 1980, with total Australian GDP being about five and half times larger than Chile's in 2010.

But the relative magnitude of different economies is probably reflected more meaningfully by GDP measured in PPP (Purchasing Power Parity) terms. Australia's GDP in 1960 was only about three times larger than Chile's, compared with about seven times larger on a simple exchange rate basis. The gap between the two economies is narrower again when considered in terms of average income per capita on a PPP basis – the ratio between the two being only 2.1 in 1960.

While these comparisons may provide the reader with some useful background information, it is not evident that they illuminate issues about initial (mid-century) conditions that might have influenced the subsequent development of KIMS suppliers in Chile. The role of scale as a demand side influence on the development of input suppliers to the mining industry is not reflected very well by the scale of the whole domestic economy. What is likely to matter much more is the demand for those inputs that is generated specifically by the scale and growth of mining production, primarily for export markets. That is examined in Chapter 6.

On the supply side, the scale of overall production in the economy is likely to be a less significant influence on the development of knowledge-intensive suppliers than the structure of production activities undertaken within that total, perhaps especially the scale of manufacturing industry and its composition. Similarly, the total size of the population is probably a less significant influence than its skill composition. These two issues are reviewed below in Sections 3.8.2 and 3.8.3.

Table 3.2 The Relative scale of the Chilean and Australian economies: Population and GDP, 1940 - 2000

		1940	1950	1960	1970	1980	1990	2000
CHILE								
POPULATION (2)	(Millions)	5.1	6.1	7.6	9.4	11.1	13.1	15.2
(Growth)	(Average annual over the decade)		(1.8)	(2.2)	(2.1)	(1.7)	(1.7)	(1.5)
GDP (1)	(Const. 2000 US$ - bill.)			14.1	21.1	28.0	40.5	75.2
(Growth)	(Average annual over the decade)				(5.0)	(3.3)	(4.5)	(8.6)
GDP PER CAPITA (1)	(Const. 2000 US$)			1,841	2,201	2,500	3,068	4,878
(Growth)	(Average annual over the decade)				(2.0)	(1.4)	(2.3)	(5.9)
GDP – PPP (2)	(Internat., 90 Geary-Khamis US$ -bill)	16.4	22.4	32.4	49.0	63.0	84.0	156.2
GDP per capita – PPP (2)	(Internat., 90 Geary-Khamis US$)	3,236	3,670	4,270	5,231	5,680	6,401	10,309
AUSTRALIA								
POPULATION (2)	(Millions)	7.0	8.3	10.4	12.7	14.6	17.0	19.1
(Growth)	(Average annual over the decade)		(1.7)	(2.3)	(2.0)	(1.4)	(1.5)	(1.2)
GDP (1)	(Const. 2000 US$ - bill)			96.5	158.6	213.1	298.7	416.9
(Growth)	(Average annual over the decade)				(6.4)	(3.4)	(4.0)	(4.0)
GDP PER CAPITA (1)	(Const. 2000 US$)			9,393	12,679	14,507	17,501	21,766
(Growth)	(Average annual over the decade)				(3.5)	(1.4)	(2.1)	(2.4)
GDP – PPP (2)	(Internat., 90 Geary-Khamis US$ -bill)	43.3	61.2	91.1	152.2	210.6	291.2	414.1
GDP per capita - PPP (2)	(Internat., 90 Geary-Khamis US$)	6,166	7,412	8,791	12,024	14,412	17,173	21,732
RATIO: AUSTRALIA/CHILE								
POPULATION		**1.4**	**1.4**	**1.4**	**1.4**	**1.3**	**1.3**	**1.3**
GDP				**6.9**	**7.5**	**7.6**	**7.4**	**5.5**
GDP per capita				**5.1**	**5.8**	**5.8**	**5.7**	**4.5**
GDP – PPP		**2.6**	**2.7**	**2.8**	**3.1**	**3.3**	**3.5**	**2.7**
GDP per capita – PPP		**1.9**	**2.0**	**2.1**	**2.3**	**2.5**	**2.7**	**2.1**

Source: (1) World Bank, World Development Indicators
(2) Maddison, A (2009)

3.8.2 Manufacturing development in the two natural resource-based economies: trends and policy frameworks

This section first provides a broad overview of the changing sectoral structure of the Chilean and Australian economies (Section 3.8.2.1). It then focuses more specifically on the development of manufacturing in general and capital good production in particular, noting aspects of the policy context of those developments – first in Australia (Section 3.8.2.2) and then in Chile (3.8.2.3)

3.8.2.1 The changing sectoral structure of the economy in Australia and Chile: 1900 - 1980

Table 3.3 summarises trends in the relative magnitudes of broad economic sectors in Australia and Chile over the first eight decades of the twentieth century. In outline, the paths of change in these main sectors were similar in the two countries. In both cases natural resource-based production (the farming and mining sectors) was the dominant activity in the early decades, and the relative importance of this kind of production declined substantially by the start of the 1980s. The path followed by manufacturing in the two countries was also broadly similar. It accounted for a similarly small proportion of GDP in both in 1900/01 (around 12 per cent). That share rose over subsequent decades to a peak level of around 26 to 28 per cent, falling thereafter to similar levels around 21 per cent by the start of the 1980s. In both countries the relative scale of the remaining ‘Other’ sectors (services, including construction and utilities) followed similar rising paths over the whole period, though the share of this group started and finished at slightly lower levels in Chile than Australia.

Within this similarity at a very broad level, several more detailed similarities and differences merit further comment – very briefly in the case of Australia, and with a little more elaboration for Chile.

Although the share of natural resource-based production in total Australian GDP fell through the whole period from nearly 30 per cent in 1900/01, the combination of the agriculture and mining sectors still accounted for about 12 per cent of the total at the start of the 1980s, a substantial component of the economy. The share of manufacturing increased during the early decades of the century, but it was not until the mid-1940s that it became larger than the share of natural resource-based production. It reached a peak of 28 percent in 1955/56, roughly equivalent to the share in high-income countries in Europe and North America, and then declined steadily to about 20 per cent in 1980/81.

Table 3.3 The changing structure of the Economy, 1900/1 – 1980/81: Australia and Chile (Sectoral production as a percentage of GDP)

	A Farming	B Mining	C Natural Resource-based (A + B)	D Manu-Facturing	E Other
AUSTRALIA*					
1900/01	19.3	10.3	29.6	12.1	58.3
1913/14	23.5	5.1	28.6	13.4	58.0
1919/20	23.5	3.0	26.5	13.5	60.0
1928/29	21.2	1.8	23.0	16.7	60.3
1938/39	19.5	3.3	23.8	18.5	58.7
1948/49	21.3	2.5	23.8	26.2	50.0
1955/56	15.9	2.3	18.2	28.0	53.8
1962/63	12.6	1.7	14.3	26.8	58.9
1968/69	9.6	2.4	12.0	26.1	61.9
1973/74	9.6	4.0	13.6	23.2	63.2
1980/81	5.4	6.5	11.9	20.6	67.5
**CHILE ** **					
1900/01	12.3	21.6	33.9	12.0	54.1
1913/14	12.2	26.5	38.7	9.4	51.9
1919/20	11.7	24.0	35.7	11.7	52.5
1928/29	11.9	30.2	42.1	9.6	48.3
1938/39	11.4	20.9	32.3	11.7	56.0
1948/49	9.5	18.8	28.3	20.0	51.8
1955/56	8.4	11.0	19.4	22.8	57.8
1962/63	6.4	10.7	17.1	23.6	59.4
1968/69	6.4	9.1	15.6	24.8	59.6
1973/74	5.4	9.4	14.8	25.6	59.7
1980/81	5.7	9.5	15.2	21.2	63.6

* *Source*: Adapted from Robertson (2008), as reproduced from the original in Maddock and McLean (1987)

** *Source*: Braun-Llona et al. (1998)

In Chile the relative importance of natural resource-based production in 1900/01, about 34 per cent of GDP, was a little higher than in Australia, but the composition of that component was different: the share of mining was much greater than in Australia (about twice as high at 26 per cent), and the share of agriculture (at about 12 per cent) was considerably lower. Then, rather than falling over the early decades as it did in Australia, that dependence on natural resource-based production rose to a peak of 42 per cent in 1928/29, much higher than at any stage in the period in Australia. That was entirely a result of the relatively rapid growth of mining. Then a declining trend set in as it had in Australia about a decade earlier. But in the case of Chile the part of that decline that was attributable to the falling share of agricultural production started more steeply and earlier in Chile that it did in Australia – in the 1940s and 1950s, rather than the 1960s and 1970s in Australia. Thus, by slightly different routes, the trends in natural resource-based production arrived at the same place in the two countries by the early 1970s, accounting for around 13-14 per cent of GDP.

At the start and end points of the trends reviewed here (1900/01 and 1980/81) the relative sizes of the manufacturing sectors were similar in Chile and Australia. However Chile followed a path between those points that differed from the one taken by Australia. Instead of rising during the early decades of the century, as in Australia, the share of manufacturing in Chilean GDP in 1938/39 (about 12 per cent) was no larger than it had been in 1900/01, and it had dipped significantly below that level during two phases in the intervening period. It then rose rapidly to about 20 per cent during the 1940s, and continued to increase at a slower rate through the 1960s and 1970s. As a result it reached a peak level at nearly 26 per cent that was only marginally below the peak of 28 per cent in Australia.

But Chile reached that peak about two decades later than Australia, in the mid-1970s rather than the mid-1950s. Thus, compared with Chile, manufacturing industry in Australia accounted for a significantly larger share of a much larger total GDP for a period of about twenty years between those dates.

Thus, amid considerable similarity in the paths of change in the broad structures of the two economies through these decades, perhaps the most noticeable difference was this two-decade contrast in the relative magnitude of manufacturing within their economies. However, it is far from clear whether that contrast might contribute to explaining the difference between the countries in their paths of developing KIMS production capabilities. Manufacturing is a highly heterogeneous bundle of activities, and any influence on the specifics of the KIMS development paths would depend, among other things, on the types of manufacturing that developed over this period, on the policy context shaping that development and on the that and on the interaction that may have occurred between particularly relevant types of manufacturing and the development of the natural resource-based industries, especially mining.

Any serious analysis of those issues lies far beyond the feasible scope of this thesis. Nevertheless, a glimpse of selected aspects is provided below, first for the case of Australia (Section 3.8.2.2) and subsequently for Chile (Section 3.8.2.3).

3.8.2.2 The scale and structure of manufacturing and its policy context: Australia

The development of manufacturing and natural resource-based industries in Australia between 1900 and the 1950s-1960s passed through two different phases. The first was a continuation of the highly cyclical development path that characterised most of the nineteenth century and ran through to the 1930s. The second, starting from the 1940s, involved a more steady growth path running through the initial 1940s – 1970s Gestation phase of KIMS sector development.

<u>Cyclical development and the deepening of protection for manufacturing: up to the 1930s:</u>

The long cyclical development process of the nineteenth and early twentieth centuries was driven by a succession of export-led booms in primary, natural resource-based industries, mainly in agriculture. In the 1830s as the original coastal settlements moved inland they opened up rich farmland that was the basis for a boom in wool production; the early 1850s saw the rush to exploit alluvial gold deposits in Victoria and New South Wales; a second wool boom opened up in the 1880s. Further expansion in agriculture followed from diversification of production, mainly into dairy products, wheat and fruit, in the first two decades of the twentieth century; and this was followed by a technological intensification of agriculture in the 1920s as limits to further expansion into new fertile farmland were approached. With the expansion of agriculture and stagnation of mining, the composition of output from these natural resource-based sectors changed over the early decades of the twentieth century and, having accounted for about 10 per cent of GDP in 1900, mining only accounted for 1.8 per cent in 1930 (Freebairn, 1987, p.161).

These periodic surges in export-intensive natural resource-based production were interspersed with periods of slow or negative growth linked to global market changes in the 1840s, 1890s and the years following 1929. But running through these fluctuations was a slow increase in manufacturing production. Until well into the twentieth century this was primarily concerned with simple consumer goods like shoes, clothing and food products for domestic markets, as well as the basic stages of downstream processing for exported agricultural and mining products. Equipment inputs for agricultural and mining production were technologically very simple and some of the more basic forms of these were also manufactured. However, with stagnation in the mining industry running through to the 1940s, there must have been little or no new investment in the industry, and even simple equipment manufacturing for mining was probably very limited.

Based on this pattern of production, manufacturing accounted for only 12.6 per cent of GDP in 1910/11. But two factors at the start of the century contributed to changing this by the end of the 1930s.

The first was the creation in 1901 of the federal Commonwealth of Australia that integrated the previously separate colonies. This had two consequences with respect to the policy framework for manufacturing development. On the one hand the tariffs on trade between the former colonies were abolished, so creating a much larger integrated Australian market. On the other hand, a common external tariff on imports (mainly manufactures) was established as part of the financial basis for the new federal government, so creating a broad protectionist framework for manufacturing development.

The second was the onset of the First World War in 1914. This disrupted both export trade in resource-based commodities and imports of manufactures. The combination encouraged resources to shift towards manufacturing, the most notable example of which was the establishment of the country's first steel plant set up by the Broken Hill Proprietary Company, an emerging local mining company.

Although the federal tariff system was initially set up primarily as a fiscal measure, the tariff levels were regularly raised with increasingly explicit protectionist intentions concerned with stimulating manufacturing development. Average tariff rates doubled over the decade to 1920. Then, following the institutionalisation of tariff administration by the establishment of a Commonwealth Tariff Board in 1921, together with large increases in 1930 designed to protect the balance of payments, they doubled again by 1932 (Capling and Galligan, p.70). By the end of the decade, after consolidation of the tariff system over thirty years, Australia had become one of the world's most highly protected manufacturing economies. At the same time some of the States, especially South Australia, linked tariff protection to direct subsidies and concessions to manufacturers as part of an explicit policy to develop an extensive manufacturing sector (Sinclair, 1976, p.202)

Not surprisingly, manufacturing production increased and its composition began to change as expansion emerged around new nuclei in sectors like steel, automobile assembly and electrical equipment. But, as noted above, overall structural change in the economy was limited, with manufacturing accounting for only around 14-15 per cent of GDP in 1926/7. It rose higher as total GDP fell in the post-1929 depression, but in 1939 after the recovery from the mid-1930s it still accounted for only 18 per cent of GDP.

However, already by the late 1920s it was recognised that the system was being used not only to extend manufacturing production in an ever widening diversity of industries where prospects of international competitiveness were remote, but also to sustain what might once have been 'infant' industries as they passed into technological senility:

“Manufacturers were abusing the system of protection in a number of ways. Some attempted to shelter plant and machinery that was out-of-date, and products which were inferior or more expensive, behind increased protection. While technological advances were revolutionising manufacturing processes and the quality of products around the world, Australian manufacturers were seeking to protect from competition their old-fashioned processes and lower quality products. The result, as the Tariff Board made clear, was that Australian people were being denied the benefits of modern technology and engineering.” (Capling and Galligan, p.88)

One reflection of this was that during the first three decades of the century Australia exhibited an anomaly among high income economies: the manufacturing sector’s share of total employment was greater than its share of GDP. Thus, despite high wage levels, manufacturing was a relatively labour-intensive (low labour productivity) sector in the economy. But it would be another fifty years before the protectionist framework was substantially dismantled in the late 1980s and early 1990s.

Expanding manufacturing and the persistence of protection: from the 1940s to the 1980s:

In the post World War II period Australia entered a phase of accelerating growth stretching into the 1960s: average annual rates of growth of real GDP were 3.7 per cent between 1948/49 and 1953/54, 4.1 per cent over the next ten years, and then 5.1 per cent between 1962/63 and 1968/69. Three strands of change contributed to that trend.

First, with the possibility for further extension of the area of agricultural land closing during the 1930s, a belated technological intensification of agriculture followed from the 1940s. from the late 1940s to the end of the 1960s output increased, though as a slowly falling share of GDP; labour productivity grew more rapidly than output; and the number employed in agriculture fell. (Sinclair, 1976, pp.212-216)

Second, a boom in the mining industry took off from the 1940s. However, unlike previous booms this involved a wide range of minerals and, together with their frequent location in huge deposits, this created opportunities for long-term production expansion. Consequently, as noted above, the historical trend of mining output as a falling share of GDP was reversed by the 1960s, on its way to a further rapid rise in the 1970s. But at the same time, rapid technological intensification also occurred in this sector, contributing to rising labour productivity and falling total employment.

Third, manufacturing output expanded at an unprecedented rate of more than 6 per cent per year between 1949/50 and 1967/68. With productivity also rising, but at a slower rate, manufacturing employment increased rapidly. At the same time the composition of manufacturing changed in directions that had begun in the 1930s. This involved not simply a further diversification of industries, but also a structural shift towards more technologically complex types of manufacturing: moving a little away from basic consumer goods (food, clothing, textiles) and towards such things as chemicals, iron and steel, electrical products and also automobile production with a somewhat larger local content than the earlier assembly activity. (Sinclair, 1976, pp. 214-215)

However, these changes in the manufacturing sector occurred in the context of continuing heavy protection. Indeed three factors in this post World War II period reinforced the protectionist regime for manufacturing. First, the World War had demonstrated the strategic vulnerability arising from Australia's high level of dependence on imported manufactures. Second, in the 1950s technological advances in the primary natural resource-based sectors, especially in agriculture, led to reductions in employment, and this raised the socio-political demands on manufacturing to act as an absorber of labour in the economy. Third, in order to address another balance of payments and foreign exchange crisis, tariffs were reinforced by import quotas and licensing. Then in 1960 pressure from manufacturing interests led to the further raising of tariffs to compensate for the removal of the quota and licensing system.

Reflecting these domestic pressures to sustain the protection system, and even to reinforce it, Australia refused to take part in any of the multilateral tariff reduction arrangements negotiated under the General Agreement on Tariffs and Trade (GATT) during the 1950s and 1960s. Thus by the end of the 1960s

Australia shared with New Zealand the distinction of having the highest manufacturing tariff rates in the industrialised world, and nearly half of Australian manufacturing industry had effective protection at rates in excess of 50 per cent. (Capling and Galligan, pp.96 and 107)

A first tentative step towards reducing the level of protection was taken in 1973. This involved an across-the-board cut in tariff levels by 25 per cent. However, pressure by several of the more heavily protected industries (mainly textiles, clothing and footwear) led to a restoration of import quotas. Following this, further steps to dismantle the protectionist environment were not taken until the late-1980s. However, as part of the background to later chapters in the thesis, it may be useful to bear in mind that Australia followed an unusual route to changing this policy context for manufacturing industry: it put in place a new framework of policy measures to strengthen manufacturing capabilities before it dismantled the structure of protection, a phasing of policy change that contrasted with the approach in many developing countries, especially in Latin America.

But by the early 1980s the government began to build up a programme of selective interventions for specific industries, focusing on capability strengthening activities such as export promotion, skill training, increased R&D and easier access to finance for investment. Increasingly the policy emphasis shifted towards such ‘positive’ actions rather than further ‘defensive’ protectionist measures, concentrating increasingly on fostering innovative, export-oriented industries. Such micro-level interventions to strengthen capabilities were coupled to macro-economic reform and devaluation after an economic crisis in 1985-6, and manufacturing investment surged to unprecedented levels, while output expanded rapidly with a much greater export component. The opportunity was then taken to dismantle the tariff system in two steps. First, in 1988 a programme was initiated to cut the maximum rate to 15 per cent over a number of years. Then in 1991 a further programme of phased reductions was initiated, reducing the maximum rate top 5 per cent by 1996. (Capling and Galligan, pp.117-166).

The capital goods component of manufacturing development

The preceding comments about the development of the manufacturing sector as a whole relate to only a very broad set of conditions that probably could only have had a very indirect and general influence on the Emergent phase of KIMS sector development in Australia. In principle, a much more directly relevant issue would have been the extent to which there emerged a significant 'capital goods' component of manufacturing – a sector that, as supplier of machinery and equipment to the mining industry, might perhaps have provided an important knowledge base for the emergence of an innovative KIMS sector in Australia.

Unfortunately, information about the development of this component of Australian manufacturing up to the 1950s and 1960s is scant. Readily available data about manufacturing production do not identify categories such as the production of 'machinery' or 'engineering products', and descriptive narratives of the development of manufacturing make no mention of the development of such activities. Available data about manufacturing exports provide a little more detail, but still falling short of a clear picture – as indicated in Table 3.4.

Table 3.4 Manufactures and 'Capital Goods' in Australian Exports: 1951/2 – 1971/2

	1951/52	**1961/62**
Total Exports (US$ million)	1,656	2.046
All Manufactures - % of Total	8.7	13.8
Of which - as % of all manufactures		
'Simple' Manufactures *	58.3	55.5
'Elaborate' Manufactures**	41.7	44.5
Of which:		
Machines and metal products		
as % of all manufactures	18.0	24.7
as % of total exports	1.6	3.4

* 'Simple' (or 'simply transformed') manufactures consisted of chemicals, non-ferrous metal manufactures, iron and steel.

** 'Elaborate' (or 'elaborately transformed') manufactures include steel, motor vehicles and parts and aircraft and parts.

Source: Pinkstone (1992), Annex Tables 52, 53 and 57.

This shows manufactured exports as a very small proportion of total exports in 1951/52 (about 9 per cent), but rising to a more substantial proportion by the early 1970s. Within that a distinction is made between ‘simple’ and ‘elaborate’ manufactures – the former consisting mainly of mineral products with the most basic forms of initial processing. These accounted for nearly 60 per cent of manufactured exports in 1951/52, a share that fell slightly to 50 per cent by the early 1970s. ‘Elaborate’ manufactures were not necessarily very elaborate – consisting in large part of textiles, leather goods and processed foods. But they also include a category of ‘machines and metal products’. This accounted for only 18 per cent of all manufactured exports in the early 1950s, and hence for a tiny fraction of all exports (less than 2 per cent). Ten years later in the early 1960s this had increased to only slightly more than 3 percent of total exports.

Thus it seems to be the case that during the 1950s and 1960s the connections between mining and manufacturing were still heavily concentrated on downstream mineral processing, and there had probably not yet emerged a significant upstream sector of suppliers of manufactured inputs to mining who were also the basis for substantial exports of knowledge-intensive capital goods.

This view is reinforced by a descriptive glimpse of the extent to which links had developed between the mining industry and a local capital goods sector during the 1950s and 1960s as a result of the mining boom that has started in the 1940s. Reflecting on the connection between this boom and the rest of the economy, Sinclair (1976) noted that by the 1960s:

“The main connection between the boom and the growth of other sectors of the economy was through the processing of minerals which was part of the explanation of the increased size of the manufacturing sector. However, the high import content of the capital equipment used and the remission of profits overseas, the source of most of the funds, greatly restricted backward and final-demand linkages with other Australian industries.” (pp. 216-217)

Thus by the 1950s and 1960s, the starting point for the main analysis in the thesis, it is difficult to see in Australia a set of ‘initial conditions’ in the manufacturing sector of the economy that can clearly be described as particularly conducive to the emergence of suppliers of knowledge-intensive goods and services to the mining industry. Certainly, it is difficult to argue that, at this stage in the development of its KIMS capabilities, Australia had any particularly significant advantage in that area as a result of having built up a thriving and internationally competitive industry supplying capital goods to the mining sector.

The patterns of Australia's international trade in capital goods in subsequent years are looked at later in comparison with the pattern in Chile. However, it is important to note that, with respect to the mining industry in the mid-20th century, data about domestic and international trade in capital goods probably provides a fairly poor picture of the existence and location of innovative technological capabilities. Two issues need to be considered.

On the one hand, at that stage in the development of the mining industry only a proportion of its capital goods were traded. Instead, a substantial fraction resulted from on-site construction involving bricks, fabricated metal and timber structures, along with relatively simple cast-iron vessels and machinery components that were integrated on-site into 'machinery'. Also, even where manufacturing was involved, as with the cast iron vessels or machinery components, a substantial proportion was often undertaken on-site in the larger mining companies' own workshops (Blainey, 1968; Green, 1977; O'Malley, 1988). Thus, although a very important proportion of the industry's capital goods was obtained from external suppliers, both local and international, another large and unknown proportion was invisible in even the most disaggregated production and trade statistics.

On the other hand, the engineering knowledge base underlying the development, design and production of those capital goods was located in the mining companies themselves. The narrative histories of the development of the industry and its firms during this period provide numerous indications of novel process technologies being developed by the mining companies' engineers, especially among the larger companies like Broken Hill Proprietary (BHP) that usually had their own research units and engineering departments (Green, 1977; O'Malley, 1988). When novel components of new facilities could not be produced in internal workshops, the necessary knowledge base for innovation was often generated by in-house testing and experiments, both on-line and in laboratories and pilot plants. This might lead to mining companies pulling local suppliers into innovation to meet the process requirements – as in the case of BHP at its zinc and steel plants (Green, 1977)

This pattern of substantial skill development and knowledge accumulation *within* the mining companies has implications for how one assesses the initial conditions of the human capital resources of the industry in Chile and Australia in the mid-twentieth century, as discussed briefly in Section 3.8.3. Examination of that pattern and its change over time also plays a major role in the core analysis of the development of the KIMS sectors in the two countries in later chapters of the thesis.

Section 3.8.2.3 The scale and structure of manufacturing and its policy context: Chile

As in the case of Australia until the mid-twentieth century, almost the entire history of Chilean economic development has been driven by a succession of export-led booms in primary, natural resource-based industries. Mining acted as the key driver of growth in most cases, although agriculture has played a major role in several. In addition some of these phases of natural-resource led growth have been accompanied by the creation or development of manufacturing capabilities. but as noted earlier (Table 3.3), this was at a lower level until relatively recently (Cariola and Sunkel, 1982 and Meller, 1998). This pattern can be summarised, as in Box 3.2, as a sequence of five major growth periods. (Bulmer Thomas, 1998; Thorp, 1998; Bértola and Ocampo, 2010; Meller, 1990; Cariola and Sunkel, 1982).

This section outlines some of the main features of the three periods between the late 1870s and the late 1980s – periods that led into, overlapped with, and followed the important Gestation phase of global KIMS development in the 1950s to 1970s. For the second and third of those periods the focus is on the development of manufacturing, and the review concludes with an overview that concentrates more specifically on the capital goods sector in comparison with Australia.

Box 3.2

Different growth periods in Chile, with main growth drivers

1. **1830s –mid-1870s**. Main growth drivers: Copper, silver and wheat production:

2. **Late 1870s – late1920s.** Main growth drivers: Nitrate and saltpetre, with agricultural exports declining significantly

3. **1930s – early 1970s** Main growth drivers: manufacturing industry (under Import substituting industrialisation), and copper becoming the main mining activity .(Bulmer Thomas 1998, Thorp 1998, Bértola and Ocampo 2010)

4. **Late 1970s – late 1980s** Main growth drivers: Copper production, also with economic liberalization leading to renewed growth in agriculture and fisheries

5. **1990s – 2000s** Main growth drivers: Copper production (led by multinationals), and export-led agricultural and fishery production.

(i) Late 1870s – late1920s: growth and nitrate production

In the early 1880s Chile defeated Peru and Bolivia in a war prompted by disputes over the tax regime for exploiting nitrates in the northern region of Antofagasta, which was then part of Bolivia. As a result, territory containing valuable mineral resources, particularly nitrates, was annexed to Chile. Along with consequences of victory in another war in the south against the indigenous population of the Araucania, Chile's territory almost doubled. The expansion in the northern territories was particularly important because of the opportunity it gave for a new period of export-led expansion based on mining and nitrate production. Mining almost doubled its share in GDP as nitrates faced increased demand from European agriculture that confronted increasing domestic costs and external competition.

The scale of all previous mining booms experienced by the Chilean economy was insignificant compared to the nitrates boom (Meller, 1996). This was reinforced by the fact that the scale of nitrate production led to the introduction of a new technology: the energy- and labour-saving Shanks system, which had been developed in England for the production of Soda. Based on this technology productive capacity increased three-fold during the 1880s and production costs were reduced by 40 percent (Pinto and Ortega, 1990). The Shanks system put Chile at the technological frontier in terms of the productive system used, but this technology became gradually obsolete as Chile did not engage in upgrading it via technological change, apart from merely substituting the use of oil for coal.

As a result, nitrate mining competitiveness came to be based on the Chilean producers' monopolistic capacity to control prices, rather than on important productivity improvement driven by higher technological capabilities (Rodriguez, 2009). After almost 30 years, nitrates production started to decline; nitrate substitutes were progressively developed in the advanced economies and production collapsed after the 1920s (Cariola and Sunkel, 1982; Meller, 1998; Salazar and Pinto, 2002). Nevertheless this export-led growth had important impacts in the country, in terms of urbanization, demographic change, the development of public services, stimulating primary education, and strengthening government capabilities. In addition it created a small market for manufacturing production.

(ii)The 1930s – early 1970s: Import substituting industrialisation and the leading role of copper in mining

As in most Latin-American countries, Chile was severely impacted by the global crisis of the 1930s: in 1932 GDP dropped by about 40 per cent, imports and exports fell by around 80 percent and prices of the main mining products (nitrates and copper) collapsed by 70 to 80 percent. The most immediate effect was that the relative significance of mining in the economy fell sharply during the early part of this period, although it resumed its leading role after a decade -

accounting for more than half of total exports over the entire period and reaching 65 percent during the 1960s

However, a more pervasive consequence of the crisis of the early 1930s was a substantial shift in government policy towards much greater support for the development of local capabilities in order to reduce dependence on the international economy, and also towards much greater efforts to tackle social problems such as unemployment.

The aim of reducing dependence on the international economy focused in particular on supporting the development of manufacturing industry, with government playing a more active role in the economy via the implementation of import substituting industrialization policies. These took two broad forms. The first involved an initial stage of reliance on government intervention in market-based incentives, such as fixing prices and setting tariffs. In a second stage, the government started to play a much more direct role in production by creating and running state-owned companies in strategic sectors such as energy, steel, petroleum and sugar (Meller, 1996). The share of Chilean GDP accounted for by state-owned companies grew from 14.2 percent in 1965 to 39 percent in 1973.

As a consequence of these measures, the share of manufacturing industry in GDP increased rapidly from 13 percent in the late 1920s to around 25 percent by the late 1960s (Table 3.3 earlier). As indicated in Table 3.5, this relatively rapid growth of output in manufacturing was matched by a shift in the pattern of productivity growth: for most of the previous period labour productivity had grown most rapidly in the mining sector, but over the three decades between 1941 and 1970 productivity growth increased particularly rapidly in manufacturing.

Table 3.5: Labour productivity in Agriculture, Mining and Manufacturing: 1861-1990

	Average Labour Productivity by Sector					
	Agriculture		Mining		Manufacture	
Decade	*(1995 - Chilean $)*	*Growth compared previous decade (%)*	*(1995 - Chilean $)*	*Growth compared previous decade (%)*	*(1995 - Chilean $)*	*Growth compared previous decade (%)*
1861-1870	306,451		1,953,885		296,894	
1871-1880	310,565	1	2,327,033	19	410,845	38
1881-1890	289,884	-7	4,442,939	91	544,716	33
1891-1900	381,860	32	6,627,818	49	632,756	16
1901-1910	381,302	0	9,862,445	49	704,453	11
1911-1920	449,312	18	10,338,340	5	978,085	39
1921-1930	512,215	14	8,222,246	-20	1,288,229	32
1931-1940	548,291	7	5,662,550	-31	1,165,937	-9
1941-1950	534,608	-2	7,081,199	25	1,960,930	**68**
1951-1960	669,209	25	6,255,126	-12	2,834,845	**45**
1961-1970	892,414	33	10,210,606	63	4,721,208	**67**
1971-1980	1,173,278	31	10,813,615	6	5,119,911	8
1981-1990	1,309,001	12	17,617,006	63	4,684,919	-8

Source: Braun-Llona, 1998

Table 3.6 shows the sectoral composition of the overall growth of manufacturing in terms of the growth of direct employment in different manufacturing branches. Over the 1929-1967 period, the average annual rate of employment growth in manufacturing as a whole was 3.5 per cent, and this was spread fairly evenly across the different braches with growth rates between about 3 percent and 7 per cent. However, there was a significant change in the later part of the period. This involved an acceleration in the overall rate of growth to 5.3 per cent per year between 1957 and 1967. But it also involved a shift in the sectoral composition of growth. In the earlier part of the period this had involved the expansion of relatively simple types of manufacturing that were not associated with high productivity or sophisticated technologies. However, between 1957 and 1967 the branches with the fastest rates if growth were electronic products (9.5 per cent), machinery and equipment (12.9 per cent) and automotive vehicles and transport equipment (19.7 per cent) – all sectors involving relatively complex technologies and higher manufacturing technological capabilities. Thus, it was only in the last decade of the import substitution period that there was some significant deepening of human capital and technological capabilities (Rodriguez, 2009 and Meller 2006).

Table 3.6: Employment in different industry branches: 1928-1967

Industry branch	Years 1928	1937	1957	1967	Average growth rate per year (%) 1928-1967	1957-1967
Food and beverage and tobacco	20,651	30,030	43,099	72,995	2.9%	5.4%
Textile, clothes and leather	24,890	35,741	71,892	83,104	2.9%	1.5%
Wood and cork prod., paper and printing	11,909	14,046	22,660	48,644	3.5%	7.9%
Petroleum, chemicals plastic and rubber products	3,246	6,170	14,336	29,258	4.6%	7.4%
Metallic and no metallic mineral products	7,001	16,680	23,903	32,158	2.9%	3.0%
Metallic-based manufactured products	2,742	6,364	12,852	21,487	4.1%	5.3%
Electronic and optic products and electronic equipment	35	895	3,571	8,836	6.2%	9.5%
Machinery and equipment	223	166	4,962	16,634	7.0%	12.9%
Automotive vehicles and others transport equipment	2,364	2,538	3,735	22,574	5.5%	19.7%
Furniture and other manufacturing	3,573	3,914	7,852	15,112	3.6%	6.8%
TOTAL	**76,634**	**116,544**	**208,862**	**350,802**	**3.5%**	**5.3%**

Source: Rodriguez, 2012.

However, this surge at the end of the period towards sectors involving more advanced technologies had started from a very low base. The three fast-growing branches during the 1957-1967 period had accounted for only 3 per cent of manufacturing employment in 1937. Even at the end of the period they accounted for only 13 per cent, while employment in food/beverages, textiles/leather and wood/paper accounted for nearly 60 per cent. This relatively modest shift in the sectoral composition of manufacturing should also be set in its import substituting policy context. By 1960 Chile had built up its average nominal protection for manufactures to nearly 140 per cent, one of the highest levels in Latin America.

(iii) 1970s – late 1980s: Economic liberalization and continued dependence on copper

This period started with a significant policy shift away from the import substitution regime. In part this liberalisation and deregulation involved a sharp reduction in the public ownership of enterprises. The major exception to this was in the mining industry where, following nationalisation of the industry in 1971, the Corporacion Nacional del Cobre de Chile (Codelco) was established in 1976 as a public enterprise to operate the nationalised assets. The development of the growing mining industry in this and subsequent periods is elaborated in later chapters, and the commentary here concentrates on the manufacturing sector.

Trade liberalisation was the aspect of policy change that had a major impact on manufacturing. This was implemented in stages between 1974 and 1979 and the result was a reduction in the average tariff rate from 94 per cent to 10 percent. Combined with exchange rate changes, this had a large impact on the manufacturing sector. Between 1971 and 1981 imports grew by 19 percent per year, during the 1970s employment in the manufacturing sector felt by 2 per cent per year and from the late 1960s to the 1980s the share of manufacturing in GDP fell from 25 per cent to 20 per cent (Meller, 1996). However productivity growth in manufacturing accelerated and by the end of this period manufacturing growth had resumed with a changing product composition.

Thus, this period brought an end to Chile's experience of import substituting protection for manufacturing. In comparison with Australia's experience two features might be noted. First, the period involved was much shorter in Chile (between the early 1930s and late 1970s) compared with the 1920s to 1980s period in Australia. Second, the dismantling of the system was much more abrupt in Chile: completed in about five years compared with the more extended process in Australia running from 1973 to 1996. Moreover the abrupt change in Chile was not associated with any preceding or parallel measures to enhance competitiveness and assist in the transition towards an open economy.

In other respects, however, the Chilean experience of manufacturing development by the 1980s was broadly similar to that in Australia at a slightly earlier period. This involved a considerable expansion of manufacturing behind high levels of trade protection. This growth was concentrated heavily in relatively low technology sectors, but also included the emergence of a small component of machinery production. There is however little evidence in either country that this constituted a significant base of mining-related capital goods production that might have acted as a source of knowledge-intensive production experience to underpin the growth of KIMS capabilities.

As indicated in Table 3.7, columns (A) and (B), trade data seems to confirm that broad view about the limited extent of capital goods production in the two economies. In Australia in 1963/64 exports of all types of machinery accounted for only 3.5 per cent of all exports. In Chile the proportion was about ten times smaller – 0.3 per cent. At the same time the trade balance in machinery involved a very large dominance of imports over exports in Australia (Column D) and massively so in Chile (Column E). In Chile both these rations changed dramatically over the next 30 years: the proportion of machinery in total exports was more than ten time larger by 1998/99, and the dominance of machinery imports over exports had fallen tenfold.

Table 3.7 Trade in 'Capital Goods': Australia and Chile, 1960s to 2000s

	Machinery intensity of exports (Machinery exports as % of all exports)*			**Machinery Balance of Trade** (Machinery imports/Machinery Exports)*		
	A	**B**	**C**	**D**	**E**	**F**
	Australia	**Chile**	**Ratio A/B**	**Australia**	**Chile**	**Ratio D/E**
1963/64	3.5%	0.3%	11.0	9.1	120.0	0.08
1968/69	6.0%	0.8%	7.9	6.9	46.4	0.15
1973/74	8.6%	0.3&	25.1	3.6	62.4	0.06
1978/79	5.9%	1.2%	4.8	6.0	26.6	0.22
1983/84	5.7%	1.3%	4.5	6.6	15.5	0.43
1988/89	7.3%	0.7%	9.9	6.7	44.2	0.15
1993/94	12.5%	2.8%	4.5	4.0	16.5	0.24
1998/99	13.4%	3.3%	4.1	4.2	12.5	0.33
2003/04	11.3%	2.7%	4.2	5.0	10.2	0.48
2008/09	7.0%	3.4%	2.1	6.0	8.7	0.69

Source: UN Comtrade

However, in both respects Chile was massively different from Australia. The machinery intensity of exports in Australia was about eight or ten times greater than in Chile in the 1960s (Column C); and even after the rapid rate of growth of machinery exports from Chile it was still about four times greater in the 1990s. Similarly, the dominance of machinery imports over exports was very much less in Australia than in Chile in the 1960s (Column F); and again, although the magnitude of this difference between the two countries had fallen considerably by the 1990s, it was still substantial.

It is far from clear whether these large changes in small magnitudes, and the considerable differences between them, reflect issues that were significant with respect to the paths of KIMS development in the two countries. At the very least one would need to know much more about the ways in which mining-related capital goods were incorporated in these trade flows. One would also need to bear in mind the two points highlighted earlier in connection with Australian machinery production in the 1950s and 1960s. First, running well beyond the middle of the twentieth century, only a proportion of the mining industry's investment in capital goods (perhaps quite a small, though falling, proportion) is reflected in data about international or even domestic trade in capital goods. Second, a large proportion of the technological competence for the development, design and even production of those capital goods was located within the mining companies themselves. At least until the late 1970s, those companies were the major accumulators of the types of knowledge and expertise that came to constitute the basis of the KIMS sector. The importance of this issue is examined in later chapters.

Section 3.8.3 Human capital resources

In a very broad sense the creation of human capital in Australia and Chile must have had a significant influence of the development of their KIMS industries. This would have involved the creation of human capital not only in educational organisations like universities and technical schools, but also in and by mining industry enterprises themselves. The main analysis in the thesis gives some attention to the former and considerably more to the latter. This section sketches aspects of the broader context, focusing specifically on the development of university level education.

Table 3.8 draws on alternative sources of data to summarize the evolution of the Chilean and Australian university systems between 1940 and 2002 in terms of total student enrolment. Over the entire period of KIMS sector emergence and development, Australia had a larger absolute level of university enrolment than Chile, but the magnitude of that difference varied through two phases.

During the first phase, between the 1950s and 1970s, the gap narrowed quite considerably. Initially in 1952 the number of enrolled students in Australia was nearly three times larger than in Chile, but by the 1970s it was only around 1.5 – 1.8 times larger. Thus during this important early phase of KIMS development.

Table 3.8 Human Capital Indicators: Chile and Australia, 1940 – 2002

		1940	1952	1960	1965	1970	1975	1980	1982	1985	1990	1992	2002
	Chile												
A	Total Population[1] *(Millions personas)*	5.0	6.4	7.6	8.5	9.4	10.3	11.1	11.5	12.1	13.1	13.6	15.5
B	University Enrolment[2] *(Thousands persons)*	7.4	10.2	25.8	40.3	77.0	147.0	119.0	119.5	201.1	249.8	286.0	593.7
C	University Enrolment[3] *(Thousands persons)*						149.6	145.5		197.4	261.8		
E	B/A *(%)*	0.1	0.2	0.3	0.5	0.8	1.4	1.1	1.0	1.7	1.9	2.1	3.8
	Australia												
F	Total Population[1] *(Millions personas)*	7.0	8.7	10.4	11.4	12.7	13.8	14.6	15.2	15.7	17.0	17.4	19.3
G	University Enrolment[4] *(Thousands persons)*		29.6	53.6	110.3	116.8	276.6	329.5	341.4	370.0	485.1	559.4	695.5
H	University Enrolment[3] *(Thousands persons)*						274.7	323.7		370.0	485.1		
I	G/F *(%)*		0.3	0.5	1.0	0.9	2.0	2.3	2.2	2.4	2.9	3.2	3.6
	Ratios: Australia/Chile												
	G/B		**2.9**	**2.1**	**2.7**	**1.5**	**1.8**	**2.8**	**2.9**	**1.8**	**1.9**	**2.0**	**1.2**
	H/C						**1.8**	**2.2**		**1.9**	**1.9**		

Source: 1. Madisson, A (2009)
2. Braun-Llona et at (1998)
3. World Bank (2000) "Higher Education in Developing Countries: Peril and Promise"
4. The Department of Education, Employment and Workplace Relations (2000) – Include full-time, part-time and external students

Chile was expanding the overall scale of university enrolment at a faster rate than Australia. More specifically, during the later part of this phase (between 1960 and 1975) the scale of Australian enrolment varied between 1.5 and 2.7 times the scale in Chile, and overall it was a little less than twice as large. This reflected in part the establishment of two new universities in the 1950s, but it seems to have been mainly the result of rapid expansion of the universities that had been established over the years in Chile. The first, San Felipe University, was created by the Spanish Crown in 1738, becoming the University of Chile in 1843. The Pontifical Catholic University of Chile was founded in 1898 (De Wit et al, 2005), and others followed between 1919 and 1928, with a gap during the 1930s and 1940s before the two new establishments in the 1950s (Box 8.1 below).

In the second phase from the 1980s a similar trajectory was followed. Initially during the late 1970s and early 1980s, enrolment in Australia rose much more rapidly than in Chile, and the gap widened again to the level of the early 1950s. But enrolment then accelerated rapidly in Chile and by 2002 the scale of total enrolment in Australia was only marginally greater than in Chile. A major contribution to this was made by an increase in the rate of new university creation after 1980 because of reform in the higher education system. In particular, the creation of private higher education institutions was supported as a way of meeting the demand for higher education (Brunner and Bricall, 2000). Consequently, the numbers of universities grew from the eight 'traditional' universities that where operating in 1981 to 63 in 2002. After about 160 years of development, Chilean universities had reached a total enrolment level of 600,000 students by the early 21st Century.

It is not possible to examine here whether these trends in the overall scale of university enrolment in the two countries had any implications for the development of their respective KIMS capabilities. At the very least, in order to address that question, one would want to start by identifying the composition of the overall level of enrolment in terms of disciplinary fields that might have been more and less relevant for KIMS capability development.

The scope of this study cannot encompass that kind of issue, and it is unclear whether relevant information is available in any case. However, in the case of Chile it is possible to suggest that from the very beginning there was a considerable emphasis on providing university education in scientific, technical and engineering disciplines. As indicated in Box 8.1, most of the eight 'traditional' universities that existed in 1981 had undergraduate programs in these fields, with a substantial emphasis on training in various branches of engineering, including mining related disciplines such as mining engineering and geology:

Leaving aside the differences in overall scale discussed above, the development of the university system in Australia seems to have had many similar features to those in Chile. The system had it origins in the mid-nineteenth century with the establishment of the University of Sydney in 1850. Three year later the University of Melbourne was created, followed by the universities of Adelaide and Tasmania in 1874 and 1890. Two other universities were established during the early 20th Century: the universities of Queensland (1909) and Western Australia (1911). As a result, total university enrolment reached 3,300 students by 1914, about 0.1% of the Australian population. Twenty year later (1939) this number had grown to 14,000 students – about 0.2% of the population (Breen, 2002). As in Chile, most of these universities gave considerable emphasis to scientific and engineering education, including specifically mining related disciplines (O'Malley, 1988).

Four new universities were created over the next two decades: Australian National University (1946), the University of New South Wales (1949), the University of New England (1953) and Monash University (1958). Enrolment more than doubled to 32,000 by 1948, and increased again to 53,000 by 1960 – contributing to the gap between Australia and Chile in the 1950s and early 1960s.

Then, as in Chile, subsequent expansion involved the creation of a considerable number of new universities. Between 1964 and 1975 nine further universities were established: Macquarie, La Trobe, Newcastle, Flinders, James Cook, Griffith, Murdoch, Deakin, Wollongong (Breen, 2002). By the early 2000s

Australia had 45 universities In addition, during the early 1970s, there had been significant support to make tertiary education more accessible to working- and middle-class students. Consequently, during the late 20th Century enrolment grew rapidly to 420,000 students by 1988 and 730,000 in 2001.

Box 3.3
University development in Chile to the 1950sand its coverage of scientific, technical and engineering fields

1. University of Chile (founded 1842 – source: www.uchile.cl):
The first university in Chile as replacement/continuation of the former colonial Royal University of San Felipe (founded 1738). The engineering faculty was one of the first opened, including mining engineering.

2. University of Santiago (founded 1848 and 1947 – source: www.usach.cl):
Initially created as a school of arts and crafts to support Chile´s scientific and technological development, focused on practical skills required by local industry (e.g. smelting, mechanics, blacksmith and carpentry). In 1947, it was transformed in the State Technological University and 1981 renamed as University of Santiago.

3. Catholic University of Chile (founded 1888 – source: www.uc.cl):
Created to offer training in law in technological and in management fields. In 1904 mining engineering was set up.

4. University of Concepción (founded 1919 – source: www.udec.cl):
At its early stage the University of Concepcion aimed to offer undergraduate programs in pharmacy, dentist, English pedagogy and industrial chemistry.

5. University Federico Santa María (founded 1926 – source: www.utfsm.cl):
Takes its names from Federico Santa María, a Chilean who donated a huge fortune to create a high-standard technical and scientific university. For the first 10 years of the university, the professors had to be from the best engineering schools in the world. Gives special emphasis to scientific fields, as well as engineering fields such as mechanical, electrical, electronic and chemical engineering.

6. Catholic University of Valparaíso (founded 1928 – www.pucv.cl):
The first UG programs were in electrical engineering, construction, chemistry, mining, business administration, mechanical engineering, decorative arts, and merchant marine studies.

7. Austral University (founded 1954 – source: www.uach.cl):
Started with programs in arts, agronomy, forestry, engineering and veterinary medicine

8. Catholic University del Norte (founded 1956 – source: ww.ucn.cl):
Offers programs in civil engineering and construction, marine sciences, economy and management, engineering and geological sciences, humanities and medicine.

In summary, this brief overview indicates that the university systems in both Chile and Australia provided their economies with significant supplies of human capital equipped with mining-related skills through the period from the 1950s to the early 2000s. precisely how large those flows were is unknown. More specifically, whether they were in some way inadequate in the case of Chile to support an effective path of KIMS sector development is unknown.

Certainly the trends in the two countries suggest that there was probably a significant difference between them in the overall scale of university enrolment at the important Emerging phase of KIMS capability development between the 1950s and early 1970s. But identifying that aggregate gap, and perhaps also its re-opening in the early 1980s, falls far short of providing any clear indication that the difference might have contributed significantly to the difference between the two countries in the much more specific issue of their paths of KIMS capability development. One would also need to consider questions about the 'quality' of the education provided. Also relevant might be the considerable increments to skilled human capital that accrued to Australia via immigration, especially from Europe through the 1940s to 1980s.

But beyond all those issues one would need to consider the role of human capital creation that is undertaken within mining enterprises themselves, as well as the interaction between those intra-firm activities and training activities in university education. Particularly important are planned and unplanned learning efforts that occur within mining companies, involving engineering teams tackling complex challenges in both operational activities and the development of investment projects. The thesis gives considerable attention to these issues in Chapter 7 where it examines patterns of specifically KIMS-related firm-level learning and capability building in the two countries. That analysis will suggest among other things that these intra-firm learning efforts were especially important during the early stage of KIMS capability development between the 1950s to early 1970s, when mining was a vertically integrated industry. The thesis leaves entirely open the question of whether these intra-firm activities and learning process were significantly influenced by skills supply-side issues concerned with the scale, disciplinary composition or quality of university education.

CHAPTER 4

METHODOLOGY

4.1 Introduction

This chapter explains the main features of the methods used to address the research questions listed in previous chapter. It is organised in five further sections.

The main features of the broad research strategy are summarised in Section 4.2, including a brief indication of the role of a small-sample, interview-based survey that was used for part of the research. The process of selecting that sample is described in Section 4.3, along with some of the main characteristics of the sample of firms. Section 4.4 explains how key concepts in the analytical framework discussed in the preceding chapter were defined in more detail and operationally elaborated to guide the interviews and structure the analysis. The methods of data collection are outlined in Section 4.5, giving particular attention to the steps taken to increase the reliability of recalled information about historical events. Finally, the approach to data analysis is summarised in Section 4.6.

4.2 Broad Research Strategy

The basic research problem was to ‘explain’ how KIMS supplier capabilities were relatively weak in Chile at the start of the current century (around 2000-2005) compared with those in many other major mining economies. Very early in the project it became clear that addressing this problem raised three major challenges.

First, even a cursory initial reading of some of the literature reviewed in the preceding chapter indicated that the explanation was likely to be rooted in a long historical process, involving the interaction between multiple factors. But no ‘model’, or analytical framework was available to help focus the enquiry on what were likely to be the more relevant of those factors, or to suggest ways in which they might interact.

Second, there was little existing information about many of the factors that seemed likely to be important over the relevant time period, especially about the learning and innovation efforts carried out by firms to exploit the learning potential at different stages in the development of KIMS firms (i.e. about what later came to be described as Process 2 in the model outlined in the previous chapter).

Third, the problem was essentially about cross-country difference, about Chile relative to other mining-intensive economies. A case study of the experience of Chile alone would not be adequate to illuminate reasons underlying the difference, and research would need to generate information on a comparative basis.

The broad research strategy therefore involved three main elements:

1. A ***two-phase strategy*** was adopted. Phase 1 was used to develop sufficient understanding to create a suitable analytical framework. In other words, although it has been useful to explain that framework in the previous chapter in advance of this discussion of methodology, that presentation reverses the process of research that was actually followed. The framework was not extracted from previous research as a more or less ready-made model that could be applied in this research. Its development was an outcome of, not an input to, the research strategy outlined here. It was a necessary basis for Phase 2 in which the research focused specifically on using the model as a basis for trying to explain the basic situation of the KIMS supplier sector in Chile in 2000-05. It is important to emphasize that the distinction between the two phases was not clear-cut. Although development of the framework was a necessary pre-requisite for starting Phase 2, it was far from finalised at that stage. Further refinement, both elaboration and simplification was added as a result of the continuing work in Phase 2.

2. A ***comparative historical approach*** was followed in both phases, but in different ways. In Phase 1 a long-term historical perspective was taken covering most of the 20^{th} century. This was loosely comparative, covering several mining-intensive economies – primarily Canada, South Africa and Australia, but

also European countries such as Sweden. Phase 2 adopted a shorter-term perspective covering mainly the second half of the 20th century. It also adopted a more restricted basis for comparison with the experience of Chile because, given the resource constraints of the project, the necessary detailed research could only be conducted in a single comparator country. Australia and South Africa were considered as possible candidates because their experience in mining industry development was roughly contemporary with that of Chile, but a much stronger domestic KIMS sector had developed in both cases. Australia was then selected for two main reasons. One was a matter of research design: the international isolation of South Africa during the later part of the apartheid era would have added a complicating factor into the analysis. The other was pragmatic: a greater amount of published data seemed to be available about Australia, and more numerous personal contacts were available to assist in planning and executing research in that country.

3. The research drew on ***multiple types of information source:*** (i) secondary literature and existing data; (ii) exploratory and relatively open-ended interviews; and (iii) a small-sample survey of KIMS suppliers based on structured interviews with senior managers and technical personnel. These were used in different ways in the two phases of the project.

- Phase 1 relied primarily on secondary sources and exploratory, open-ended interviews. Most of the latter were conducted in Chile, but were international in scope because of the extensive presence of foreign firms in Chile. Thus, interviews with mining company personnel included not only senior managers and engineers and R&D staff in Codelco (the large state-owned mining company) but also similar people in international mining companies (e.g. BHP Billiton). Similarly interviews focused on KIMS suppliers covered not only managers and engineers in local Chilean firms but also similar people in international KIMS firms operating in Chile – people who typically had a wide range of international experience.
- Phase 2 also relied on open-ended interviews and secondary sources – especially material about the industry in Australia. But it also drew very

heavily on an interview-based survey of a small sample of firms in Chile and Australia.

Cutting across both phases, and both types of interview, a total of 113 interviews were undertaken – 66 in Chile and 47 in Australia. Appendix 1 provides a list of all the people interviewed and their organisations. Appendix 3 includes three guidelines used in connection with the interviews: (a) the detailed guide for the key company-specific information sought in the survey interviews with KIMS suppliers (Appendix 3.1); (b) a brief summary of the firm-specific information sought in interviews with mining companies (Appendix 3.2); (c) a summary of the information about contextual issues shaping KIMS learning and innovation that was sought in both the survey interviews with KIMS firms and the more loosely structured interviews with mining companies and other informants (Appendix 3.3).

The rest of this chapter concentrates on explaining the main methodological aspects of the interview-based survey.

4.3 The Sample of KIMS Firms in Chile and Australia

In planning the interview-based survey, the total sample size was determined by a simple pragmatic consideration: the maximum number of KIMS firms that could be interviewed in a relatively short visit to Australia (approximately four-weeks). Allowing time for interviews with other organisations in widely dispersed locations (e.g. research institutes, industry associations, academic analysts, mining companies) suggested that only about 12-15 KIMS firms would be feasible. Since a balance between the two countries was desirable, a total sample of 30 was envisaged – a number that was far too small to permit any kind of generally representative sample.

Identification of the 30 firms was made from industry directories also using associated sources that provided further information about the firms. Selection was based first on two criteria reflecting the characteristics of 'local' KIMS firms.

i. The firms should supply ‘knowledge-intensive’ services to the mining industry – i.e. they should be suppliers of the category of service products falling in the left hand column of Table 2.4 (see earlier in Section 2.5). Within that, they might offer such products either: (a) as pure knowledge based services (e.g. mine planning, tailing dam design, ore and pulp transport system design, metallurgy and process design, environmental engineering, and investment project management), or (b) as a complement to sales of equipment or consumable goods (e.g. a drilling equipment provider that also provided special design and maintenance services, or an explosives supplier that also offered blasting engineering services).

ii. Firms should be ‘local’ suppliers in the sense that they were locally owned, or at least should have started-up as locally owned KIMS suppliers and, if ownership was later shared with a foreign company, an important extent of the decision making process should have remained local.

Within that group, an attempt was made to ensure some diversity across the different kinds of service product, and in the age (start up date) of the firms. But a degree of homogeneity was thought desirable in another respect: the degree to which the firms were ‘leaders’ in competitiveness in their local contexts. Since no attempt at representativeness was attempted, the comparative analysis would be aided by a sample that consisted of firms that were similarly at the ‘leading edge’ of competitiveness in their respective countries. Two further selection criteria were therefore used.

iii. Firms should have exported or at least have attempted to export.

iv. Other actors in the industry should have recognised the firm’s ‘technological leadership’ at the local level (identifiable from such things as the general interviews in Phase 1, the local industry press, previous surveys, or business association directories).

The initial group of selected firms was reduced to a total of 26 that were actually interviewed in adequate detail – 16 in Australia and 10 in Chile. Some of the basic features of these firms are shown in Table 4.1a.

Table 4.1a: Features of the Sample of KIMS Supplier Firms in Australia and Chile

		Australia	*Chile*
Total Number of firms		**16**	**10**
Start-up dates		(%)	(%)
	1970 and earlier	6%	30%
	1971-1980	19%	0%
	1981-1990	50%	40%
	1991-2000	19%	10%
	Since 2000	6%	20%
Size in 2005		(%)	(%)
(Number of employees)	Employees < 11	7%	10%
	10 < Employees < 51	29%	30%
	50 < Employees < 101	7%	10%
	100 < Employees < 501	43%	40%
	500 < Employees	14%	10%
		(%)	(%)
(Sales; Thousands US$, 2004)	Sales<5,000	11%	50%
	5,001<Sales<10,000	11%	25%
	10,001<Sales<100,000	67%	25%
	100,001<Sales	11%	0%
Type of service product		(%)	(%)
	Science-based services	13%	10%
	Consulting and Engineering Services	56%	70%
	Software	19%	0%
	Equipment and design services	13%	10%
	Inputs and contractors	0%	10%

Table 4.1(b) focuses on the extent to which the sample firms were involved in international activities. It indicates the much lower international involvement of the Chilean firms, an important issue that will be examined in more detail later.

Table 4.1b: Features of the Sample of KIMS Supplier Firms in Australia and Chile

		Australia	*Chile*
Number of firms		**16**	**10**
Degree of internationalisation		(%)	(%)
(Exports as % of total sales)	≤ 5 %	6%	60%
	5% ≤ 10 %	0%	10%
	10% ≤ 30 %	19%	10%
	≤ 30 %	75%	20%
		(%)	(%)
(Offices overseas – % Suppliers)	Latin America	44%	60%
	North America	50%	10%
	Africa	50%	0%
	Australasia	63%	0%
	Europe	38%	10%

4.4 Clarification of Key Concepts

Phase 2 of the research concentrated on the concepts in Process 1 (The broad historical process by which key features at the industry level shape the potential for learning and innovation at the micro-level) and Process 2 (The micro-level learning and innovation efforts carried out by firms to exploit the learning potential and generate particular paths of capability accumulation). In principle both sets of concepts might be clarified here in order to explain the basis for the operational aspects of survey research. However the key concepts in Process 1 are relatively well established in the literature and simple explanations are provided later in Chapters 6 and 7 when the concepts are used. This section of this chapter concentrates on clarifying the key concepts involved in Process 2: 'technological capability levels', 'technological learning'; and 'inter-organisational links and flows'. The way information was acquired about these is explained later in Section 4.5.

4.4.1 Technological capability levels

Technological learning processes aim to upgrade or increase firms' technological capabilities levels. Thus, to assess the success of the learning processes pursued by a firm it is necessary to find out whether there has been any change in its level of technological capabilities. As explained earlier in Chapter 3, technological capabilities include skills, knowledge, experience and systems for both production and technical change activities (Bell, 1982; Scott-Kemmis, 1988; Bell and Pavitt, 1995). In other words, they comprise the effort to use, assimilate, adapt, improve and/or create technology (Westphal *et al*., 1982).

Technological capabilities at lower levels (also called production capabilities) refer to a firm's abilities for implementing and mastering production of goods or services at a given level of efficiency using a given set of input combinations: equipment, skilled labour, product specifications and design, input specifications and organisation and procedures of production. This level of capability involves a basic level of operation or technology-using skills and know-how, which could be enhanced trough production experience or "Learning by doing 'production'" (Ariffin, 2000).

Technological capabilities of higher level (also called innovative capability) refer to the capability to generate and manage technological change. Through innovative capability firms change or improve their technology or organisation. This level of capabilities involves technology-changing skills, knowledge and experience (Ariffin, 2000, Figueiredo, 1999).

In order to assess the technological capability level of the sample of KIMS suppliers analysed in this research, five levels of technological capabilities were defined, as shown in Table 4.2. Levels 1 and 2 refer to production (or technology-using) capability levels; and levels 3, 4 and 5 refer to innovative (or technology-changing) capability levels.

Table 4.2: Classification of Levels of Technological Capability

Level 1 – Productive Capability: *Simple User:*   - Simple user and operator of technology that already exists; manages ongoing routine production of goods/services.
Level 2 – Productive Capability: *Advanced User*   - Advanced user of technologies that already exists; process management/control including minor improvements.
Level 3 – Innovative Capability: *Basic Innovator / Adaptor*   - Implementer of incremental quality improvement and minor adaptations – Installs the latest vintage equipment/technology; changes the existing stock through technological support and engineering services; short-term improvement and development of products/processes
Level 4 – Innovative Capability: *Intermediate Innovator*   - Undertakes product/process design and engineering; medium-term development of product/process and prototypes
Level 5 – Innovative Capability: *Advanced Innovator*   - Undertakes long-term development and research; basic research

The operational use of those categories to classify the capability levels of firms was guided by a more elaborate set of distinction between types of technological activity that the firms actually undertook. Discussion with industry experts helped to allocate those activities in categories reflecting the different types of technological capability – as shown in Table 4.3.

Table 4.3: Classification of Levels of Technological Capability

Features of product/service production process	Features of the product/services
Level 1 – Productive Capability: *Simple User* - Simple user and operator of technology that already exist - Manage routinely production of goods/services.	
▪ Preparation of initial outline of simple investment projects ▪ Routinely monitoring of investment projects and existing infrastructure ▪ Synchronising civil construction with installation work ▪ Routinely production process operation ▪ Basic production planning and control and line balancing ▪ Replication of simple and fixed specification of design ▪ Routinely quality control to maintain existing standards	▪ Simple ancillaries engineering services ▪ Construction of basic civil work ▪ Basic plant erection ▪ Disbursing finance ▪ Routinely engineering services in new or existing plants/mines ▪ Routine replacement and maintenance of equipment components ▪ Participating in installation and routine tests of performance.
Level 2 – Productive Capability: *Advanced User* - Advanced user of technologies that already exist - Process management/control including minor improvements.	
▪ Broad outline of investments project planning ▪ Customising software solutions ▪ Partial monitoring and control of expansion projects ▪ Efficiency improvements from experience ▪ International quality control systems and standard (Certification) ▪ Minor adaptations, de-bottlenecking and capacity stretching ▪ Minor clean-up of design to suit production or market ▪ Efficiency improvements from experience ▪ International quality control systems and standard (Certification)	▪ Project management services ▪ Simple project feasibility study ▪ Technically assisted feasibility studies for major expansions ▪ Standard equipment procurement. Search, evaluation and selection of technology/supplier ▪ Installation engineering (civil, electricity, mechanical, instruments, piping, and others) ▪ Technically assisted expansion ▪ Detailed engineering ▪ Basic and preventive maintenance of facilities and equipment ▪ Routine manufacturing and replacement of components under international standard/certification ▪ Replication of unchanging items of equipments.
Level 3 – Innovative Capability: *Basic Innovator / Adaptor* - Incremental quality improvement and minor adaptations - Install the latest vintage equipment/technology - Change the existing stock through technological support and engineering services - Short-term development of product/process	
▪ Minor adaptation of existing products/services design or specifications for local market ▪ Set-up of process or production engineering units ▪ Set-up of products/services development, design and engineering units ▪ Systematic studies of new process control systems and process improvements ▪ Incremental product design and development for local market ▪ Product reverse engineering ▪ Copy of new types of equipments and tools ▪ New organisational techniques (JIT, TQC, MRP, Lean Production) ▪ Statistical process control	▪ Basic engineering of individual process plants/mines ▪ Expanding plant/mine without technical assistance ▪ Procurement engineering (specification, project analysis) ▪ Full monitoring, control and execution of search, evaluation, selection of technology/supplier ▪ Full monitoring, control and execution of feasibility study and funding activity ▪ Systematic provision of technical assistance in feasibility studies, basic, detailed and procurement engineering and plant start-up ▪ Repairing and trouble-shooting of equipment problems ▪ Large equipment upgrading and manufacturing
Level 4 – Innovative Capability: *Intermediate Innovator* - Product/process design and engineering. - Medium-term development of product/process and prototypes	
▪ Process and project software development ▪ Transferring specification to production/products direct from R&D ▪ Own product/service design and development for local and regional market ▪ Development of sophisticated on-line production control and monitoring system ▪ Process reverses engineering ▪ Major improvement to machinery and equipment ▪ New product development (Patents) ▪ Own equipment design and development for local and regional market ▪ Own process design and development for local and regional market	▪ Project management of large-scale investment projects or international investments ▪ Basic engineering of whole process/mine (large scale projects) ▪ Selling or providing design services.
Level 5 – Innovative Capability: *Advanced Innovator* - Long-term development and research - Basic research	
▪ Own product/service design for global market ▪ Research based innovation and rapid prototyping ▪ International R&D into new products/process ▪ Cutting edge equipment and product/service development and design (Patents) ▪ Process innovation based on R&D (Patents) ▪ Radical innovation in organisation.	▪ Project management on a global scale ▪ World-class project management ▪ World-class engineering services ▪ Full turn key solutions ▪ Developing new production process system based on R&D ▪ Developing new product/services based on R&D

4.4.2 Technological Learning

In this research, the term technological learning (or just learning) is understood in the following senses:

- Various processes by which knowledge is acquired by, and converted within, an organisation;
- Processes that permit a firm or organisation to accumulate technological capabilities over time.

Learning processes cover a wide range of different activities used to build up technological capabilities that spans from simple upgrading of productive capabilities to learning through R&D activities (Ariffin, 2000).

There is an important variety of learning activities, such as:

i. ***Learning by doing 'production'*.** This involves the cumulated experience of production operations or project developments. By performing or doing either production operation or project development firms could increase their production capabilities and decrease of production cost. Similar gain in performance could be achieved as an end-user of products as their skills and/or understanding increase through learning by using.

ii. ***Learning by peer interaction*.** This involves the informal sharing of information and knowledge among the different individual that participate in projects and operations, such as experts and engineers.

iii. ***Learning by education and training*.** This refers to the different processes by which individuals acquire knowledge by participating in formal training or education programmes. It could involve acquiring either tacit or codified knowledge.

iv. ***Learning by hiring*.** This refers to the acquisition of knowledge embodied in individuals by hiring them so that the organisation can use their skills and knowledge, which is also gradually transferred to other members of the organisations.

v. ***Learning by taking over*****.** This refers to the acquisition of knowledge embodied in organisations by acquiring or merging with them.

vi. ***Learning by searching knowledge and information***: This refers the systematic searching what is new on the field, where is the technological frontier located, and how is the firm with respect it.

vii. ***Learning by improving, engineering and designing*****.** This refers to “problem-solving” before a new product or process design is adopted. It includes activities such as computer simulation, laboratory experiments, prototype testing, pilot production runs, standardisation of production/process and reverse engineering, imitating and adaptive copying.

viii. ***Learning by developing and researching*****.** This involves research and development activities to create new knowledge regarding a particular area.

Learning and innovation are intertwined processes and it is hard to distinguish between them. For this reason, the set of different learning activities and the associated resources allocated by a firm in order to carry out these activities is named in this research as “learning and innovation effort”.

In order to characterise the learning and innovation effort pursued by a KIMS firm over its history, this research focused on a selected group of three types of learning and innovation effort:

i. Training efforts and career path development of KIMS experts;

ii. Research, engineering and design and associated learning and innovation effort;

iii. KIMS suppliers’ interaction network as a means of learning and innovation.

Appendix 3.1 presents a number of tables used to guide the capture and classification of the changing levels of capability learning and innovation effort in the KIMS supplier firms.

4.4.3 Inter-organisational links and knowledge flows

The scheme used to characterise the external linkages of KIMS suppliers is based on the framework developed by Ariffin (2000). She defines the following categories of links or interactions between organisations and the related knowledge flows:

1. *Marketing-Production links:* These are linkages that are primarily concerned with market transaction for goods and services.

In this case, interactions between firms are purely marketing relationship involving the sale of goods and services derived from the use of existing production capabilities and do not involve significant elements designed to enhance or create those capabilities.

2. *Knowledge flow links*: These are linkages that are primarily concerned with knowledge flows. There are two types of these links: a) Linkages that contribute significantly to creating technological capabilities; and b) Linkages primarily based on the use of existing innovative capabilities that firms already possess.

In addition, other forms of interaction are defined by the level of support and encouragement from other actors, specifically from mining companies. In particular, there are 'demand mechanisms' that work as pressures for firms to progress technologically and undertake more innovative activities. Firms can be pushed to improve their skills and knowledge in order to meet higher standards driven by changes in users' standards (Hobday, 1994; Teubal, 1987).

Appendix 3.1 presents several tables used as guide for the data collection required to characterise Inter-organisational links and knowledge flows – see especially Tables A3.17-A3.21.

4.5 Data Collection

As indicated earlier, information was collected through an interview survey and other means in order to analyse the two historical processes in the model outlined at the end of Chapter 3. This section focuses on explaining key features of the interview survey. First it summarises the types of information acquired (Section 4.5.1) and then explains how the survey addressed the particular difficulties of dealing with information about relatively distant historical events (Section 4.5.2).

4.5.1 Types of information acquired in the survey

The survey was used to acquire two kinds of information. One was about the industry-level factors that shaped the context in which firm-level capabilities evolved – i.e. information about key features of Process 1 in the analytical model. This information is summarised in Table 4.4.

Table 4.4: Information about Industry-Level Factors - Process 1

Variables related to the scale and growth rate of the mining production activity
Local level of mining production activity • Mineral production selected group of minerals • Number and frequency of mining investment projects • Number of mines • Number of suppliers
International scope of KIMS suppliers and mining companies • KIMS suppliers' exports level • Geographical location of KIMS suppliers' offices • Geographical scope of mining companies operations
Variables related to the complexities and challenges of the mining production activity
Mining activity complexity level and challenges • Ore deposit grade • Cost of investment projects • Technical difficulties • Internationalisation as source of challenges and learning and innovation opportunity
Variables related to the structure and organisation of the mining industry
Vertical integration and outsourcing degrees • Organisation of the production of KIMS • Responsibilities in mining investment projects of KIMS suppliers and mining companies
Horizontal integration degree • Mergers and acquisitions by mining companies • Concentration of mineral production • Mergers and acquisition by KIMS suppliers
Specialisation degree • Number of KIMS categories offered by supplier • Sectors supplied besides mining industry by KIMS firms • Range of products supplied besides KIMS categories by KIMS firms • Types of mining companies (diversified corporation, medium size companies, juniors) • Range of minerals produced by companies • Types of KIMS suppliers
Globalisation degree • Geographical locations of KIMS firms' knowledge and innovation efforts

The second type of information was about firm-level factors – i.e. about the key variables in Process 2. This set of information is summarised in Table 4.5. It included information to characterise the development of KIMS technological capability levels in both mining companies and supplier firms – the dependent variable in the analysis. It also included information to characterise the long-term learning and innovation efforts of the sample of KIMS firms.

Table 4.5: Information about Firm-Level Factors – Process 2

Variables related the level of KIMS Capabilities Accumulated
Mining companies technological capability level
• Description of the level of technological capabilities within mining companies and their evolution
KIMS suppliers technological capability level *(DEPENDENT VARIABLE)*
• Technological capability level. The level of capabilities are ranked from 1 to 5, been 1: Simple User Level (very low level); and 5: Advanced Innovator Level (very high level)
Variables related to KIMS learning and innovation efforts
Training effort & career path of KIMS experts
• Career path of KIMS senior experts
• Number of university with mining related studies
• Importance of pursuing formal training programmes (e.g. university degrees and post-degrees)
Research, engineering and design and other learning and innovation efforts
• KIMS suppliers R&D effort (R&D as % Sales)
• KIMS suppliers technical publication effort
• Effort for hiring experts
• Effort in seeking and using best available technologies and practises and benchmarking
• Importance of attending seminars and congresses and literature reviews
• Key events' linkages with investment projects or to what extend investment projects were used as opportunistic learning
• KIMS suppliers merger and acquisition
KIMS suppliers' interaction network as a means for learning and innovation
• KIMS suppliers type and level of interaction with different organisations
• Support and encouragement during key events by mining companies and others
• Support for learning and development from mining companies and government

4.5.2 Dealing with history

A central feature of the research is that it examines changes that occurred over a relatively long period of time. Moreover, although documentary material was widely used in the study, information about many aspects of those change paths was not documented in any form, and heavy reliance therefore had to be placed on the interviews and the 'oral history' they could provide. Considerable efforts were therefore made to design an approach to the survey interviews that would achieve as much reliability as possible in both the content of information and its dating.

One aspect of this approach was to organise the interviews, after an initial presentation about the purposes of the research, around two distinct steps.

Step I: The Identification of Key Events and Stages

During this step the stages in the firm's history of capability development were identified by focusing on "key events" that marked important changes in what the firm was able to do.

Step II: Characterisation of Learning and Innovation Efforts

Then the characterisation of learning and innovation efforts, including interactions and economic performance data was collected with specific reference to those events and stages in the firm's history.

In undertaking these two steps, considerable care was taken to achieve two aims: (a) to secure the greatest possible reliability in the recollected information, and (b) to link that information as accurately as possible to specific times within the history of both the individual firms and the overall development of the KIMS sector. These two aspects of the approach are explained in more detail below.

(a) Acquiring reliable information:

The data gathering method did not request information under the headings in Tables 4.4 and 4.5 merely with reference to vaguely defined past time periods. Instead, it included a technique to focus the questions around very concrete events in the history of each firm. Pilot interviews had strongly suggested that interviewees were clearer in recalling key features of their firms' learning history when questions were focused on specific important changes, rather than if they were asked about such features in predefined years or periods which might be fairly meaningless in terms of changes of the firms' technological capability level. Senior managers and engineers could recall such specific events, in which they had often been personally involved, much more readily and clearly than they could recall what occurred in year 'x' or in the period '199? – 199?'. Thus the "backbone" of the data collection about each KIMS supplier's learning process was built around these "key events" over the lifespan of the firm.

As indicated above, these key events were identified at Step I in the interview by means of a specific discussion with the interviewee. However, given the importance of the identification of these key events, they were validated by asking more than one executive who had been working in, or connected to, the KIMS supplier over a long period and knew its history well. Such individuals were sometimes no longer employed in the firms.

The process of identifying these events was also supported by a set of standardised questions and illustrative examples of the relevant kinds of important change in the firm's capability level – as summarised in Table 4.6.

In addition to reinforcing the quality of recollected data, this 'event-centred' approach enabled the identification of phases of differing intensity in the general path of capability development in each firm – both differences between phases in the life of individual firms and differences between firms. For instance, a dynamic firm that had pursued a particularly active learning process would demonstrate a relatively high frequency of "key events", while a firm with a passive learning path involving the accumulation of capabilities for only slight adaptations would show very few.

(b) Accurate dating of information Aligning Firm Data into Common Industry Phases:

The identification of key events not only assisted in the recall of information about associated learning activities and industry-level conditions. It also enabled the changes in capability level to be dated quite accurately within the history of the firm's own development.

But, as well as being important to understand the history of events within the steps and stages of an individual firm's own development path, it was also important to connect that internal firm-specific path externally to the history of the KIMS sector as a whole. Therefore, once each firm's data had been collected, and before the main analysis was undertaken, the data were reorganised in terms of the following time periods in the overall the emergence and development of the international KIMS sector:

Stage 1 – Gestation (From around the 1940s to the early 1970s)

Stage 2 – Emergence and Development (From around the mid-1970s to the early 1980s)

Stage 3 – Internationalisation (From around the late 1980s to around the late 1990s)

Stage 4 – Consolidation (From the early 2000s and ongoing).

The basis for this classification of stages is explained later in Chapter 5.

Table 4.6: Criteria to Select Key Events on KIMS Firm's History

Main Criterion
Key events should be related to significant steps forward in term of firm's technological and organisational capability. Key events are those projects or activities that represented a significant challenges and efforts that lead to a change in terms of what was the firm was able to do. ***Related Questions*:** ▪ Which projects or activities represented or are associated to an important step forward in terms of what the firm was able to do? ▪ Which projects or activities have represented an important challenge that led to important changes in firm's technological or organisational capabilities level? ▪ Do these events clearly mark a "before and after" in term of what the firm was able to do?
***Examples of key events and sources of challenges*:** a) *Technology updating*: Project or activity that required the use of a technology never used before by the firms (e.g. the first time in using modelling and simulation software to valuate an ore deposit for mine designing). b) *Performing task of higher complexity*: Project or activity that represented a new level of complexity never faced before by the firm (e.g. first time that an engineering firm is responsible for the development of a whole investment project, including design, construction, procurements and starting up). c) *Technology capability level augmenting*: Project or activity that comprises changes in the level of firm's technological capability (e.g. the first time a drilling service provider who had been a user of technology so far, modified the equipment instead of just using it). d) *Higher organisational capabilities requirements*: Project or activity that comprised coordinating multiples actors, various organisational tiers, and new contracts schemes (e.g. a contract that requires a joint venture with other firms and subcontracting several function). e) *A challenge that requires research, development and engineering*: First time the firm launches research, development or engineering programmes to deal with new challenges (e.g. a project related to a mine that has a complex geology never seen before that requires important research and engineering efforts). f) *New standards introduced by mining companies*: A project or contracts that meant higher production quality and security standards required by a mining company (e.g. new requirements defined by standards of an international mining company). g) *New markets standards and regulations*: A project facing more demanding standards derived from regulation or market standards (e.g. higher environmental and labour standards or first export experience to a country with tighter regulations).

4.6 Data Analysis

The data analysis involved four main steps, as follows:

Step I: Estimating the changing levels of technological capability of leading Chilean and Australian KIMS suppliers over the last 40 years (in effect, the ‘dependent variable’ in the analysis);

Step II: Identifying whether and how differences between Chile and Australia in the selected industry-level factors and their interaction affected the potential for learning and innovation faced by the KIMS suppliers in the two countries;

Step III: Identifying differences between Chilean and Australian KIMS suppliers in the level of learning and innovation effort they made to exploit the learning and innovation potential they have been facing over the last four decades;

Step IV: Exploring the association between the inter-country differences in KIMS suppliers’ capability levels and differences in the combination of industry-level factors and learning efforts in the firms.

Although much of the descriptive information used in the analysis is in numerical form, especially in connection with capability levels and learning processes, the analysis of relationships between the various sets of data is essentially qualitative.

The results of the analysis are presented over the next four chapters. Chapter 5 reviews the development of the KIMS supplier sector and concludes with information about the evolution of the level of technological capabilities in the Chilean and Australian KIMS firms. Then Chapter 6 analyses the evolution of the industry level factors that shaped the potential for learning and innovation of KIMS suppliers in both countries and explores the association with the evolution of technological capability levels. Chapter 7 analyses the firms’ levels of learning and innovation effort and its implications for the capability levels achieved. Finally an integrated analysis is pulled together in Chapter 8.

More detailed aspects of methodology are explained over the next three chapters as the data about the different factors is presented.

CHAPTER 5

THE DEVELOPMENT OF KIMS FIRMS AND INDUSTRIES

5.1 Introduction

This chapter serves two broad purposes. First it presents general information about KIMS firms and the overall development of the international KIMS sector. Second, it provides a background historical outline of the development of the Chilean and Australian KIMS supplier sectors that will be examined in more detail in subsequent chapters.

Section 5.2 outlines what KIMS suppliers are. It first outlines the whole mining industry supply sector, including KIMS and non-KIMS suppliers. There are three reasons for this breadth:

i. It provides an outline of the entire supplier sector to help to indicate the distinctive features of KIMS;

ii. '*Traditional'* suppliers of equipment, machinery, consumable goods and material inputs are an important part of the context of KIMS suppliers[4];

iii. There is no clear borderline between KIMS and *'traditional'* suppliers. Indeed the border is becoming increasingly blurred since the latter are gradually incorporating more and more KIMS into the products and services they provide.

Section 5.2 also outlines four broad historical stages in the development of the international KIMS supplier sector. These are a key element in the analysis of the Chilean and Australian KIMS suppliers' learning experiences that follows in Chapters 6 and 7.

Section 5.3 presents an historical overview of the mining sectors in Chile and Australia. This is important not simply as general background to the development of the KIMS supply sector in those countries. It is also important

[4] The term 'traditional' suppliers refer to suppliers of equipment, machinery, consumable goods and material inputs.

because KIMS capabilities were initially accumulated within mining companies and the development of these in-house specialised capabilities was a key source for the emergence of KIMS suppliers as a distinct sector, although the significance of that 'incubator' role of the mining companies differed between the two countries. Specifically, it has been much greater in Australia than in Chile.

Finally, Section 5.4 outlines the differences in the evolution of KIMS capabilities in Chile and Australia, taking into account the capabilities accumulated within mining companies as well as in supplier firms. This last section is therefore an introduction to the following chapters (Chapters 6 and 7), which analyse in much more detail the process of accumulating KIMS suppliers' technological capabilities, the key topic addressed in this research.

5.2 Overview of the KIMS Supplier Sector to the Global Mining Industry

5.2.1 What are KIMS?

Although suppliers play an important role in supporting innovation and competitiveness in the mining industry, as well as enhancing the mining industry's contribution to the development of mining economies, this sector has been generally neglected in studies of the industry's development. In particular, there is no study that provides a clear picture of the sector's size and structure and how these have been evolving. This section therefore presents some general features of the suppliers to the mining industry, with particular reference to KIMS. However, presenting a detailed description of the sector goes far beyond the scope of this research, and only a rather broad outline is provided, covering three issues:

i. The diversity of the sector;

ii. Key characteristics of the 'traditional' supplier firms, in particular their size and internationalisation;

iii. Key characteristics of KIMS suppliers.

(i) The diversity of the mining industry supply sector

The sector supplying the mining industry is highly diverse and fragmented. It includes a considerable number of firms – about 18,000 worldwide in 2005 according to Infomine[5] and these include providers of heavy and light equipment or machinery, suppliers of consumables inputs, contractors, knowledge-based services and consultants, project management firms and re-sellers or distributors.

Infomine's figure probably underestimates the real number of suppliers, since many small and locally oriented suppliers are not considered in its records. For instance, according to BHP Billiton´s procurement records, in Chile alone there are over 3,000 locally based suppliers and about 40 per cent of them sell more than half of their products and services (in terms of value) to the mining industry. In other words, in Chile about 1,200 suppliers have as their main customer the mining industry (Boston Consulting Group, 2007; Lagos *et al*., 2007).

The mining industry supplier sector is also very diverse in terms of the customer sectors served. This is evident in three main ways, two of them related to the diversity within the mining industry and one to the suppliers' diversity:

- First, the mining industry is heterogeneous in terms of the different types of minerals produced;
- Second, the whole mining process involves at least five stages, from exploration to mine closure, and each one has distinctive suppliers;
- Third, suppliers to the mining industry are not just exclusively for this sector; they provide products and services to many other industries.

Next is provided further details about the features listed above.

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[5] Infomine is a world leading provider of mining industry information, including a complete directory of suppliers to the mining industry at global level as well as related to specific leading mining countries (see http://www.infomine.com/suppliers/search/suppliersCompanySearch.asp, accessed 2005).

The heterogeneity of minerals produced: Minerals can be classified into three main categories:

i. Metals;

ii. Non-metals;

iii. Energy minerals.

Table 5.1 presents further details of the different groups of minerals[6].

Table 5.1: Group of Minerals

Category	*Subcategory*	*Examples of Minerals*
1. Metals	Ferrous metals	Iron ore, niobium, tantalum, titanium.
	Precious metals	Gold, platinum group metals, silver.
	Base metals	Aluminium (bauxite), cobalt, copper, lead, magnesium, molybdenum, nickel, zinc.
2. Non-metals	Industrial minerals	Bentonite, iodine, kaolin, magnesia, potash, salt and sodium compounds, silica, sulphur and sulphur compounds.
	Precious stones	Diamonds, gems.
	Structural materials	Cement, clay, granite, gypsum, lime, marble, calcareous stones, olivine, sand and gravel, sandstone, slate
3. Energy minerals		Coal and coke, gas, oil, tar sands, uranium and thorium (note that uranium and thorium are metals).

Source: MacDonald, 2002; UNCTAD, 2007.

In terms of value, the size of each of these sectors is different. In 2005, world 'mine' production value, including the three mineral categories, reached approximately US$ 3.3 trillion. The breakdown of this figure is as follows (Brett, 2006; Ericsson and Noras, 2005; UNCTAD, 2007; USGS, 2006):

i. Energy minerals production value: 85 per cent of total mineral production. Oil and gas are responsible for 82 per cent of total energy minerals production value (Crude oil production level can be used to illustrate the size of the energy sector in terms of volume. In 2005 world crude oil production reached 3,899 mill tonnes, which is 2.2 times the aggregated

[6] This research is mostly focused on suppliers to the metallic mining sector.

level of production of the following eight minerals: copper, iron ore, gold, nickel, zinc, silver, lead and bauxite of crude oil; Brown et al, 2010);

ii. Metal production value: 9 per cent of total mineral production. Eight metals (copper, iron ore, gold, nickel, zinc, silver, lead and bauxite) are responsible for approximately 75 per cent of metal production value;

iii. Non-metallic minerals value: 6 per cent of total mineral production.

Considering the range of minerals produced it is possible to find different types of mining company, such as:

i. Large diversified global mining companies (e.g. BHP Billiton) engaged in the production of several types of minerals;

ii. Locally based, specialised producers (e.g. Codelco), engaged in the production of one specific mineral (e.g. copper);

iii. Junior mining companies seeking opportunities for new mine investment projects for one or several types of mineral.

In a similar way, the suppliers can be classified in terms of their specialisation in different sub-sectors of the mining industry. For example, some firms such as Bechtel (a large international engineering services supplier) provide products and services covering a wide range of minerals, whereas others, such as AMC (a specialised mining engineering consultant firm) are more selective or specialised in just one category or subcategory of minerals.

Main stages of the mining process: The whole mining process involves five stages: i) exploration; ii) project development (regarding to mine development or process plant projects); iii) mining operations; iv) processing operations (refining and metallurgy); and v) mine closure.

Each of these stages requires specific skills, knowledge and technology. Accordingly, there are different levels of specialisation in suppliers – both in the KIMS suppliers and the other supplier sectors. There are suppliers specialised in one specific stage of the whole mining cycle and there are multi-stage suppliers.

Suppliers to the mining industry meet requirements beyond the mining sector: Suppliers to the mining industry provide their products and services to other industries too. For example, the mining industry accounts for 20-30 per cent of the sales of producers of large machinery such as Komatsu, Caterpillar, Sandvik, Atlas Copco, Terex and Metso (Boston Consulting Group, 2007). Another example is Weir Group, a British world leading supplier of specialised valves, mill-lines and cyclones for the mining industry. Weir has a 25 per cent market share of these products for the mining sector, and Weir’s sales to the mining sector are 16 per cent of the firm’s total sales (source: www.weir.co.uk; accessed 2005).

This picture of diversification looks very similar if we consider ‘pure’ KIMS suppliers. For instance, Fluor Corporation, one of the world's largest engineering services companies, targeted over 20 different industrial sectors, the mining industry being just one of them (source: www.fluor.com; accessed 2005).

The Chilean experience illustrates well this kind of variation in the extent to which suppliers specialise in providing products and services to the mining industry or diversify across a wider range of other industries. Indeed, it has been estimated that only 39 per cent of the suppliers to the mining industry get more than 50 per cent of their income from this industry (Lagos *et al*., 2007).

(ii) Characteristics of firms in the traditional supplier sector

A few countries and firms dominate traditional suppliers of equipment and consumables. Most of the suppliers come from the US, Europe and Japan and have been building and strengthening their capabilities over a long period of time, spanning more than a century in many cases.

Table 5.2 below gives a general idea about this group of leading suppliers in terms of size (employees and sales), age and home country.

Table 5.2: Leading Equipment and Input Suppliers to the Mining Industry[7]

Supplier's Name	Type of equipment/input	Home country	Global Presence	Start-up Year	Sales (Mill US$)	Employees
Boart Longyear	• Drilling equipment • Other industrial machinery	United States	Yes	1911	600 (1997)	8,000 (1997)
Atlas Copco	• Drilling equipment • Construction, Mining & Forestry Machinery & Equipment	Sweden	Yes	1873	4,280 (1998)	23,400 (1998)
Sandvik	• Machinery and equipment for drilling • Mine automation systems • High-alloy steels, special metals, and resistance materials • Steel tools for metalworking	Sweden	Yes	1868	5,230 (1998)	42,000 (2006)
Bucyrus	• Electric mining shovels • Draglines • Drilling equipments • Shovels	United States	Yes	1880	232 (1995)	1,200 (1995)
Terex	• Drilling equipment • Mining trucks • Shovels • Crushers • Other construction machinery	United States	Yes	1925	7,600 (2006)	7,000 (2006)
Caterpillar	• Turbine and engines • Trucks, tractors and trailers • Other construction and mining machinery	United States	Yes	1883	22,800 (2003)	69,200 (2003)
Orica	• Explosives and blasting accessories	Australia	Yes	1877	n.a.	14,000 (2006)
Dyno Nobel	• Explosives and accessories	Australia	Yes	1835	1,000 (2005)	3,500 (2005)
Hitachi	• Trucks • Shovels • Other construction and energy machinery • Environmental equipment	Japan.	Yes	1880	3,290 (2002)	10,500 (2002)
Komatsu	• Bulldozers • Dump trucks, shovels • Crushers • Mining and construction equipment • Electronics	Japan	Yes	1894	7,800 (2002)	30,760 (2002)
Liebherr	• Excavators, shovels • Mining trucks • Aerospace • Machine tools	Germany	Yes	1949	6,000 (2006)	26,300 (2006)
ITT Flygt	• Pumps • Mixers and accessories	Sweden	Yes	1901	1,150 (2006)	4,500
Weir Group	• Pumps • Mill lining systems • Valves • Cyclones	United Kingdom	Yes	1871	2,580 (2006)	8,000 (2006)
Metso	• Crushers and mills • Rock and minerals processing systems • Pulping making machinery	Finland	Yes	n.a.	4,200 (1998)	23,000 (1998)
FLSmidth Minerals	• Grinding machines • Crushers and mills • Raw materials storage • Conveyors	Denmark	Yes	1882	2,620 (2004)	10,200 (2004)
Outotech	• Mineral processing systems • Engineering services	Finland	Yes	1910	1,000 (2006)	1,800 (2006)

The majority of these firms are big players with global production systems. They keep consolidating their leadership and widening their scope of products

[7] This list of firms is based on the selection of leading suppliers to the mining industry presented in the *World Investment Report* 2007 (UNCTAD, 2007, p. 113). The sources of the information regarding each firm are the *International Directory of Company Histories*, Vols 7, 17, 26, 28, 30, 32, 34, 48, 50, 52, 53, 63, 64, and 72; and the Web pages of each firm.

through important innovation efforts and also through merging and acquiring other firms. For instance, Komatsu has manufacturing plants in more than 20 countries and so does Caterpillar (these firms are the leading suppliers of trucks for the mining sector). Another illustrative case is Metso (the leading supplier of rock processing machinery), which was created through the merger of Valmet and Rauma in the late 1990s. Later on, in the early 2000s Metso acquired Svedala – which in turn had acquired Allis Chalmers and Trellex during the 1980s and 1990s. Metso become a major supplier of machinery and equipment for the process industry and created an internal unit focused on the mining sector. These patterns of concentration in large global players have created significant barriers to competition and new entrants.

Surrounding such concentration of supply in core product areas, there are suppliers of other types of supplementary products and service suppliers. For instance, there are: i) re-sellers and distributors and related technical assistance suppliers; ii) repairers, re-builders, and maintenance services suppliers; iii) parts and replacement manufacturer suppliers; iv) training services suppliers; v) contractors; vi) expert consultant services and other KIMS; and vii) others. These 'supplementary' suppliers might be either part of the main supplier network, or final user firms themselves, and mining companies encourage their development in order to have products and services available close to their operations and also to have independent expert advice.

Table 5.3, using data from the Infomine suppliers' directory (www.infomine.com, accessed 2005), shows the existence of a large number of suppliers associated with some of the traditional and consolidated sectors. Each of the supplier categories presented in the table are dominated by a much smaller number of large global players. However other supplier firms emerge and develop, many of which are KIMS. For instance, the largest explosive provider – ORICA – has about half of the world's explosives market share. This firm besides providing explosives and accessories also offers knowledge-based blasting solutions to the mining companies. In addition, within the explosives and blasting products and services segment there are numerous other supplier firms such as contractors firms and small highly specialised KIMS suppliers that provide blasting engineering services (e.g. blast designs, blast optimisation and fragmentation analysis).

Table 5.3: Suppliers in Traditional Sector: Numbers in Selected Categories

Category of Suppliers	Number of Firms
Explosives, blasting system, accessories and services	94
Crushers and mills and related services	209
Drilling equipment and accessories	500
Pumps and related services	384
Trucks	165

Source: Based on www.infomine.com, accessed 2005.

(iii) Characteristics of KIMS suppliers

KIMS cover a wider range of activities, which are related to both investment projects and on-going operations. As indicated earlier, these firms could be 'pure' knowledge intensive service organisations, or their service product could be part of the product package offered by suppliers of goods, equipment and machinery. There is not a widely accepted definition of KIMS and the categories of services that they comprise. For the purposes of this study the following basic grouping of KIMS types has been created:

Group 1 Services mostly related to the exploration stage such as geotechnical engineering, geo-statistics, geophysics, geology, geochemistry, economic geology and drilling.

Group 2 Services mostly related to the project development stage such as project management, EPCM (engineering, procurement and construction management) services, due diligence and construction management.

Group 3 Services mostly related to the mining stage such as Seismicity, rock mechanics, mining engineering, mine design and blasting).

Group 4 Services most related to the processing stage such as metallurgy, leaching, hydrometallurgy and chemistry.

Group 5 Services mostly related to environmental services and the closure stage such as paste and thickened tailings, remediation, environmental engineering and acid mine drainage.

Group 6 Others relate to no particular stage, such as mechanical engineering, management, maintenance, electrical engineering, data interpretation services, civil engineering and biotechnology.

There is no data about the overall size of the KIMS sector, either globally or in particular countries. However it is widely expected that the sector will continue to grow rapidly. According to experts interviewed during the fieldwork, it is expected that the mining industry will keep expanding significantly over the next 10 to 20 years, and this expansion will drive considerable growth of the whole supplier market. Within that, it is expected that KIMS will grow at a faster rate than the other suppliers.

Several distinctive feature of the KIMS sector can be highlighted. One is about the greater geographical spread of KIMS suppliers' home countries compared to 'traditional' supplier sectors. The latter are dominated by a few firms, most of which come from a small group of developed countries. In contrast, KIMS suppliers come from a wider range of countries, including developing as well as developed countries. Partially, this is due to the fact that KIMS supply requires a close interaction with user firms' operations and investment projects. This involves close interaction at the 'field level', and therefore they typically need to be locally based.

Table 5.4 illustrates the dispersion of KIMS suppliers according to their country of origin. With data from one of the most popular directories of suppliers to the mining industry, the table shows the total number of suppliers of each of a selected number of KIMS categories organised by the home countries of the firms.

As in the case of the 'traditional' suppliers, the US is the leading supplier country. But there are several differences from the pattern among 'traditional' suppliers. New countries have entered the sector, in particular a group of developing countries, such as Chile, Brazil and South Africa. In addition, two important developed countries with substantial local mining industries – Canada and Australia – have a much higher share compared to their position among 'traditional' suppliers.

Though not shown in this table, the level of internationalisation of KIMS firms operations differs between countries. For example, a review of the web pages of the 73 Australian and 60 Chilean firms showed that only about 20 per cent of the Chilean KIMS included in this table have at least one office in a foreign country, whereas for the Australian case this figure is approximately 50 per cent.

Table 5.4: Number of KIMS Supplier Firms by Country and KIMS Categories

Country	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Total	%
US	118	32	42	37	72	33	**334**	**34.9**
Canada	89	30	33	25	28	21	**226**	**23.6**
Australia	26	12	11	9	10	5	**73**	**7.6**
Chile	25	3	6	10	2	14	**60**	**6.3**
Brazil	24	5	16	0	5	6	**56**	**5.8**
UK	19	5	11	7	3	1	**46**	**4.8**
South Africa	11	8	7	5	4	2	**37**	**3.9**
Peru	5	3	3	3	0	3	**17**	**1.8**
Germany	1	4	2	1	2	2	**12**	**1.3**
Argentina	4	2	1	2	1	1	**11**	**1.1**
China	2	1	1	3	1	2	**10**	**1.0**
India	4	2	2	1	0	0	**9**	**0.9**
Other European (13)	14	5	5	0	4	4	**32**	**3.3**
Other Latin American (3)	5	2	4	0	0	1	**12**	**1.3**
Other Asian (8)	4	3	3	1	1	1	**13**	**1.4**
Other African (7)	7	1	1	0	0	0	**9**	**0.9**
Other in Oceania	1	0	0	0	0	0	**1**	**0.1**
TOTAL	**359**	**118**	**148**	**104**	**133**	**96**	**958**	**100.0**

- Group 1 Services mostly related to the exploration stage
- Group 2 Services mostly related to the project development stage
- Group 3 Services mostly related to the mining stage
- Group 4 Services most related to the processing stage
- Group 5 Services mostly related to environmental services and the closure stage
- Group 6 Other related to no particular stage

Source: Elaborated on the basis of Infomine's supplier directory by selecting a representative collection of categories of KIMS, amalgamated into the six groups outlined in the text above.

Another distinctive feature of the KIMS sector firms compared to 'traditional' suppliers is the wider dispersion of firm size (in terms of employees). The size of 'pure' KIMS supplier firms runs from a single highly specialised consultant, such as a consultant in geosciences, to multinational engineering firms. For example, Bechtel, one of the largest engineering companies in the world, had approximately 40,000 employees worldwide in 2007. However, over the last decade the KIMS industry seems to have been consolidating as mergers and acquisitions have led to larger firms. At present, the large range of firm sizes still exists but, according to the executives of several KIMS firms interviewed during the research, the market share of 'larger' firms seems to be growing.

Finally, another characteristic that distinguishes KIMS firms from 'traditional' suppliers is their age. For instance, the most common foundation dates of all the Australian and Chilean firms included in Table 5.4 are 1985 and 1987 respectively.[8] This contrasts with the foundation dates of the leading 'traditional' equipment and machinery suppliers, which in many cases have over 100 years of existence (see Table 5.2 above).

5.2.2 Stages in the Development of the International KIMS Sector

With its roots in the in-house accumulation of KIMS capabilities in mining companies, the emergence, development and evolution of a distinct, globally organised KIMS supplier industry has been a historical process whose life span covers more than half a century, starting around the 1940s. This section presents a periodisation of this process in four consecutive generic stages, through their overlap with imprecise starting and finishing dates. The identification of these stages came from interviews with experts of mining companies, supplier firms and university and technology centres in Chile and Australia, supplemented with the review of selected literature – in particular Segal (2000) and Dodgson and Vandermark (2000a).

The stages of KIMS sector development are identified in generic terms as worldwide phenomena, without referring to the particularities in any specific mining economy. However, each country has become involved and participated in this historical process in different ways and in many cases at different times. This has involved some common features across different mining countries as well as particular features for each. One of the central arguments of the thesis, developed through Chapters 6 to 8 with specific reference to Australia and Chile, is that the country specificities of these stages have shaped the development of 'local' KIMS sectors and the competitive positions they have achieved in this global industry.

[8] This information was obtained from a review of the webpage of each firm.

- **Stage 1 – Gestation**

(From around the 1940s to the early 1970s)

During this period world mining production experienced a significant expansion, most of the mining companies' activities, including production, investment projects and innovations were to a significant extent locally based.

During this stage, the industry was vertically integrated and most of the industry's KIMS capabilities were accumulated within mining companies. In consequence, KIMS providers, which played an important role in supporting production expansion, were internal engineering departments or technical units of mining companies and there were only a few external providers, which were closely related to mining companies. The bulk of innovation and learning took place within or close to mining companies. Correspondingly, the accumulation of the capabilities that enabled KIMS supplier sector emergence was a consequence of several decades of learning and innovation effort undertaken mostly by mining companies, who were the key drivers of the development of KIMS capabilities at this gestation stage.

- **Stage 2 – Emergence and Development**

(From around the mid-1970s to approximately the early 1980s)

At this stage, world mining production kept growing, but at a slower pace compared to the previous stage, especially during the first part of this stage. Other regions such as South America, Australia and Asia captured a higher share of world mining production.

At the same time, the mining industry initiated a process of vertical disintegration, and technological capabilities became increasingly spread among mining companies and suppliers as many functions previously carried out within mining companies were spun-out. Consequently, a highly diverse and fragmented supplier sector for the mining industry emerged. Especially important was the emergence and growth of KIMS suppliers and contractors.

New KIMS suppliers took advantage of capabilities that in the previous stage were accumulated and upgraded within mining companies and that during this second stage became part of their own capabilities. In addition, KIMS suppliers kept developing further their capabilities by participating in new investment projects and operations related to their ‘parent’ mining companies and to others.

Also, new technologies, especially information technologies, enabled the industry to speed up the rates of innovation and productivity growth. This was part of the process of technological rejuvenation experienced by the mining industry, outlined in Chapter 2 and also in Section 3.4, which kept fostering learning and innovation in the decades to come.

User-producer interaction was a key learning and innovation driver; however this interaction did not necessarily involve a symmetrical two-way knowledge based interaction. Instead, mining companies usually presented new challenges and opportunities for learning and innovation associated with new investment projects or operational upgrading requirement. But suppliers typically generated the solutions as mining companies usually did not participate actively in this and limited their role to checking the plausibility of suppliers’ proposals.

- **Stage 3 – Internationalisation**

(From approximately the late 1980s to around the late 1990s)

During this period the growth rate of world mining production increased, relying importantly on Australia, South America and Asia. Mining companies’ production activities became increasingly spread worldwide, and both mining companies and suppliers participated in production projects and operations on an international basis. In this context, KIMS suppliers deepened their knowledge and kept growing, first locally and then internationally.

Interactions between mining companies and suppliers kept playing an important role in learning and innovation processes, and there was a higher level of collaboration in learning and innovation projects. In addition, other interactions such as supplier-supplier interaction also become important.

During this stage a major deployment of products and services that came along with rejuvenation took place and a rapid development of pervasive applications based on ITs led to big impacts in terms of cost and productivity.

- **Stage 4 – Consolidation**

  (From the early 2000s and continuing)

At this stage, the growth rate of mining production increased again and the forecasts show a scenario of production expansion over at least the next decade and even beyond.

The process of merging and acquisition, which started at the 1990s, kept taking place among mining companies, and this has led to higher concentration based on bigger multi-mineral mining companies. The KIMS supplier sector has also begun to show consolidation features. The frequency of mergers and acquisitions has been gradually increasing. KIMS have not only merged or acquired ‘peer’ firms; they have also been merging and acquiring suppliers in other, closely related supplier categories. Consequently, KIMS suppliers are widening the range of products and services offered and bigger firms are gaining control. This process has been encouraged by mining companies that have been seeking to simplify their external interactions by using larger supplier companies that are increasingly expected to offer ‘complete solutions’.

The rejuvenation process keeps shaping the industry’s performance through pervasive applications; however their impacts are diminishing and innovation projects require larger budgets compared to previous stage.

Interactions, including both user-producer (mining company-supplier) as well as producer-producer (supplier-supplier) interactions, are an important source of innovation and learning. These interactions take place within a complex network of actors organised on a ‘glocal’[9] basis.

On the one hand, global innovation systems are set-up, which are articulated by large mining companies and large suppliers. On the other hand, KIMS suppliers and contractors need to work close to mining investments and operations, which creates important local innovations systems. Also, in addition to mining companies, some ‘key suppliers’, such as international project management firms and some equipment and input suppliers have gotten a higher degree of control of the whole interaction web.

[9] The term ‘Glocal’ is an amalgamation of the terms Global and Local.

The information above about these four stages is summarised in Figure 5.1, providing a general overview of the entire process of development of the international KIMS sector since the middle of the last century. The upper row shows the different stages and the approximate lifespan of each. (Since the transition from one stage to the next is gradual, a diagonal separates the stages.)

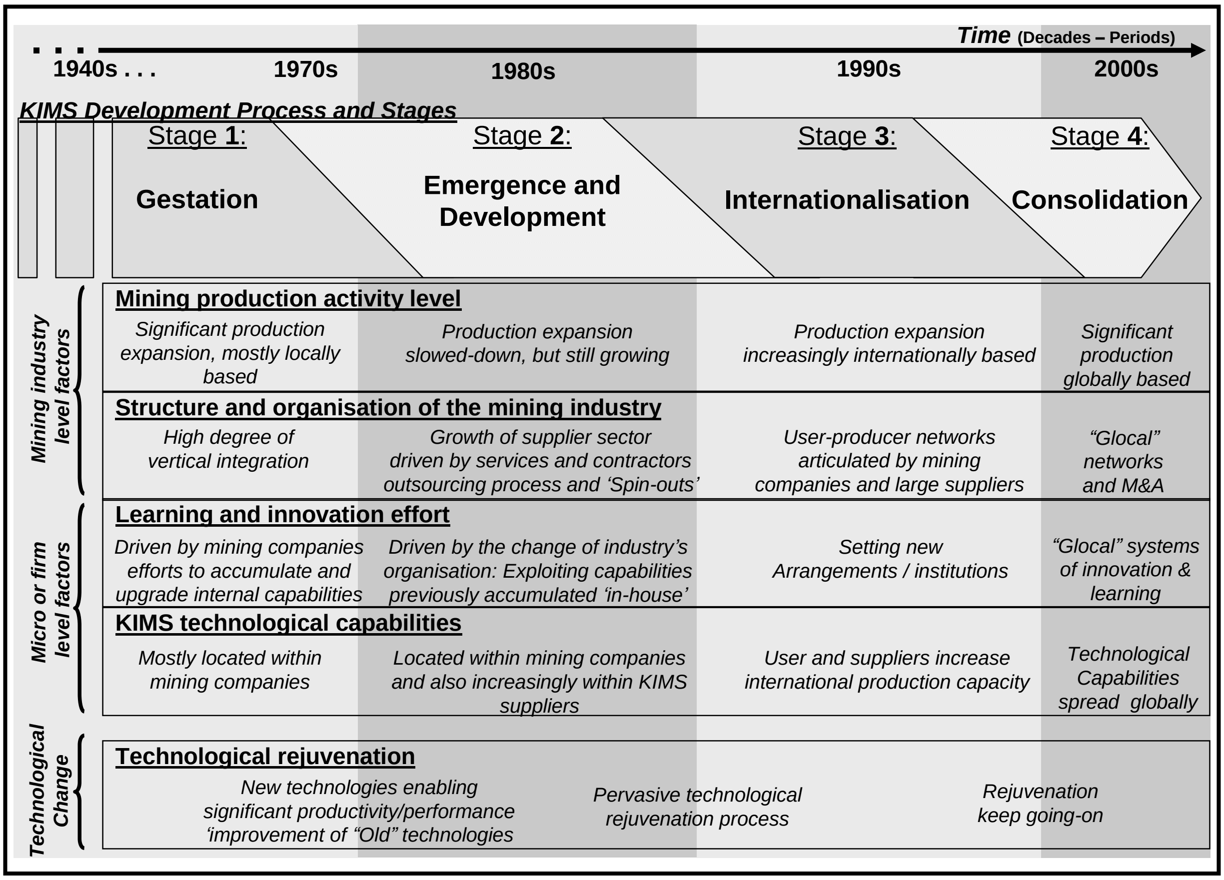


Figure 5.1: Historical Stages of KIMS Sector Development

The four rows in the mid-section summarise the information in the outlines above in terms of the key features of the conceptual framework outlined earlier in Section 3.6 and they show how these have evolved over the different stages. The first two cover factors at the level of the mining industry that shape the potential for learning and innovation. The next two cover features of the learning and innovation cycle associated with the efforts at the micro level to exploit the potential shaped by external, industry-level and other factors.

The row at the bottom shows features of the process of technological rejuvenation, which opened special opportunities for learning and innovation not only for the mining industry but for the entire economy. Rejuvenation besides posing new demands for learning in new areas of technology opened up opportunities for the development of KIMS firms as entry barriers were diminished. KIMS sector firms took advantage of this, which fostered their own learning and innovation processes.

As stressed earlier, this discussion of stages in the evolution of the KIMS sector is a broad global picture. In individual countries both the mining industries as a whole and the KIMS sectors in particular have moved through those stages in different ways and at different times. The next section examines the development of the mining industries in the specific cases of Australia and Chile, The industry contexts for the development of the KIMS supplier sector are examined later in Section 5.4.

5.3 Historical Overview of the Chilean and Australian Mining Industry

This section presents an introductory overview of the history of the Australian and Chilean mining industries, showing in general terms how their technological capabilities have been evolving. This outlines the context within which the long process of KIMS gestation and emergence as a distinct supplier sector occurred in each country. This is important because the level of learning and innovation effort in mining companies shaped the difference between the emergences of a strong or weak KIMS sector. Also, once the emergence of a KIMS sector started, KIMS capabilities within mining companies did not disappear, but continued to play an important role as a source of learning for KIMS suppliers.

5.3.1 Historical Overview of the Australian Mining Sector

In the early 19th century, soon after the first British colony was settled in New South Wales, coal was discovered and began being mined in order to provide fuel for heating and cooking. Later, during the 1840s metals started to be mined in South Australia. The first were lead and copper, and the scale of production was small in terms world mine production.

During the 1850s the Australian mining industry experienced a significant boom prompted by the gold rush in Victoria. As a consequence, during this decade Australia produced almost 40 per cent of the world's gold (www.nationalminesatlas.gov.au). Most of the industry was based on individuals who profited from digging easily accessible minerals. Mining was not really a knowledge-based activity. Nevertheless it was important because it forced the development of an institutional setting that facilitated entrepreneurial development within an organised framework.

In the 1870s, mining based on individual diggers became exhausted. But a second mining boom took place, which was based on the exploitation of larger mines. These were managed by Cornishmen who had much practical experience but were untrained in metallurgy and resisted the use of new technology from the US and Europe, the global technological leaders at that stage. During this period important organisational capabilities were developed, but mining was not an engineering and technology-based activity. Although there was a very important emergence of Schools of Mines, they did not interact or engage with the mining industry because of the industry's reluctance to engage with modern technology. Nevertheless these universities and schools played an important role. They filled a considerable gap in Australia's education system by providing a more general educational service by which the population could improve their education (Vandermark, 2003).

In the 1870s the range of minerals mined was augmented. In addition to gold, coal and copper, manganese and tin were also mined, and in the 1880s a new mining boom took place in the Broken Hill area. Important technology transfer was achieved by recruiting highly paid American engineers and metallurgists from the Rocky Mountains. The import of US engineers, metallurgists and geologists led to a transformation of mining into a knowledge-based activity that used up-to-date technologies and organisational systems. Almost all the regions opened a School of Mines, whose value was acknowledged by the industry which caught up with the technological frontier in both metallurgy and mining. In some areas the Australian industry's capabilities were even at a higher level than in US, the world's fastest growing mining industry and the technological benchmark at that time (Vandermark, 2003).

Despite the technological sophistication achieved by Australian mining in the late 19th century, the industry did not grow at the pace it did in the US. To a significant extent this was because Australia made a very limited effort to develop and apply modern geological and exploration methods. Thus potential new mines remained unknown and mining activity did not experience the exponential growth it showed in the US (Vandermark, 2003; Wright, 1997). As a consequence, by the first half of the 20th century, the dynamism of Australian mining began to decline. The only major discoveries in the first half of the century were lead, zinc and copper deposits at Mount Isa but their full potential was not realised until the 1950s (Duffy, 1996; Vandermark, 2003).

During the 1950s and 1960s big mining companies reinvigorated the industry as well as universities and research centres. Exploration activities increased significantly and the rate of growth of mineral production experienced a substantial increase. In addition to significant growth in the production of minerals that historically had been mined – copper, iron ore, zinc and others – new discoveries of other minerals were made – bauxite, nickel, tungsten, rutile, uranium, oil and natural gas – and this fostered a new mining boom. The Australian industry resumed its highly innovative dynamism that had been 'interrupted' during the early 20th century.

By the 1970s mining technological capabilities, including KIMS capabilities, were updated. Mining companies had accumulated significant technological capabilities in almost all mining functions. In addition mining companies together with the government supported the development of research capabilities in research centres and universities. By the early 1980s, several large mining companies had accumulated important technological capabilities.

A major change occurred during the 1980s when mining companies began to spin-out the KIMS and other services' capabilities they had accumulated internally. Although some of these capabilities remained within mining companies, a significant share of them were now located in new organisations such as independent consultants, KIMS suppliers firms and contractor companies. The 1980s was a transition period as the setting that had been characterised by a highly vertically integrated industry was 'dismantled'.

Resources previously located within mining companies were re-located outside the companies and new supplier firms made use of them. In particular, KIMS suppliers exploited the capabilities previously accumulated within mining companies, and followed an active ‘learning by doing’ process, which was enabled by the industry’s new organisation of production.

However, while this vertical disintegration marked a very significant change, one should not over-emphasise the division of technological labour between mining companies and KIMS suppliers. The former continued to play a major role in developing and deploying the knowledge base of the industry. For instance, the average number of academic publications of BHP over the period 1981 to 2000 has been similar to CSIRO’s minerals division (CSIRO, the Commonwealth Scientific and Industrial Research Organisation, is Australia's national science agency and one of the largest research agencies in the world). Besides BHP, other mining companies such as Rio Tinto, WMC and MIM have also maintained an important rate of academic publications (Vandermark, 2003). Additionally, in terms of R&D expenditure Australian mining companies are among the top investors. For example, in 1996 five mineral mining companies were among Australians top 20 investors in industrial R&D.

Nevertheless, the new setting was accompanied by an important reduction of learning and capability building efforts carried out by mining companies. In particular, expert training activities were weakened. The impact of this was not perceived during the 1980s. In fact, it was hidden by the productivity increase produced by the new organisation of KIMS as external services, together with the pervasive use of emerging innovations and technologies. It was only much later, in the late 1990s that the limited scale of the industry’s human capital in general and technical expertise in particular became evident, and by the early 2000s it was critical.

During the 1990s mining companies initiated an important international expansion and their production capacities and some technological capabilities started to be spread globally. They also developed capabilities to implement large mining investment projects using international financial systems, rather than internal or purely national financial resources.

Australia became a leading mining economy. It is one of the largest producers of several metallic minerals such as bauxite (1st), zinc (2nd), gold (3rd), iron ore (3rd), and nickel (4th). Additionally, it is among the leading countries in the production of energy minerals, such as black coal and uranium, and produces important levels of gem and industrial diamonds, and mineral sands.

In parallel with this mining industry development, KIMS suppliers also developed international production capacity and higher managerial capabilities and enhanced their research capabilities. Australian leadership therefore emerged also on the side of the suppliers of technology and KIMS services. For instance, Australian mining software, expert consultants and project management services can be found worldwide. Also, Australian universities and mining research centres have an internationally recognised prestige in these areas. This dual track of interconnected development in the mining industry itself and in the KIMS supplier sector was enhanced by the fact that since the 1990s there has been a more deliberate effort to set-up a new 'sectoral innovation system' to encourage innovation and learning in the Australian mining sector in order to keep and foster Australia's world leadership on mining. However, it is still too soon to assess precisely how effective this approach has been.

5.3.2 Historical overview of the Chilean mining sector

During the early 19th century, Chile continued running the mining activity inherited from the Spanish colonial period (1545-1810). Gold, silver, and copper were exploited in several towns. Production was based on the exploitation of several small ore deposits with high grade ore, and minerals were easy to extract. Over the 19th century European experts arrived in Chile in order to improve mining industry performance. They taught and introduced new mining technologies. This was not a significant inflow of European engineers, geologist or metallurgist, but a rather sporadic arrival of experts. Nevertheless they made an important contribution to improving mining performance (Valenzuela, 2004, 2005a, 2005b and 2005c).

During the 19th century gold and silver production decreased because the deposits became exhausted, and copper gradually became the main metal produced in Chile. By the 1850s Chile produced 40 per cent of world copper output. At that time, copper production was based on the exploitation of several small and high-grade ore deposits where copper was easily extracted. The subsequent refining stage of production generally used up-to-date European metallurgical technology, and this had a major influence in shaping the expansion of copper production. In particular, the Welsh copper refining process was applied in Chile, generating important improvements in copper mining productivity. In the second half of the 19th century pyrometallurgical technologies such as the reberveratory and flash furnaces were introduced leading to the production of high 'quality' copper bars and ingots – with 97 per cent and 99.5 per cent copper purity respectively, the purest copper produced via pyrometallurgy at that time (Valenzuela, 2004, 2005a, 2005b and 2005c).

This phase of expansion had several follow-on effects. In particular mining education was encouraged at different levels. In the 1840s the University of Chile was founded, and by the 1850s it included mining engineering among its degrees. In the 1850s a mine school at Copiapó was created (which later on became the University of Atacama), and in the 1880s the School of Mining at the University of la Serena was founded. The expansion of Copper production also triggered the development of infrastructure, in particular railways; and new mineral processing technology demanded coal as fuel, leading to the development of coal mining.

However, copper production started to decline by the 1880s. Paradoxically, at that time world copper consumption started to experience an unprecedented expansion led by the world's industrialisation – especially to satisfy the demand from the growing electrical, telephone and telegraph sectors – and the scale of global copper production showed a dramatic increase (Valenzuela, 2004, 2005a, 2005b and 2005c; O'Brien, 1994). This expansion in global demand not only led to a transformation of the scale of global output; it also transformed the methods of mining over a few decades as most of the world's leading copper producers replaced the exploitation of rich, small deposits by exploiting much larger deposits with lower grade ores. This new type of mining required technology based on large scale production in both mining and processing. But Chile remained locked into mining techniques for high-grade ore deposits that were becoming exhausted – techniques that were largely manual, with low productivity and high costs. The country lacked the expertise and capabilities – technological, organisational and financial – to develop and run operations and projects at the scale required by the new modern operations.

By the end of the 19th century Chilean copper mining activity was significantly diminished. The US took the global lead and in 1900 produced 54 per cent of world copper output, whereas Chile produced just 5 per cent. In effect, Chile was by-passed by the transformation of the global copper industry that was driven by the development of the new technological system, which was associated the 'industrial revolution' at the end of the 19th century. The industry missed out on the opportunities that were opened up by this constellation of technological innovation and its associated industrial transformation.

The local context for this collapsing significance of the industry was important. Another significant development was taking place in the Chilean economy in parallel with the decline of the copper industry, and probably causally influencing it. In the 1880s, when copper production started to decrease, saltpetre (nitrates) mining boomed. In terms of trade, this activity was much larger than copper mining, and it maintained a significant growth rate for almost the next four decades. This nitrate mining boom, much larger than the previous copper-based boom gave an important boost to the Chilean export sector (Meller, 1996). By the 1890s Chile supplied 73 per cent of the world nitrate market. This led to further development of infrastructure as well as in banking and trade systems. Also, the Chilean government increased significantly its revenue, which led to further development in infrastructure and the education system.

It has been argued, that the saltpetre boom contributed to weakening the cooper boom by transferring resources from one activity to the other. The limited local expertise and capital that had been available to run copper mining went to the nitrate export business (O'Brien, 1994). After all, setting up the new export industry based on saltpetre seemed to be easier and less risky than entering into the new ‘industrial copper production era’ led by US technology and capital. However, by the 1920s Chilean nitrate leadership began to decrease. Natural nitrates started to lose markets to synthetic nitrates invented during the World War I. Chilean producers were not able to improve their productivity and competitiveness (Palma, 1979) and by the 1930s the scale of nitrate production fell below the 1880s levels.

Copper production did not resume a significant role in the Chilean and international economy until around the 1910s and 1920s – several decades after the decline in the late 19th century. This reinvigoration was externally driven, being led by US investors who developed and ran new and very large copper mines (El Teniente, Chuquicamata and Potrerillos) based on the modern technology that had been developed over the previous decades. By the 1930s copper mining started gradually to recover its leadership, and during the 1930s Chile produced around 16 per cent of world copper output. This figure increased to around 18 per cent during the 1940s. Over the following three decades the production level continued growing, although the Chilean share of world copper production decreased.

Over the whole period from the 1900s to the 1960s copper mining in Chile was mostly controlled and run by US mining companies. Over this first half of the century capabilities at the local level were inadequate to run the industry. But gradually higher production, technological and organisational capabilities were accumulated. For instance, in the 1950s the Chilean government built the first ‘national’ smelter, totally constructed by Chilean workers, many of whom had been trained 20 years earlier in a smelter run by US companies. The first ‘national’ smelter served as a training ground for the construction of a second ‘national smelter’ in the 1960s (O’Brien, 1994).

The first half of the 20th century was also characterised by a permanent dispute between the Chilean government and US firms related to the contribution of the mining industry to the country’s development. The Chilean government claimed that mining was an enclave that was not doing enough to contribute to national development, either in terms of productive linkages to other activities or in terms of government revenue.

By the 1970s these concerns, combined with the growing domestic technological and managerial capabilities, drove the Chilean copper industry Nationalization. The Chilean government began to operate the four largest copper mines in the country (Chuquicamata, El Teniente, Andina and Salvador); and the state owned Corporación Nacional del Cobre (Codelco) was created and became the world's largest copper producer. Box 5.1 below summarises the historical process that led to Codelco's creation.

After the nationalisation copper production in Chile started to grow at a much higher rate. Later, in the 1990s, production grew even faster. This later production expansion was led by the significant arrival of investment of multinational corporations from the major mining economies (Canada, Australia, South Africa and the US).

The dynamism of the copper mining industry, especially since the 1990s, has led to the development of university programmes on geology, mining and metallurgy. Additionally research centres have been created, some of which participate in international research programmes. At the same time, the Chilean mining industry has come to use up-to-date technologies (Katz *et al*., 2000) and in some areas, such as large mining investment project development, Chilean capabilities in the form of the expertise of individuals are known worldwide. In recent years international mining companies and international engineering consultant firms have hired Chilean engineers to participate in projects in foreign countries such as Australia.

Despite the growth of Chilean mining sector over the recent decades, Chilean owned suppliers to the mining industry, in particular KIMS suppliers, have shown a limited international presence. To a significant extent this has been the case because the Chilean KIMS sector has missed important parts of the process that led to KIMS emergence and development in other contexts. In particular, from the 1950s to the late 1970s, almost no role was played by the US companies. Since they had accumulated very limited internal capabilities, there was little that could be vertically disintegrated and spun out.

Box 5.1: Key Dates in Codelco's Prehistory

- **1909**: Production at El Teniente mine starts. El Teniente is a very large deposit of copper ore on the Andes Mountains about 50 miles north of Santiago. It was bought and put into production by a US mining company. By the 1950s El Teniente was the largest underground copper mine in the world. It encompassed 300 square miles, several miles of tunnelling, 43 miles of railroad, an aerial tramway, extensive mining, milling, smelting, and refining facilities, and housing and community facilities to meet the needs of 16,000 people.
- **1915**: Chuquicamata mine is put into production by a US mining company. Chuquicamata is a very large copper ore deposit located in northern Chile's Atacama Desert. By 1930 Chuquicamata had been developed into the world's largest open-pit copper mine.
- **1928**: Potrerillos copper mine is put into production by a US mining company. Potrerillos mine is about 100 miles south of Chuquicamata. By 1955 Potrerillos open-pit deposits were exhausted.
- **1955**: The Chilean government creates the "Copper Department" (Departamento del Cobre), a government agency to oversee, and to provide information about, copper production, trade and price levels.
- **1959**: El Salvador mine, which is below the surface of Potrerillos, comes into full production.
- **1966**: The Copper Department is transformed into the "Chilean Copper Corporation". This organisation creates joint ventures with foreign companies to exploit mines. For instance, Kennecott (El Teniente's owner) sells 51 per cent of its mining operations in Chile to the Chilean government and received a ten year contract to continue managing the joint venture after making a commitment to a huge increase in production. Another important US mining company (Anaconda) refused to sell to the government but signed a contract to increase production. In return the government promised to reduce taxes. Despite these joint ventures, the Chilean government controlled none of the large mines, and production stagnated.
- **1970**: Andina open-pit mine comes into full production. Andina is located 50 kilometres northeast of Santiago and its facilities are 3,500 meters above sea level.
- **1971**: The mining industry is nationalised and the Chilean government gets control of Chile's most important copper mines (Andina, Chuquicamata, El Salvador and El Teniente) and related processing facilities.
- **1976**: The Corporacion Nacional del Cobre de Chile (Codelco), is established to run the four mines which produced 82.4 per cent of Chile's total copper output. Full production resumed this year and the following year Codelco's mines production grew by about 30 per cent.

Sources: Own elaboration based on The International Directory of Company Histories, 2001; www.codelco.com; www.infomine.com; www.ame.com.au, all accessed 2005.

Additionally, during this period, there were few other processes to accumulate capabilities at the local level. There was some additional effort, as in the development of national smelters, but it was mainly concentrated on developing basic levels of engineering and technology adoption/absorption capabilities, and it did not continue to achieve higher levels.

Since the nationalisation (early 1970s) higher levels of technological capabilities have been accumulated but these did not reach the scale or level to generate a more pervasive emergence and development of KIMS services. After the nationalisation many technicians and engineers left, and there was a drop in the level of technological capabilities at local level. Codelco had to concentrate its efforts on building technological capabilities to keep mines running and on expanding mineral production. Thus from the late 1970s to the late 1980s, Codelco's main priorities were to develop operating skills.

During this period Codelco's technological capability building was basically carried out by engineers who, working at ongoing production processes, needed to find ways of solving operational problems. At this early stage, some important innovations were carried out, such as the development of a furnace smelter (the El Teniente Converter) to increase smelting capacity in the El Teniente mine, and the development of panel caving, a mining technique that improved block caving methods used in underground mining.

During the late 1980s and early 1990s Codelco's technological development and innovation activities were set-up as part of a continuous improvement activity. Engineers were encouraged to prepare research proposals aiming to get operational improvement based on the use and adaptation of technologies available. During this stage the geological and geo-mechanical features of Codelco's ore deposits, made mining 'easier' in comparison to what happened in other countries. This allowed Codelco to keep production costs at a competitive level by addressing immediate operational challenges or problems. Accordingly, using and adapting technology already available was enough to cope with these challenges. The capabilities accumulated over this period were far from insignificant, but they included little in the innovating area that could be spun out. Codelco accumulated basic engineering competence to enable acquisition and absorption of technology, which led to the accumulation of some internal capabilities as an advanced user and adaptor (according the capability level categories presented in Chapter 4).

In terms of the rejuvenation effect, the Chilean mining industry captured only a small part of the opportunities opened up by this process. To a significant extent the rejuvenation was importantly driven at a global level by the pervasive use of ICTs. New entrants faced low barriers to entry at an early stage of this new techno-economic paradigm, which was around the 1970s and 1980s. Australian KIMS experts made the effort to exploit the opportunities during the early stages of rejuvenation, and this led Australia to become a world leader associated with mining software. In contrast, Chilean KIMS suppliers, especially those associated with mine planning activities, entered late and became first only advanced users and later on adaptors.

By the mid-1990s Codelco's mining activities had became increasingly complex. In this context technological development and innovation became a requirement to keep the company's competitiveness. In other words, technological development and innovation become an important factor behind Codelco's ability to reduce cost, increase productivity and grow. Similar features were also being experienced by other mining companies based in Chile.

In 1996, 20 years after nationalisation, Codelco defined its first 'Research and Technological Innovation Policy', which is summarised in the following strategic principles:

i. Use the best available technology to tackle problems and operational challenges;

ii. Carry out continuous research and technological innovation efforts in those areas where the market does not provide integral solutions;

iii. Improve research and innovation organisation and management;

iv. Encourage professional development and specialisation;

v. Develop cooperation agreements; and

vi. Protect Industrial Property.

In 1998, IM2 (The Institute for Mining and Metallurgy), Codelco's corporate R&D centre, was created. By 2001, IM2 worked on a portfolio of more than 85 research projects and applied for 14 patents. By 2006 IM2 employed about 60 research staff.

To address several of the technological challenges, Codelco has built international alliances with leading supplier firms such as DBT (German supplier of equipment – from hydraulic shield supports, electrohydraulic controls, conveyors, ploughs and shearers to crushers and diesel transport vehicles); Sandvik (Finnish-Swedish supplier of cemented-carbide and high-speed steel tools for metalworking applications; machinery, equipment and tools for rock-excavation, and stainless and high-alloy steels); MMD, Mining Machinery Developments (UK, mineral sizer equipment supplier); and Orica (Australian, explosive and blasting engineering supplier).

Additionally, in recent years Codelco has developed several strategic joint ventures for the development of key technologies. For instance, Biosigma is a bioleaching technology joint venture owned 66.7 per cent by Codelco and 33.3 per cent by Japan's Nippon Mining, and MiCoMo (Mining Information Communications and Monitoring), is a joint venture between Codelco and Nippon Telegraph & Telephone Corp (NTT) that aims to develop ITC applications for mining such as remote control system for mining operations using a photonic network.

The participation of locally owned Chilean suppliers in these alliances and joint ventures with Codelco has been very limited (Morales, 2005).

Codelco is also participating in international research consortia such as: (a) MMT, Mass Mining Technology, which is a programme coordinated by the University of Queensland (Australia) that carries out fundamental research to support strategic technological developments in underground mass mining; and (b) The Block Caving Study Group, which has been working since 1998 with the participation of Codelco, De Beers, Rio Tinto, Newcrest Mining, LKAB, Sandvik, Western Mining Resources, BHP Billiton, Orica, INCO, Xstrata.

In summary, over the last three decades Codelco has built a higher level of technological capability. Over this time its R&D budget has increased more than six times: over the 1980s the average R&D budget per annum was US$ 6 million, during the 1990s this figure grew to US$ 18 Million, and during the period 2000-2006 it reached US$ 36 Million (Morales, 2001 and 2007). During the period 1995-2004 Codelco made 80 patent applications and by 2005 had 23 patents granted – more than all Chilean universities and research centres combined (Martínez, 2005).

Despite the increased R&D budget, this effort seems small compared to Australia. For instance, spending US$ 6 million per annum just after the whole rejuvenation window was opened, was far from the scale required to participate in the process. The magnitude of Australian mining companies' R&D has been much higher than in Chile. In 1996 BHP spent 15 times more in R&D activities than Codelco.

5.4 KIMS Technological Capability Levels in Australia and Chile

This section provides more than merely background and context for the later chapters. It deals with what was identified in the conceptual framework in Section 3.4 as a central component of the overall analysis in the thesis – the level of KIMS capabilities in the two countries. As explained in Section 3.6, these capability levels play two key roles in the overall model that is being explored in the thesis:

1. On the one hand, the capability level of the KIMS suppliers is the dependent variable of central interest, the focus for the explanatory analysis in the next two chapters;

2. On the other hand, within the cumulating historical process of KIMS capability development, the level of capability in one period is an important influence on the learning that can be achieved in the subsequent period, i.e., an independent variable in explaining the path of capability development.

Although the development of the mining industries in the two countries covered a similar historical period, there were – as shown in the previous section –

distinctive differences between the two cases. This section examines more specifically the differences between the two countries in the capability levels that were accumulated within specialised KIMS suppliers to the mining companies.

The section rests on a different methodological basis from that used in the previous section. The review about mining companies' capabilities, including their KIMS capabilities, was essentially qualitative based on information derived from secondary sources and a wide range of relatively open-ended interviews. But the review of suppliers' capabilities in this section is based on more quantitative information derived specifically from the interview-based survey of suppliers in the two countries.

The methods used for that survey were described earlier in Chapter 4, but a brief recapitulation about one central feature is provided here – the classification of the five capability levels – based on the technological activities undertaken by the firms as shown in Table 5.5[10].

Table 5.5: Classification of Levels of Technological Capability

Level 1 – Productive Capability: *Simple User:* Simple user and operator of technology that already exists; manages ongoing routine production of goods/services.
Level 2 – Productive Capability: *Advanced User* Advanced user of technologies that already exist; process management/control including minor improvements.
Level 3 – Innovative Capability: *Basic Innovator / Adaptor* Incremental quality improvement and minor adaptations – Installs the latest vintage equipment/technology; changes the existing stock through technological support and engineering services; short-term improvement and development of products/processes
Level 4 – Innovative Capability: *Intermediate Innovator* Product/process design and engineering; medium-term development of product/process and prototypes
Level 5 – Innovative Capability: *Advanced Innovator* Long-term development and research; basic research

As also explained earlier, the sample of KIMS firms in the survey was structured to include 'leading edge' firms in both countries. Table 5.6 summarises the evolution of the technological capabilities of those firms since 1970. The upper rows of the table show the total number of firms that had been established by the various dates. Then the capability levels of the firms are shown in two ways.

[10] Reproduced from Chapter 4 (Section 4.3.2).

First, the middle rows of the table show the distribution of the firms in each country between levels of capability. To simplify the presentation for this purpose, the five capability levels in Table 5.5 above are collapsed into the following three categories:

1 Technology users (combining Levels 1 and 2 in Table 5.5);
2 Technology adaptors (Level 3, Basic innovator/adaptor); and
3 Technology innovators (combining Levels 4 and 5).

The second, the last three rows in the table show an average 'score' for each country at each of the eight dates. Although this is merely the average of an arbitrary allocation of the scores 1-3 for each of the five underlying capability levels, it provides a convenient summarisation.

Table 5.6: Evolution of KIMS Suppliers Sample's Technological Capabilities Level

Stages in KIMS development	Technological Capability Level							
	Stage 1		Stage 2		Stage 3		Stage 4	
	Gestation		Emergence and Development		Internationalisation		Consolidation	
	1970	1975	1980	1985	1990	1995	2000	2005
1. Number of firms in the sample								
Australia	1	1	3	9	11	14	14	16
Chile	3	3	3	6	7	8	9	10
2. Proportion of firms at each capability level (%)								
2.1. Technology Users								
Australia	100%	100%	33%	37%	0%	0%	0%	0%
Chile	100%	100%	100%	83%	43%	13%	11%	20%
2.2. Technology Adaptors								
Australia	0%	0%	67%	50%	70%	69%	38%	27%
Chile	0%	0%	0%	17%	57%	74%	67%	40%
2.3. Technology Innovators								
Australia	0%	0%	0%	13%	30%	31%	62%	73%
Chile	0%	0%	0%	0%	0%	13%	22%	40%
3. Average 'score' for firms capability levels (Score: 1= User; 2 = Adaptor; 3 = Innovator)								
Australia	1.0	1.0	1.7	1.8	2.3	2.3	2.6	2.7
Chile	1.0	1.0	1.0	1.2	1.6	2.0	2.1	2.2
Chile/Australia	100%	100%	59%	67%	70%	87%	81%	81%

Although the number of firms is very small for the early 1970s, Table 5.6 suggests that the situation was very similar in the two countries at that time, the stage when a distinct KIMS supplier sector had barely emerged. In both countries the few interviewed firms that did exist as independent KIMS suppliers at that time were only Technology Users. Thereafter, however, two different patterns of capability accumulation evolved. Over the 30-year period from 1975 to 2005, most Australian KIMS firms developed first into adaptors and then into innovators, but most Chilean KIMS suppliers lagged behind in becoming adaptors and then, compared to Australia, a smaller proportion evolved into innovators.

In a little more detail, the survey results indicate that, already by 1980, nearly 70 per cent of the small number of Australian firms had reached the Adaptor level. Five years later, the total number of firms had expanded rapidly, and a similar proportion was either at the Adaptor level or had moved on to become Innovators. By the 1990s none of the larger number of Australian firms remained as merely Technology Users, while one-third had become Innovators. Later, by the mid-2000s, it was still the case that none of the KIMS suppliers were merely Technology Users, while the proportion that had accumulated Innovator-level capabilities had more than doubled to 73 per cent.

In contrast, all the Chilean KIMS suppliers remained at the Technology User level at the start of the 1980s. Five years later only 17 per cent of them had moved up to the Adaptor level, and none had achieved innovator-level capabilities. Even in 1990, there were still no firms at this level, although more than half had reached the Adaptor level. It was not until the mid-1990s that a small proportion achieved Innovator level capabilities – 13 per cent, the same proportion as in Australia a decade earlier. This proportion had risen to 40 per cent by the mid-2000s, only a little more than half the proportion in that category in Australia at that time. Among the remaining 60 per cent, 20 per cent were still at the Technology User level.

Thus the level of technological capabilities accumulated by both Australian and Chilean KIMS suppliers was more or less steadily rising over the period from the late-1970s to the mid-2000s. However, the Australian KIMS suppliers moved ahead more rapidly at the start and maintained higher average levels of capability than the Chilean suppliers over the entire period. Nevertheless, as indicated by the *relative* scores in the last row of Table 5.6, KIMS suppliers in Chile gradually caught up with their Australian equivalents after their slow start. However, the catch up process seems to have peaked in the mid-1990s, with

Chilean firms falling back again to a lower relative capability level over the subsequent ten years through to the mid-2000s.

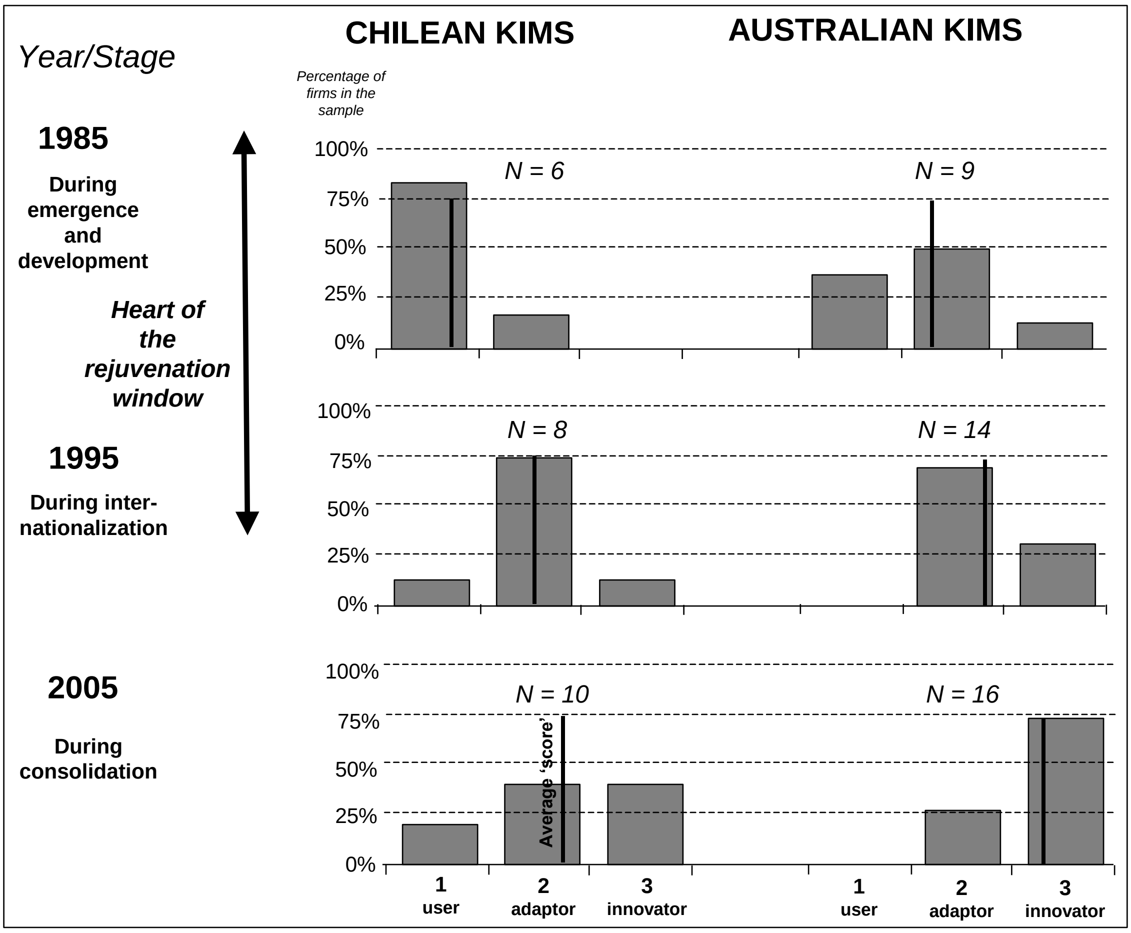
But this contrast between the capability development paths in the two countries involved more than just this general Chilean lag through the period. Probably more important was the specific timing of some of the differences relative to more general events in the development of the industry as a whole. Two of these timing issues appear to have been particularly important.

The first was the lag in the Chilean path at the start of the process in the late 1970s and early 1980s with no firms moving above the Technology User level by 1980 (and very few doing so by 1985). This occurred just at the time of the global emergence of a specialised KIMS supplier industry, and the difference between the Chilean and Australian paths through this phase was significantly shaped by the level of capabilities that had already been accumulated within mining companies in the previous Gestation stage. Since KIMS capabilities embodied within mining companies were much higher in Australia than in Chile, the role of mining companies as capability 'incubators' was much more significant in Australia than in Chile, and provided a much more significant kick-start to the subsequent spin-off and knowledge spill over processes as the mining companies extended their vertical disintegration. It seems likely that this source of already created competence was particular important in contributing to the very quick achievement of Innovator and Adaptor levels of capability among the rapidly growing number of new entrants to the specialised KIMS industry in Australia during the early 1980s.

The second issue was about the timing of key features in the two paths relative to the immediately subsequent stages in the development of the specialised KIMS supplier industry, and more generally in relation to the window of opportunity opened up by the rejuvenation phase of the mining industry as a whole. This is discussed here with reference to Figure 5.2 that uses selected and simplified information from the earlier Table 5.6.

Because of their earlier development of Adaptive and Innovative capabilities in the late 1970s and early 1980s, the Australian KIMS suppliers were in a better position than their Chilean counterparts to exploit the opportunities arising during the heart of the rejuvenation period (roughly 1985 to 1995). Not surprisingly therefore, information gathered during the survey illustrated ways in which Australian KIMS suppliers undertook more intensive and earlier efforts to exploit the opportunities opened up by the industries technological and organisational rejuvenation, especially the opportunities associated with the use of information technologies in new ways.

Figure 5.2: Evolution of the Percentage of KIMS Suppliers by Level of Technological Capability



Then a little later into the rejuvenation phase, KIMS suppliers in the two countries were in different positions to exploit the opportunities that arose through the late-1980s and early-1990s when the global KIMS sector as a whole began to shift from the emergence and development stage to the internationalisation phase. Far more Australian KIMS firms than Chilean ones had built up the bases of adaptive and innovative capabilities required to move into international markets.

Finally, during the late-1990s and early 2000s globalisation and consolidation of the KIMS supplier industry became a key driver for sustained competitiveness and continuing accumulation of new and higher levels of technological capability. Once again, the Australian KIMS sector was in a position to play a leading role in these significant forms of organisational change. In contrast, the Chilean KIMS supplier sector – either because of a lack of capabilities or of inadequate awareness of the significance of these changes did not exploit the opportunities. As will be elaborated later, Chilean firms became objects of the global consolidation of the sector by firms from other countries, rather than playing active roles as consolidators themselves.

This section has now addressed the first of the Research questions posed at Chapter 3.

How have the levels of technological capabilities accumulated within KIMS suppliers in Chile changed since the 1970s, and what have been the main contrasts with experience in Australia?

Two comments should be added about the answer to that question.

First, the history of the development of technological capabilities in the Australian and Chilean KIMS supplier sectors is not simply a story of leading and lagging paths over a period of more than 30 years. It is also a story about how those paths interacted with wider developments in the global industry to result in what may prove to have been a missed opportunity for the laggards. Just as the Chilean mining industry, one of the global leaders at the time, was by-passed by the phase of radical transformation in the industry's technology in the late 19th century, so it may have 'missed the bus' again in the late 20th century as another phase of radical transformation, and the associated rejuvenation of mature industries, opened a window of opportunity' to create an internationally competitive KIMS supplier sector.

Second the argument here is not that this missed opportunity resulted from a few inappropriate choices by key actors in Chile (e.g. Codelco). Instead the argument is that, as outlined in the explanation of the dual process model of technological learning at the end of Chapter 3, a wide range of international and national circumstances cumulatively acted to impose massive constraints on the path of KIMS development in Chile.

The thesis now turns to address those two sets of circumstances. First, Chapter 6 will examine the historical processes by which the potential for learning and innovation was shaped by three key industry-level factors. Then, Chapter 7 will examine the more detailed micro-level learning and innovation cycle within firms themselves. Chapter 8 will integrate these two analyses.

CHAPTER 6

INDUSTRY-LEVEL FACTORS SHAPING THE POTENTIAL FOR KIMS LEARNING AND INNOVATION IN CHILE AND AUSTRALIA

6.1 Introduction

The conceptual framework outlined in Chapter 3 (Section 3.4) highlighted a number of industry-level factors that are likely to have shaped the opportunities and potential for learning and innovation contributing to the emergence of an internationally competitive KIMS supplier sector over the last three or four decades. The purpose of this chapter is to examine these factors for the specific cases of Chile and Australia, seeking to identify any difference that might help to explain the different paths of KIMS sector development in the two countries. These factors are:

i. The scale and growth of mining production;

ii. The technological and organisational complexities and challenges facing the mining industries;

iii. The structure and organisation of the mining industry.

Section 6.2 examines the evolution of the scale and growth of the Chilean and Australian mining industries and Section 6.3 outlines the complexity and challenges associated with the growth of the industry, mainly in the domestic industries. Then Section 6.4 examines issues concerned with the structure and organisation of the mining industry in the two countries. Finally, Section 6.5 provides an overview of the aggregated effect of the interaction of all these factors in shaping the potential for learning and innovation of the Chilean and Australian KIMS sector.

6.2 The Scale and Growth of Domestic Mining: Opportunities for the KIMS Sectors in Chile and Australia

The basic argument underlying this section is that, as discussed in Chapter 3, both the rate of growth and scale of the domestic mining industry have a major influence on the frequency of opportunities for entry, learning and innovation by specialised suppliers in the KIMS sector. The section therefore examines differences in those conditions in Chile and Australia over the last 50 years. It does so in three steps. First, Section 6.2.1 examines growth, scale and diversity in the domestic mining industries. Second, it focuses more specifically on the opportunities provided by major new investment projects in the two industries (Section 6.2.2). Then finally, in Section 6.2.3, it examines the opportunities and threats, arising from differences in the internationalisation of mining companies in Australia and Chile.

6.2.1 The growth and scale of domestic mining

As indicated in Chapter 2, world mineral production started to grow at a higher rate after the Second World War compared to the preceding five decades. Indeed, during the period 1950-1975 the world production of most metals grew three times faster than it did over the first half of the 20th century. Later on, during the period 1990-2005, metal production maintained an even higher growth rate (for more detail see tables and figures in Appendix 2).

Some of the ‘new’ leading mineral production economies, such as Australia, followed this growth trend almost immediately, growing at a higher rate compared to world production. Others, such as Chile, started to increase their production growth rate much later. More detailed features of the patterns of growth are shown in Tables 6.1 and 6.2 below. These show the growth of mining production from the 1930s to the early 2000s at the world level and in Chile and Australia. The tables cover production of eight metallic minerals: copper, iron ore, gold, nickel, zinc, silver, lead and bauxite.

The picture for copper alone is indicated in Table 6.1. Part 1 of the table shows that the growth of copper production during the two decades that preceded the

1950s was very slow: between 1929 and 1951 copper production in the world, Australia and Chile grew by only 35, 15 and 18 per cent respectively. This changed dramatically between 1951 and 2005 when world copper production expanded nearly six-fold. But the pace of change was uneven through the whole period, and three different phases can be distinguished:

i. *A "Fast" growth period*: During the 1950s and 1960s annual world copper output grew by 5 million tonnes (an increase of about 180 per cent);

ii. *A "Slow" growth period*: During the 1970s and 1980s annual world copper output grew by less than one million tonnes (an increase of about 110 per cent);

iii. *A "Very fast" growth period*: During the 1990s annual world copper output grew by about 4.5 million tonnes (an overall increase of about 50 per cent from what was by 1990 a very much larger base).

The paths taken by Australia and Chile through these periods differed. From a very small base Australian copper production grew about 60 times, In contrast, Chilean copper production grew 14 times. But more important than the difference in these aggregates over the whole period were differences in the timing of the two growth paths.

As indicated in Part 1 of Table 6.1, Australian expansion of copper production took off at the start of the fast phase of global growth during the 1950s and 1960s, and output increased thirteen-fold over the two decades. Reflecting the global pattern, there was little expansion during the 1970s, but it resumed again in the 1980s. Then, again reflecting the global expansion path, the annual rate of output surged ahead, nearly tripling during the 1990s.

In contrast, the Chilean industry expanded little during the global fast growth phase of the 1950s and 1960s, and it experienced an initial stage of significant growth of production only about 30 years later than Australia, around the late 1970s, after mining industry nationalisation and the creation of the state owned mining company, Codelco. Later, during the 1990s, mineral production experienced a second much higher increase, with expansion being driven largely by the investment of multinational mining companies in Chile.

Table 6.1: Copper Mine Production: World, Chile and Australia (1929-2005)

Year	World		Australia			Chile		
	Tonnes (000s)	*Production level compared to 1951*	*Tonnes (000s)*	*Production level compared to 1951*	*Share of World Production*	*Tonnes (000s)*	*Production level compared to 1951*	*Share of World Production*
Part 1: Levels of production								
1929	1,956.2	0.7	13.7	0.9	0.7%	320.8	0.8	16.4%
1951	2,631.8	1.0	15.8	1.0	0.6%	379.0	1.0	14.4%
1961	5,332.4	2.0	117.3	7.4	2.2%	671.9	1.8	12.6%
1971	7,333.7	2.8	212.7	13.5	2.9%	872.7	2.3	11.9%
1981	8,190.7	3.1	229.3	14.5	2.8%	1,081.2	2.9	13.2%
1991	9,090.0	3.5	318.2	20.1	3.5%	1,818.0	4.8	20.0%
2001	13,648.8	5.2	900.8	57.0	6.6%	4,736.1	12.5	34.7%
2005	15,010.4	5.7	930.6	58.9	6.2%	5,313.7	14.0	35.4%

Part 2: Absolute Increments in production

	Australia *Total*	Australia *Average Annual*	Chile *Total*	Chile *Average Annual*
1951-1961	101.5	10.2	292.9	29.3
1961-1971	95.4	9.5	200.8	20.1
1971-1981	16.6	1.7	208.5	20.9
1981-1991	88.9	8.9	736.8	73.7
1991-2001	582.6	58.2	2,918.1	291.8
2001-2005	29.8	6.0	577.6	115.5

Source: Own elaboration based on data presented in Appendix 2.

Nevertheless, despite its relatively late start, the expansion of Chilean production has been very significant and has driven an important technological upgrading process in the entire Chilean mining sector, including mining companies and suppliers. However, as elaborated later, the 'quality' of this learning and upgrading was initially concentrated on gaining the experience needed to master up-to-date technology (i.e. acquiring advanced-user and adaptor capability levels according to the categories presented in Chapter 4), rather than capabilities for creating new technology.

At the same time though, it is important to note another feature of the two countries' expansion paths through this period – the absolute scale of the increments being added to production capacity. This is important with respect to the opportunities that growth provides for KIMS suppliers because, to a significant extent, it is the magnitude of investment in new and expanded production operations that drives the demand for many types of KIMS. It is therefore of interest to note from Part 2 of Table 6.1 that, despite the slower rate of growth in Chile during the 1950s to 1970s the magnitude of the additions to capacity were consistently greater than in Australia. This became even more pronounced in the 1980s, 1990s and early 2000s.

In principle therefore, if we look at the copper industry alone, the growth-driven opportunities for KIMS suppliers in Chile were much greater through the whole 50-year period than they were in Australia. However, many types of KIMS are fairly generally applicable across different kinds of mining, and one must consider a much wider spectrum of mineral production than only copper.

Tables 6.2a to 6.2b show the Global, Australian, and Chilean growth paths in non-copper metallic minerals. In summary, the tables show that Australia has been able to maintain a high rate of diversified production expansion by participating in successive mining booms involving different groups of metals. This involved three main stages. First, as noted above, Australian copper production experienced significant growth in the 1950s. Then during the 1960s and 1970s the expansion of Australian metal production was led by iron ore, nickel, silver, lead and bauxite. Finally, during the 1980s and 1990s copper again, together with gold, zinc and silver, were responsible for sustaining a high rate of expansion of mining production. Furthermore, if a wider scope of minerals is taken into account that includes not only metallic minerals but also energy minerals, such as uranium and coal, then the diversified expansion of Australian mining activity is even more impressive.

In contrast, running through the whole 50-year period the expansion of mineral production in Chile was almost exclusively based on copper. The only exception involved a significant expansion in the production of gold and silver, but this was from a small base, and it occurred late in the period, alongside the rapid expansion of copper production.

This difference in the diversity of mineral output growth had a significant effect on the overall scale of the mining industry. With respect to copper, Chile has had a much larger scale of production than Australia all the way through the period, and Chilean copper production was still about six times larger than in Australia in the early 2000s. As shown above, one consequence of this large scale was that even quite slow rates of growth involved substantial increments of production capacity, and hence larger demands for investment-related KIMS.

However, the picture changes if a wider range of metals is taken into account. For instance, in 1951 Chile and Australia had approximately the same level of iron ore production, each having roughly a one per cent share of world production. In 2005, 55 years later, Australia produced 34 times more iron ore than Chile. Similar differences can be observed in other metals such as gold, nickel, zinc, lead and bauxite, and also in non-metallic and energy minerals. A partial indication of how these patterns of growth and scale in the two countries' mining industries translated into differences in a large part of the opportunities for entry and learning by KIMS firms can be provided by an analysis of the frequency of major mining-related investment projects.

Table 6.2a: Iron Ore Mine Production: World, Chile and Australia (1929-2005)

Year	**World**		**Australia**			**Chile**		
	Tonnes	*Production level compared to 1951*	*Tonnes*	*Production level compared to 1951*	*Share of World Production*	*Tonnes*	*Production level compared to 1951*	*Share of World Production*
1929	201,175,000	0.7	-	-	-	1,810,575	0.6	0.9%
1951	294,103,000	1.0	2,352,824	1.0	0.8%	3,235,133	1.0	1.1%
1961	486,887,677	1.7	5,355,764	2.3	1.1%	6,816,427	2.1	1.4%
1971	762,948,887	2.6	60,272,962	25.6	7.9%	10,681,284	3.3	1.4%
1981	828,282,052	2.8	81,999,923	34.9	9.9%	7,454,538	2.3	0.9%
1991	955,552,000	3.2	117,532,896	50.0	12.3%	8,599,968	2.7	0.9%
2001	1,049,438,618	3.6	181,552,881	77.2	17.3%	8,395,509	2.6	0.8%
2005	1,544,062,062	5.3	262,490,551	111.6	17.0%	7,720,310	2.4	0.5%

Table 6.2b: Gold Mine Production: World, Chile and Australia (1931-2005)

Year	World		Australia			Chile		
	Tonnes	*Production level compared to 1951*	*Tonnes*	*Production level compared to 1951*	*Share of World Production*	*Tonnes*	*Production level compared to 1951*	*Share of World Production*
1931	0.695	0.7	-	0.0	-	0.001	0.1	0.1%
1951	1.042	1.0	0.028	1.0	2.7%	0.005	1.0	0.5%
1961	1.468	1.4	0.034	1.2	2.3%	0.001	0.3	0.1%
1971	1.446	1.4	0.020	0.7	1.4%	0.001	0.3	0.1%
1981	1.283	1.2	0.018	0.6	1.4%	0.013	2.5	1.0%
1991	2.170	2.1	0.234	8.3	10.8%	0.028	5.4	1.3%
2001	2.533	2.4	0.281	10.0	11.1%	0.043	8.3	1.7%
2005	2.430	2.3	0.262	9.3	10.8%	0.041	7.9	1.7%

Table 6.2c: Nickel Mine Production: World, Chile and Australia (1931-2005)

Year	World		Australia			Chile		
	Tonnes	*Production level compared to 1951*	*Tonnes*	*Production level compared to 1951*	*Share of World Production*	*Tonnes*	*Production level compared to 1951*	*Share of World Production*
1931	68,487	0.4	137	-	0.2%	-	-	-
1951	167,000	1.0	-	-	0.0%	-	-	-
1961	444,769	2.7	-	-	0.0%	-	-	-
1971	773,899	4.6	43,338	-	5.6%	-	-	-
1981	884,737	5.3	90,243	-	10.2%	-	-	-
1991	985,361	5.9	68,975	-	7.0%	-	-	-
2001	1,280,591	7.7	204,895	-	16.0%	-	-	-
2005	1,448,996	8.7	185,471	-	12.8%	-	-	-

Table 6.2d: Zinc Mine Production: World, Chile and Australia (1943-2005)

Year	World		Australia			Chile		
	Tonnes	*Production level compared to 1951*	*Tonnes*	*Production level compared to 1951*	*Share of World Production*	*Tonnes*	*Production level compared to 1951*	*Share of World Production*
1943	2,018,000	0.9	143,278	0.7	7.1%	-	-	0.0%
1951	2,300,000	1.0	197,800	1.0	8.6%	-	-	0.0%
1961	4,204,250	1.8	382,587	1.9	9.1%	-	-	0.0%
1971	6,721,181	2.9	551,137	2.8	8.2%	-	-	0.0%
1981	5,848,200	2.5	520,490	2.6	8.9%	-	-	0.0%
1991	7,258,424	3.2	1,023,438	5.2	14.1%	29,034	-	0.4%
2001	9,119,732	4.0	1,513,876	7.7	16.6%	36,479	-	0.4%
2005	10,083,167	4.4	1,371,311	6.9	13.6%	30,250	-	0.3%

Table 6.2e: Silver Mine Production: World, Chile and Australia (1930-2005)

Year	**World**		**Australia**			**Chile**		
	Tonnes	*Production level compared to 1951*	*Tonnes*	*Production level compared to 1951*	*Share of World Production*	*Tonnes*	*Production level compared to 1951*	*Share of World Production*
1930	8,019	1.3	-	-	0.0%	24	0.8	0.3%
1951	6,180	1.0	334	1.0	5.4%	31	1.0	0.5%
1961	7,368	1.2	405	1.2	5.5%	66	2.1	0.9%
1971	9,171	1.5	679	2.0	7.4%	83	2.7	0.9%
1981	11,253	1.8	743	2.2	6.6%	360	11.7	3.2%
1991	15,672	2.5	1,175	3.5	7.5%	674	21.8	4.3%
2001	19,000	3.1	1,976	5.9	10.4%	1,349	43.7	7.1%
2005	20,411	3.3	2,408	7.2	11.8%	1,408	45.6	6.9%

Table 6.2f: Lead Mine Production: World, Chile and Australia (1929-2005)

Year	**World**		**Australia**			**Chile**		
	Tonnes	*Production level compared to 1951*	*Tonnes*	*Production level compared to 1951*	*Share of World Production*	*Tonnes*	*Production level compared to 1951*	*Share of World Production*
1929	1,786,178	0.9	180,404	0.8	10.1%	-	-	-
1951	1,916,545	1.0	228,069	1.0	11.9%	7,666	-	0.4%
1961	2,899,106	1.5	333,397	1.5	11.5%	2,899	-	0.1%
1971	4,125,854	2.2	490,977	2.2	11.9%	-	-	-
1981	3,355,800	1.8	389,273	1.7	11.6%	-	-	-
1991	3,314,000	1.7	579,950	2.5	17.5%	-	-	-
2001	3,099,540	1.6	759,387	3.3	24.5%	-	-	-
2005	3,336,479	1.7	767,390	3.4	23.0%	-	-	-

Table 6.2g: Bauxite Mine Production: World, Chile and Australia (1929-2005)

Year	**World**		**Australia**			**Chile**		
	Tonnes	*Production level compared to 1951*	*Tonnes*	*Production level compared to 1951*	*Share of World Production*	*Tonnes*	*Production level compared to 1951*	*Share of World Production*
1929	2,148,949	0.2	-	-	-	-	-	-
1951	10,781,854	1.0	-	-	-	-	-	-
1961	28,434,522	2.6	-	-	-	-	-	-
1971	60,176,941	5.6	12,336,273	-	20.5%	-	-	-
1981	85,541,000	7.9	25,576,759	-	29.9%	-	-	-
1991	107,916,000	10.0	40,468,500	-	37.5%	-	-	-
2001	140,215,886	13.0	53,842,900	-	38.4%	-	-	-
2005	176,101,013	16.3	59,874,344	-	34.0%	-	-	-

Source: Own elaboration based on data presented **in Appendix 2**.

6.2.2 The frequency of mining investment projects

As noted earlier in Chapter 3, investment projects generate a large part of the demand for KIMS, and hence shape the opportunities for growth, diversification and new entry to the industry by KIMS suppliers. They also open up significant learning opportunities for those firms – for example, training opportunities related to acquiring the capabilities to manage complex projects, and learning opportunities to build new capabilities and to test new innovations and technologies. Consequently – leaving aside the scale of those projects, the higher their frequency – the greater the potential for learning and innovation.

Table 6.3: Number of Mining Investment Projects in Chile and Australia
(At any stage of development: feasibility study and design or under construction)

	1986			1987			1988			1986-1988		
Mineral	*World*	*Chile*	*Australia*	*World*	*Chile*	*Australia*	*World*	*Chile*	*Australia*	*World*	*Chile*	*Australia*
Copper	**72**	**11**	3	**69**	**11**	**5**	**56**	**9**	**5**	**197**	**31**	**13**
Aluminium	55	0	6	43	0	5	42	0	5	140	0	16
Iron Ore	31	0	6	24	0	7	23	0	7	78	0	20
Lead and Zinc	39	0	4	34	0	8	32	0	7	105	0	19
Gold	115	1	21	143	4	16	124	2	13	382	7	50
Sub-Total Metallic	***312***	***12***	***40***	***313***	***15***	***41***	***277***	***11***	***37***	***902***	***38***	***118***
Share of World Total	*100%*	*3.80%*	*12.80%*	*100%*	*4.80%*	*13.10%*	*100%*	*4.00%*	*13.40%*	*100%*	*4.20%*	*13.10%*
Uranium	26	0	6	19	0	6	18	0	6	63	0	18
Precious metals	15	0	0	23	0	0	21	0	0	59	0	0
Light metals	13	2	1	28	1	6	28	1	6	69	4	13
Other metals	14	0	1	12	0	2	9	0	2	35	0	5
Oil sand/shale	26	0	2	11	0	1	10	0	1	47	0	4
Phosphate	26	1	0	28	0	0	28	0	0	82	1	0
Potash	10	0	0	9	0	0	9	0	0	28	0	0
Soda Ash	2	0	0	2	0	1	1	1	0	5	1	1
Industrial material	20	0	1	8	1	1	7	1	1	35	2	3
Sub Total Non-Metallic	***152***	***3***	***11***	***140***	***2***	***17***	***131***	***3***	***16***	***423***	***8***	***44***
Share of World Total	*100%*	*2.00%*	*7.20%*	*100%*	*1.40%*	*12.10%*	*100%*	*2.30%*	*12.20%*	*100%*	*1.80%*	*10.40%*
Total	***464***	***15***	***51***	***453***	***17***	***58***	***408***	***14***	***53***	***1,325***	***46***	***162***
Share of World Total	*100%*	*3.20%*	*11.00%*	*100%*	*3.80%*	*12.80%*	*100%*	*3.40%*	*13.00%*	*100%*	*3.50%*	*12.20%*

Source: Engineering and Mining Journal, 1985, 1986, 1987, 1988, 1989.

By drawing on data about major investment projects in the industry provided in the *Engineering and Mining Journal*, this section examines the frequency of such projects in Chile and Australia during key phases in the industry's expansion: the mid-1980s, and the 1990s. Taking account of 14 different minerals, Table 6.3 shows the number of investment projects in the world, Chile and Australia during the first of those periods when the Chilean industry was starting to grow at a higher pace. It indicates that over the three years the number of copper-related investment projects in Chile was substantially greater than in Australia – 31 and 13 respectively. However, if a wider range of important metals is taken into account, the situation was reversed: there were only 38 projects in Chile compared to 118 in Australia. That gap becomes even wider if investment projects in a range of non-metallic minerals are included. Over the three years 162 projects took place in Australia, while only 46 projects took place in Chile – about 3.5 times more projects in Australian than in Chile.

That pattern changed during the 1990s when Chilean mineral production experienced very significant expansion, mostly driven by copper-related investment. In fact, as Table 6.4 shows, over the last decade of the 20th century the number of copper-related projects in Chile was about six times greater than in Australia (69 compared to 11), and there was also a significant number of gold-related projects. As a consequence the total number of metallic mining investment projects was the same in both countries (83), even when taking into account the relatively large number of Australian projects involving metallic minerals other than copper (aluminium, iron ore, lead, zinc and gold).

Table 6.4: Number of Mining Investment Projects in Chile and Australia during the 1990s (Projects at any stage of development)

Mineral	Chile	Australia
Copper	69	11
Aluminium	0	8
Iron Ore	0	24
Lead and Zinc	0	16
Gold	14	24
Total	**83**	**83**

Source: E&MJ, 1987, 1988, 1989, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000.

Thus, taking account of the growth, scale and diversity of production, the experience of the two mining industries since the 1950s appears to have offered greater learning opportunities for KIMS suppliers in Australia than for those in Chile. Additionally, the timing of this broad difference seems to have been particularly important in influencing the potential for industry entry and learning by specialised KIMS suppliers in the two countries. With growth rates rising from the 1960s in Australia, and spanning a large range of mining sectors, the associated opportunities for industry entry, learning and innovation by Australian KIMS suppliers began to increase during the relatively early stages of the global rejuvenation of the mining industry and the associated stage of emergence and development of the specialised KIMs sector. In Chile on the other hand, growth that was primarily centred on copper mining was quite limited until the 1980s, and only accelerated significantly during the 1990s. By then, as explored later, several other factors were changing the conditions for entry, learning and innovation by Chilean KIMS suppliers.

However, this analysis of industry-level conditions that shaped opportunities for KIMS suppliers has so far considered only the domestic mining industries in the two countries. The next section brings into the picture the international operations of Australian and Chilean mining companies.

6.2.3 The internationalisation of Chilean and Australian mining companies

Over the last 50 years mining companies' activities have become increasingly international and, with respect to the development of opportunities for industry entry, learning and innovation by domestic KIMS suppliers, differences between countries in the internationalisation of their nationally based mining companies have been potentially important in two main ways:

- First, mining companies themselves may acquire and accumulate knowledge and experience about technologies and their application in diverse contexts, as well as knowledge about global problems and opportunities that stimulate awareness of both needs for innovation and possible directions for pursuing such innovation. Such knowledge and expertise may become available from those companies to specialised KIMS suppliers in numerous ways – via the creation of new spin-off KIMS firms based on knowledge assets initially accumulated by mining companies, by the migration of personnel to existing KIMS firms, or by the transfer of know-how in the course of interactions between mining companies and their suppliers.

- Second, there is considerable evidence that mining companies have played important roles in the internationalisation of domestic KIMS suppliers with which they have become familiar in the domestic context. They may 'pull' such suppliers with them when they move into international operations, providing encouragement and facilitations for their entry into international markets. The KIMS firms then learn directly for themselves in the new international contexts.

It is therefore a matter of considerable significance that Australian and Chilean mining companies show significant differences in the international scope of their mining activities over the last three or four decades.

As noted earlier, by the nationalisation of the mining industry in Chile, Codelco took over the major mines accounting for around 90 per cent of Chilean copper production. The extent of subsequent internationalisation of Codelco's activities therefore determined a very large part of the internationalisation of the whole industry. But Codelco's production operations have remained exclusively at the local level for the subsequent 30 years. Over the recent years another much smaller Chilean mining company – Antofagasta Minerals – has shown efforts towards international expansion. For instance, the company has acquired a copper mining property in Pakistan and is launching exploration projects in different countries in Latin America. However, this is a very recent trend that only started in 2006, and is far behind the international scope of mining companies from Australia, Canada and South Africa.

In Australia the first mining companies to expand their operations abroad were the 'junior' companies – small mining firms, mostly engaged in exploration activities and looking for new projects to sell on later to larger mining companies. These firms started actively seeking mineral deposits in foreign countries during the late 1970s and early 1980s. Largely because they were smaller firms with limited in-house KIMS capabilities, the mining juniors encouraged Australian KIMS suppliers to go abroad with them to carry out the feasibility studies and designs for the development of new investments.

Large firms then followed the Australian juniors in a very similar way. In particular, over the 1980s and 1990s BHP initiated a significant international expansion, and by 2006 the company had more than 100 operations in 25 countries worldwide. As with the juniors, but on a much larger scale, BHP-Billiton's internationalisation was followed by many of its suppliers.

Thus, the internationalisation of Australian mining companies played a major role in supporting the expansion of KIMS suppliers into activities in foreign countries. This enabled Australian KIMS suppliers to gain access to significant learning and innovation possibilities that were initially embodied in new investment projects and later in ongoing mining operations. The access to these overseas opportunities played a major role in extending the learning and innovation opportunities that had earlier been provided by the sequence of domestic mining booms initiated in Australia in the 1950s.

Summing up, with respect to the influence of the scale and growth of the mining industry on learning opportunities for KIMS suppliers, there were two kinds of difference between Chile and Australia. First, the growth of the domestic industries differed, with the acceleration of growth in Chile lagging behind that in Australia. This timing was probably a matter of considerable significance because the opportunities for Chilean KIMS suppliers opened up more significantly only as the emergence and development phase of the international KIMS supplier industry was, during the 1990s, passing into the stage of accelerating internationalisation. Second, the difference was then further reinforced because Australian mining companies were major players in that internationalisation of the mining industry, and this enhanced the learning and innovation opportunities for Australian KIMS suppliers. In contrast, the dominant domestic mining company in Chile made no effort to develop international activities, and hence played no role in helping local KIMS suppliers learn their way into the exploitation of international opportunities.

However, there was also a further effect of the difference between Chile and Australia. Along with the internationalisation of activities by mining companies and KIMS suppliers from other countries like the US and Canada, the internationalisation of the Australian firms had another type of negative effect on KIMS supplier development in other mining countries with lagging levels of KIMS capabilities. In particular, during the 1980s when the development level of the KIMS suppliers in Chile was much lower than in Australia, BHP’s investment in the country pulled along its Australian KIMS suppliers who then crowded out local KIMS suppliers.

6.3 The Complexity and Challenges Facing the Mining Industries

The potential for learning and innovation in KIMS suppliers – either directly through their own activities or indirectly via the learning and innovation of mining companies – is not shaped only by the scale and rate of growth of their domestic industries, and by their exposure to international mining activities. As outlined in the framework presented in Chapter 3, it is also shaped, or induced, by the kinds of challenge they face in those domestic and international contexts: the more complex and demanding those challenges the greater the potential, or inducement, for learning and innovation.

In principle, those challenges may take many forms and may arise in many ways, but this section focuses primarily on challenges related to technology and organisation, so leaving aside such issues as the pressures of competition. In principle also, those challenges may arise in connection with activities in both domestic and international activities, but the thesis focuses here on the former. These are particularly important, especially for emerging firms in a new specialised industry, such as the KIMS sector between the 1970s and early 1990s.

This section explores differences between Chile and Australia in the nature and timing of such challenges. It first outlines the conceptual framework within which different types of complexity and challenge, and their effects are reviewed. It then examines the contrasting experiences of Chile and Australia with respect to these issues. The contrasts are summarised the end of the chapter.

6.3.1 Challenges for learning and innovation

The complexities of mining activities and the challenges they pose for mining companies and their suppliers arise in two kinds of activity:

i. Activities in connection with major investment projects for new or expanded operations.

   As we have emphasised earlier in connection with the frequency of investment projects, typically these pose the greatest challenges as well as the greatest opportunities to learn about, develop and introduce new technologies and modes of organisation. Behind new projects, there are usually considerable exploration efforts, involving complex systems and methods to discover and survey deposits. In addition, finding ways to extract and process the ore in such projects may require significant innovation efforts depending on the complexities of the ore body.

ii. Activities in connection with maintaining on-going operations at a competitive level, achieving also environmental and social standards.

   Significant challenges also arise in connection with ongoing operations, and these may arise in every stage of the mining process from exploration, mining and ore extraction to metallurgical processing and waste treatment. They may be about such things as minimising energy and water requirements, modifying metallurgical processes to meet the complex features of ore deposits, improving the organisational arrangements for truck fleet maintenance in order to maximise truck's availability, optimising blast designs and procedures, or improving the environmental performance and safety of mining operations.

In a very general sense, investment and operational activities at every stage of the mining process have become increasingly challenging and complex over time. In most of the leading mining economies the period of ‘easy’ discoveries of ore deposits is over, more sophisticated exploration technologies are required, and these need to be tailored to different geological terrains (Upstill and Hall, 2006). Almost every operation has been heavily shaped by technological innovations, which have been a response to the significant complexities and difficulties of mining production. At this general level, these trends have posed similar challenges for all mining companies and KIMS suppliers more or less wherever they are located.

As stressed earlier, alongside these general trends associated with specific geo-science, mining and metallurgical technologies, the industry has also had to engage with the emergence over the last four or five decades of more disruptive and generally applicable new technologies such as biotechnology, electronics, automation, robotics, modelling, and ICTs in many different forms. These too have added to the complexity of mining activities and to the associated challenges facing the industry. Again, at a general level, these challenges and opportunities have been broadly similar for all mining companies and their KIMS suppliers.

Although these, at one level, are general pressures facing all companies and mining industries, there may be specific circumstances in particular situations that increase the intensity of the pressure to learn about and implement the use of novel technologies or to engage in developing more innovative technological and organisational solutions to mining problems and opportunities. For example, the trends in falling ore grades may be steeper in some locations than others, or they may induce technological responses in some locations sooner than in others, in either case pushing firms in those locations more intensively towards technological learning and innovation. The complexity of mineral formations in some situations may be greater than in others, so pushing firms that are particularly active in, or particularly dependent on, such locations towards the implementation or development of improved or novel exploration or mining technologies, or towards modified processing technologies.

In contrast, mining firms and their KIMS suppliers with activities concentrated in relatively ‘easy’ and ‘simple’ mining conditions may face more limited inducements to pursue learning and innovation. They may be more able to continue to operate effectively and profitability by using and introducing fairly established technological and organisational methods of production.

In addition, the likelihood that projects and operations of different difficulty or complexity of mining conditions might support learning and innovation efforts is shaped by the diversity of projects and operations of different levels of difficulty or complexity. This aspect of the diversity of projects and operations can play an important role in opening-up the opportunity to set up learning processes that lead to a gradual accumulation of capabilities. Indeed, a high degree of diversity of different level of complexity would enable to develop a long-term learning process based on participating in consecutive investments projects or operational challenges of cumulatively higher complexity. For instance, gold mining projects based on carbon-based extraction methods are usually far less complex than copper mining projects, which involves a much larger scale of production and more sophisticated processing technologies. KIMS supplier firms might start to cope with gold projects complexities, and by participating in several gold projects might foster its capabilities to gradually become more suitable for supplying services to mining projects of higher difficulty.

The analysis in this section uses a highly simplified framework for comparing the differences between Chile and Australia, taking into account the following scenarios about domestic mining conditions:

i. *Most of the projects and operations are ‘easy/simple’*: The country has mining projects and operations ranged within a narrow scope of low level complexity/difficulty;

ii. *Most of the projects and operations are ‘difficult/complex’*: The country has mining projects and operations within a narrow range of high level complexity/difficulty;

iii. *Projects and operations are spread across a wide range of distinctly discontinuous levels of complexity/difficulty*: The country has mining projects and operations ranged within a wide scope of different levels of complexity/difficulty and distributed discretely, that is, there is a significant difference in terms of difficulty between a project or operation at a given level of complexity/difficulty an the project or operation at the next level;

iv. *Projects and operations are spread across a wide range of continuously distributed levels of complexity/difficulty*: The country has mining projects and operations ranged within a wide scope of different levels of complexity/difficulty and distributed continuously, that is, there is a minor difference in terms of difficulty between a project or operation at a given level of complexity/difficulty an the project or operation at the next level.

These categories, of course, reflect merely static scenarios, but it is quite likely that the circumstances in a country's mining industry will change over time in ways that move around the four scenarios. The rest of this section of the thesis explores how the mining industries in Chile and Australia moved around these scenarios during the second half of the 20th century.

6.3.2 Contrasting complexity and challenges in Australia and Chile

From the 1950s through to the 1970s in Chile the industry operated large copper mines that had been considered complex projects when they had started up earlier in the 20th century. While little engineering was carried out in Chile and expatriate managers ran the mines, there were in any case only limited pressures to upgrade the long-established technology because, compared with other regions of global copper production, the industry in Chile was still operating profitably in an 'easy/simple' scenario of high grade ore. For instance, Table 6.4 shows that the average ore grade in Chilean copper mines in 1980 (1.7%) was 89 per cent higher than the world average (0.9%). Another perspective on the relatively simple nature of the technology at that time is provided by the industry's experience after nationalisation: following the departure of many experts and the sharp reduction of output, the previous level of production was recovered after only one year.

During the 1980s mining production showed some increase and this required elements of technology updating. For example, mining software packages were applied in mine planning processes, and some of the Chilean engineers that participated in this simple updating created one of the few domestic mining engineering consulting firms at that time. But despite this increase in the complexity of mining technology, the scenario still involved relatively high grade ore: although the difference between the grade of Chilean copper mine ore and the world average decreased by 1990, it remained 63 per cent higher. At the same time, compared with mining industries in advanced economies, Chilean mining had to face much more limited challenges in terms of the complexities of deep underground mining, automation and innovation to meet rising social and environmental standards. In other words the overall conditions facing the industry could be described as relatively ‘easy/simple’.

During the 1990s the very significant expansion of mining production radically changed that scenario. Highly challenging ‘complex/difficult’ projects called for an abrupt step of discontinuous change in technology and organisation. By 2000, Chilean copper mine ore grade advantage was significantly diminished (1%), only 11 per cent higher than the world average, and more complex mining technologies and operations began to be introduced. However the young Chilean KIMS firms were not able to deal with the challenges, not only technological but also organisational and financial. So, at this stage of rising internationalisation in the KIMS industry, it was primarily international suppliers who captured most of the more complex learning opportunities arising from these projects.

This pattern continued through the early 2000s. Mining conditions gradually became even more difficult and complex as the Chilean mining industry opened up a new phase of rapid growth and investment providing important learning and innovation opportunities. At the same time the Chilean ore grade continued to fall and, as indicated in Table 6.5, it was projected to fall to one of the lowest in the world (0.6%), 14 per cent lower than the world average. Other aspects of technological and operational complexity also increased sharply. For example, the world’s largest underground copper mine is in Chile, operating at very deep levels with complex rock mechanics conditions. The world’s largest fleet of 'giant' trucks is also in Chile, and this has opened important opportunities to enhance maintenance capabilities, and the industry has started to introduce robotic applications. This scenario of 'complex/difficult' conditions opened up important learning opportunities for KIMS suppliers, but only for those that already had high level capabilities – few of which were local Chilean firms.

In contrast, by the early 2000s the Australian mining sector had been moving through cumulatively rising levels of technological and organisational complexity for more than 50 years. These were much less centred specifically on the ore grade in copper mining as shown in Table 6.5 – partly because the regional average includes some non-Australian operations and, more importantly, because of the country's much greater diversity of mineral production. In contrast, however, the growth of the Australian industry involved not only the challenges of the greater diversity of minerals, but also greater pressures to develop solutions to meet rising social and environmental standards.

Table 6.5: Evolution of Copper Mines Ore Grade (Average %): 1980-2015

	Stages in the Development of the KIMS Sector			
	Gestation	*Emergence and Development*	*Internationalisation*	*Consolidation*
	On-going mines			**Investment projects**
	1980	**1990**	**2000**	**2007-2015**
Region/Country	**Ore grade (%)**	**Ore grade (%)**	**Ore grade (%)**	**Ore grade (%)**
Africa	1.4	1.3	1.2	1.8
America	0.8	0.8	0.9	0.6
Asia	0.5	0.9	1.0	0.7
Oceania/Australia	2.9	1.3	1.7	0.9
World	0.9	0.8	0.9	0.7
Chile	**1.7**	**1.3**	**1.0**	**0.6**

Source: Picozzi, 2007; and Morales, 2001.

Already in the 1950s and 1960s the rapidly expanding mining industry in Australia encountered new kinds of mining conditions calling for much more complex technological and organisational solutions than those being used in Chile. Then during the 1970s and into the 1980s continuing growth involved a widening diversity of minerals and there were different types of mining companies. This diversity and heterogeneity not only maintained a pipeline of projects in which existing KIMS capabilities could be employed, they opened unique challenges and new opportunities for the emerging KIMS sector at the early stages of the global industry's rejuvenation phase. In particular Australia pioneered the application of ICTs in several areas of the industry's activities, a phase of learning and innovation that was the source of the current position of international leadership held by several Australian mining software firms.

As the growth of the copper segment of the industry re-accelerated in Australia in the late 1980s, the industry encountered conditions of decreasing ore grades that stimulated further continuity in learning and innovation to develop higher productivity processes with rising rates of mineral recovery. These pressures, along with a greater diversity of mining conditions, increased learning and innovation opportunities again. Then with the growing internationalisation of the industry from the 1990s, the KIMS supplier industry that had by then been accumulating higher capabilities for a long period was able to respond to the challenges and exploit the opportunities.

In conclusion, in Chile over most of the period of KIMS sector development, the prevailing scenario involved relatively 'easy/simple' projects and operations that generated limited learning and innovation opportunities. During the 1990s this scenario changed abruptly into highly 'difficult/complex' projects and operations, opened up more challenging learning opportunities for KIMS suppliers that had already accumulated adequately high levels of capability, which was not the case with Chilean firms. In contrast in Australia, the prevailing scenario was of projects and operations of significant difficulty which evolved gradually into higher level of complexity. This scenario enabled the development of learning processes that led to a steady and continuing accumulation of capabilities.

6.4 The Structure and Organisation of the Mining Industry in Australia and Chile

The structure and organisation of the industry shape the opportunities to participate in learning and innovation possibilities that may be opened-up by the factors reviewed so far: (i) the scale and growth of mining and its internationalisation (Section 6.2) and; (ii) the complexity and challenges faced (Section 6.3). It might be the case that important learning and innovation possibilities are emerging in particular contexts, but participating and profiting from them might differ between national industries because of the differences in the sector's structure and organisation.

This section examines how these issues about industry organisation and structure have shaped the potential for learning and innovation in Chile and Australia. This is done in two steps:

- First, Section 6.4.1 reviews how aspects of the structure and organisation of mining companies have influenced KIMS learning and innovation in different ways in the two countries;
- Then Section 6.4.2 reviews selected features of the evolution of the structure and organisation of the KIMS sector and how these changes shaped effective learning and innovation opportunities.
-

6.4.1 The structure and organisation of mining companies

Three aspects of the organisation and structure of mining companies are examined in this section:

i. The broad type of activity undertaken by 'mining' companies;

ii. The extent of vertical integration among the larger companies; and

iii. The implications of mergers and acquisitions in the industry during the late 20th century.

i Broad Types of Mining Company

Mining companies are not a homogenous group, and three categories are commonly identified.

a. Producers of Minerals ('Mining Producers')

a1 ***Senior Multinational Corporations***: These are large global corporations that control several large scale mines and process plants located worldwide. These are multi-commodity and vertically integrated organisation such as BHP Billiton, Anglo-American and Rio Tinto. Besides having significant production and technological capabilities, these corporations have important financial capabilities.

a2 ***Medium sized mining companies***: These are companies that have few mines and are usually focused on the production of a small number of commodities. Additionally, these companies may have a lower degree of control of the whole mining process – from exploration, through mining and possessing – than senior corporations, since they might not manage the operations at each stage of the mining process. Generally these firms have two different origins: i) Seniors or long-term producers that have not been able to grow to became multinational firms; or ii) 'Expansionary' juniors (described below) that have managed to find a deposit, have developed and put it into production without losing control of the operation. Later on they may have used this start-up mine to finance further expansions.

b. Juniors

These are exploration companies with important geological and fund raising skills that do not have any mineral production. The value of Juniors depends on their capacity to increase the price of mineral deposits. They seek to attract investors to pursue further development of mining projects, which are subsequently sold on to a Mining Producer in one of the other two categories.

In general, the higher number of Juniors and Mining Producer companies the higher the learning and innovation possibilities. But the two types of company stimulate KIMS suppliers' learning and innovation in different ways. Juniors pursue new discoveries and Mineral Producers, especially Seniors, pursue development projects. In other words, Juniors sell potential mining projects and Mineral Producers sell minerals. This difference encourages learning and innovation in different ways. For instance, Juniors are usually keen to encourage and support small KIMS suppliers in developing technological adaptations that might make feasible the exploitation of deposits that were previously not viable. In contrast, senior mining companies in general prefer to hire ‘well known’ KIMS suppliers due to their internal risk management criteria and the requirements of their closely associated financial institutions. They may be less keen to try ‘new’ solutions developed by small KIMS suppliers that have not been tested before.

Historically, the number of Mining Producers and Juniors in Chile has been much lower than in Australia. In Chile there have been only a small number of Junior firms, and the few that exist, are mostly foreign companies from countries such as Canada and Australia that keep a close relationship with KIMS suppliers of their home country. In Chile, most of the exploration has been carried out by Mining Producers.

Up to the early 1970s the most important mining companies based in Chile, those that controlled the bulk of the Chilean mining activity, were mining companies from the US that played a passive role as supporters of local capability building. Most KIMS were sourced from US suppliers or provided by the mining companies’ internal units, which were also based in the US. The first important Chilean mining company (in terms of scale of production) was Codelco, which started up in the early 1970s. Codelco’s production requirements drove an important process of capability building at the local level, which comprised capability building within the corporation as well as in its external (local) suppliers.

In contrast, Australia has had a large number of both Juniors and Mining Producers. Australian Juniors have played an important role by supporting the adoption, adaptation and development of techniques that enabled (or made feasible) the exploitation of ore deposits with complex geological features. For instance, during the 1980s Juniors drove the development of several gold mining projects, which were analysed and designed by small and emerging KIMS suppliers, which adapted techniques used in foreign countries, such as South Africa, to Australian conditions. In addition, locally owned mining companies in Australia have played an important role over the entire 20th century. Mineral production was dominated during the first half of the 20th century by local firms such as BHP. In the 1960s a larger number of foreign companies started to arrive in Australian, but local mining companies remained important. By the 1980s, Australian KIMS suppliers provided their services to local as well as to foreign mining firms.

Table 6.6 illustrates the difference in terms of diversity and numbers of mining companies at the world level, and in Australia, Chile and Canada. The table is based on the number of firms participating in the local stock exchange. Chile has a much less developed local stock exchange than Canada and Australia, and because of that the comparison shown in the table might be biased against Chile. Nevertheless according to executives of mining companies the general pattern shown in the table is appropriate. Chile has had a much lower number and diversity of mining firms than Australia.

Table 6.6: Number of Mining Companies by Type/Size (2000s)

<table>
<tr><th rowspan="2"></th><th colspan="2">World (2006)</th><th rowspan="2">Number of Australian Companies* (2004)</th><th rowspan="2">Number of Chilean Companies* (2004)</th><th rowspan="2">Number of Canadian Companies (2002)</th></tr>
<tr><th>Number of Companies</th><th>Share of Market Capitalisation</th></tr>
<tr><td>Senior Corporations</td><td>149</td><td>80%</td><td rowspan="2">16</td><td rowspan="2">4</td><td>10</td></tr>
<tr><td>Intermediates Mining Firms</td><td>957</td><td>15%</td><td>31</td></tr>
<tr><td>Juniors and Explorers</td><td>3067</td><td>5%</td><td>266</td><td>1</td><td>1600</td></tr>
<tr><td colspan="6">* Number of firms with shares in the local Stock Exchange. It is assumed that junior are those firms that capitalised less than US$200 million (Definition of The Metals Economics Group, 2000)</td></tr>
</table>

Source: Based on MacDonald, 2002; Brett, 2006; Moscoso, 2006.

ii The Degree of Vertical Integration

Another important aspect of the organisation and structure of mining companies that has shaped KIMS learning opportunities is the degree of vertical integration (the degree to which products and services are supplied in-house). Before the 1970s, internal units of Mining Producer companies, or closely associated organisations, not only carried out exploration, mining and ore processing activities, but also provided a range of inputs of goods, equipments and services for those activities. For instance, the conceptual and basic engineering of investment projects was carried out mostly by mining companies' own engineering departments, with some external support from engineering and consultant services suppliers. In addition, large mining companies usually owned companies manufacturing various kinds of equipment and had internal units for undertaking the related operational functions. For example, they might own a drilling equipment manufacturer and also have an internal ‘drilling unit’.

These vertically integrated organisations were very important training centres. Junior engineers, geologists and metallurgists had the opportunity to rotate over different units and posts, interacting with experts of different fields, and learning how to integrate different areas of knowledge. They also had the opportunity to use expensive laboratories or even processing plants to try and test new technologies and adaptations. Later on, around the late-1970s and early-1980s many internal units supplying KIMS were divested. It was common to find that the experts that used to work at these units set-up small KIMS supplier firms, which over time accumulated higher capabilities and evolved into global players.

In Australia, up to around 1980, mining companies supported and encouraged training and experience acquisition of young engineers that were staff members, many of which later on started-up their own KIMS suppliers firm. Internal capabilities accumulated over several decades within mining companies (or in closely related organisations) were one of the main sources for the emergence of the Australian KIMS sector. Around the 1980s KIMS suppliers that were ‘spun out’ from mining companies kept supplying and interacting with their parent mining companies. They also started to supply and interact with other mining firms. As a consequence, learning and innovating by interacting closely with the activities of mining companies gradually became an external network phenomenon, led by organisations that has initially acquired the capabilities and learnt to interact when they were part of mining companies´ internal units.

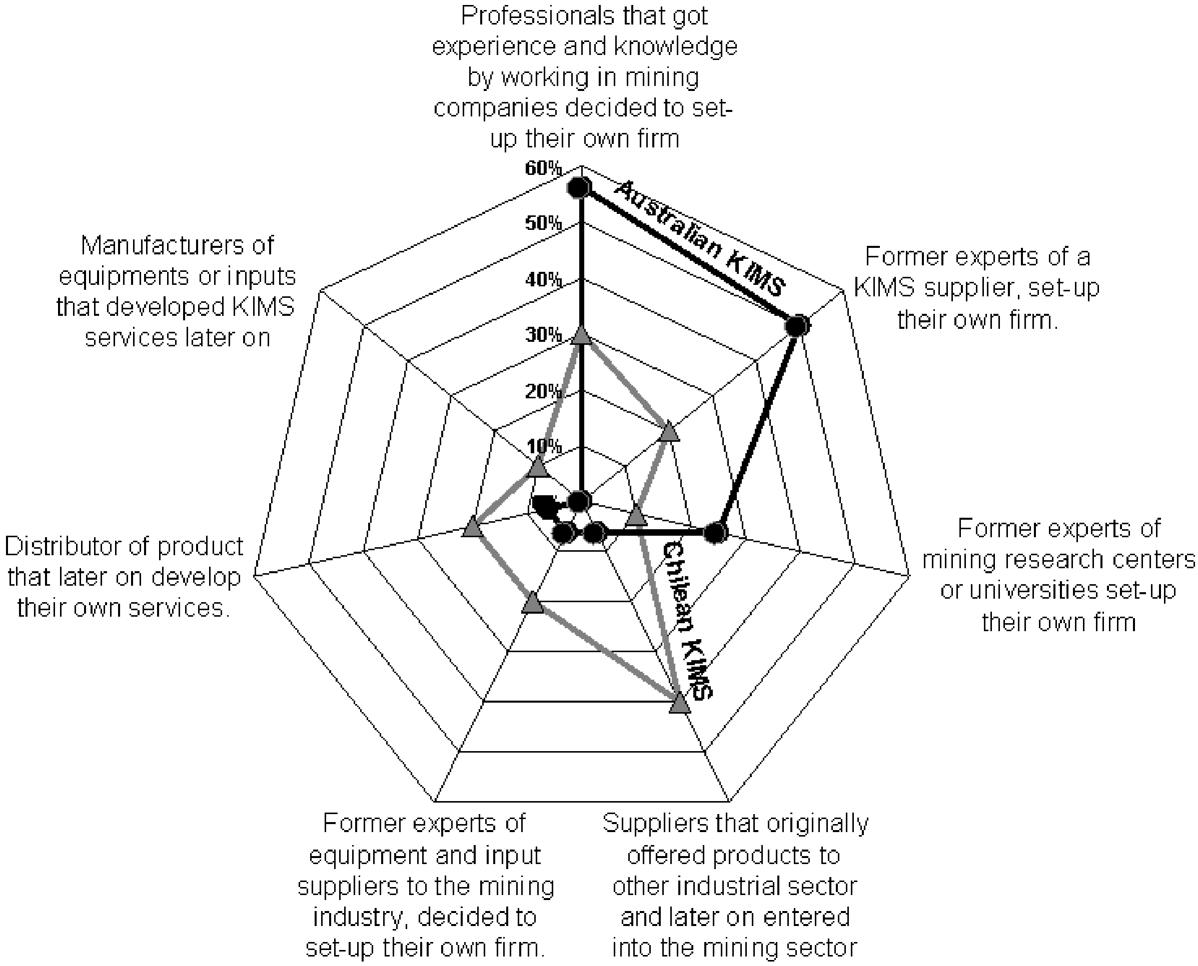
However, the process of vertical disintegration and outsourcing later showed a downside. Specifically, the experts’ training system that was set-up within mining companies was weakening and was not replaced (at least during the short and medium term) by any other system with the same level of effectiveness. Rotation opportunities for young experts diminished, along with the extent to which mining companies’ plants, laboratories and facilities were used as training and testing infrastructure. The consequences of this change were perceived much later, around the mid- and late-1990s, when the shortage of experts became a very important issue for the industry as a whole. By the late 1990s there were not enough graduated engineers, geologists and metallurgists to meet the growing demand for skilled labour, and junior engineers had less experience and 'practical' knowledge compared to the situation during the 1970s and before.

In Chile up to the 1970s based mining companies locally had a much weaker level of internal engineering and KIMS capabilities. Thus, mining companies' internal capabilities were not enough to provide the basis for the development of a wide KIMS sector with numerous suppliers as happened in Australia. However, during the late 1970s and 1980s KIMS capabilities within the nationalised mining company (Codelco) were created and enhanced driven by the requirements for keeping production running and growing. Also driven by Codelco's requirements, the capabilities of a small group of local engineering firms were enhanced.

During the 1980s Chilean mining companies – Codelco and the few large international mining companies with operations in Chile – started to outsource several services, including KIMS services. As consequence, new KIMS suppliers started-up, many were run by engineers that left mining companies (especially Codelco). However, because the period of accumulating in-house KIMS capabilities in mining companies was shorter (and the level of mining activity was lower) than in Australia, the base of accumulated capabilities in these companies contributed to a much weaker emergence of a Chilean KIMS sector. During the 1990s, the process of learning and innovation based on an external network was also developed in Chile. Learning and innovation based on interacting with mining companies was carried out by KIMS suppliers with higher capability levels; but in many cases these were international suppliers that crowded out local suppliers. In other words, in Chile as in Australia, mining companies played different roles over the different stages of KIMS sector development. In particular, during the Gestation stage, KIMS capabilities were accumulated within Codelco, but this stage was much shorter in Chile. Therefore, few KIMS suppliers emerged as a consequence of spinning off capabilities previously accumulated within Codelco. During the next stages Codelco supported learning and innovation as a user-producer interaction based process. However, in general Codelco supported international KIMS firms that arrived and set up operations in Chile rather than supporting local KIMS suppliers, which were fewer and more limited in terms of capabilities than in Australia. Thus, local KIMS suppliers in Chile had major difficulties to capture learning and innovation opportunities required to strengthening their development because opportunities provided by mining companies for the development of the KIMS sector were exploited by international suppliers.

The difference between Chile and Australia in terms of KIMS capabilities accumulated within mining companies as a source for the emergence of the KIMS sector is illustrated in Graph 6.1. This shows the difference in terms of the type of origin of the samples of Australian and Chilean KIMS suppliers studied (10 Chilean and 16 Australian KIMS – as explained in Chapter 4). The percentage figures refer to the proportion of the KIMS firms in each country. However, although three of the points on the graph refer to the pre-KIMS activities of the same firm, four of the points refer to the previous employment of key individual professionals who originally set up the KIMS firms. As there was often more than one of these per firm, frequently with differing previous experience, the proportions of firms in the categories sum to more than 100 per cent.

Graph 6.1: Origin of KIMS Suppliers in Chile and Australia



Source: Own survey.

It is striking that a large proportion of the Australian KIMS suppliers were started up by key founding individuals who had previous professional experience closely involved with mining or with the specifics of KIMS-related technologies: 56 per cent in mining companies, 50 per cent in other KIMS firms, and 25 per cent in mining-related research and academic centres. In contrast, the proportions for Chilean firms established by professionals with these backgrounds were only 30, 20 and 10 per cent. There was also a large difference in terms of the previous activities of the KIMS firms. Most Chilean KIMS suppliers (40 per cent) emerged from previous activities as suppliers to other industries of products that were unrelated to KIMS or even mining technologies. Only later did they migrate to the mining sector. That type of non-mining and non-KIMS origin accounted for only a very small number of Australian firms (5 per cent).

iii Mergers and Acquisitions

Over recent decades there has been an increase in the level of mergers and acquisitions by mining companies. Large senior mining companies have been acquiring medium size companies and merging or acquiring other large companies (Brett, 2006). This has been striking in the case of Australia – as illustrated by the case of BHP, the largest Australian mining company (Table 6.7).

Table 6.7: Mergers and Acquisitions by BHP

BHP's Key Acquisitions/Mergers
• 1935: BHP buys Australian Iron & Steel • 1969: BHP buys 50% of John Lysaght Australia • 1984: BHP buys Utah Group for US$2.4bn • 2001: BHP and Billiton merge in US$58bn deal • 2005: BHP Billiton buys WMC for US$9.2bn

As a consequence of such paths of merger and acquisition, the value chains governed by these large mining companies have became global in scope and have expanded to the production of multiple types of minerals. This has had a two-way effect on the learning and innovation opportunities facing KIMS suppliers to these companies.

On the one hand, having initially focused on their local markets, suppliers have gained access to these international value chains with opportunities to supply a larger number of mining operations and investment projects. For instance, many of BHP´s Australian KIMS suppliers got the chance to provide their services to other operations and projects in foreign countries and were encouraged to adapt their organisation to become globally organised firms. But in contrast to Australia, no Chilean mining company has pursued any important merger and acquisition process. In particular, Codelco – probably because of its significant copper ore reserve in Chile – has not been keen to expand by this strategy and its production has remained locally based.

On the other hand, as the large mining companies were transformed by mergers and acquisitions, they contributed to the internationalisation of KIMS suppliers located in the host countries of their mining activities around the world. KIMS teams in these countries that had the capabilities to achieve the required international standards gained access to markets throughout the global networks of the mining companies – both in those companies' home countries and in others. In principle, such KIMS teams, in Chile for instance, might be located either in locally owned Chilean KIMS firms or in the Chile-based subsidiaries of large multinational KIMS suppliers or even mining companies. In practice, however, they have consisted almost entirely of the latter. For example, during the mid-2000s teams of Chilean engineers have been engaged to work in BHP projects in Australia, including major upgrading and expansion projects at the company's huge multi-ore mining operation at Olympic Dam in South Australia. However, most of these teams have been parts of international mining companies or international engineering consulting firms located in Chile. The participation of locally owned Chilean KIMS firms has been small.

Thus, the phase of intensive merger and acquisition in the mining industry over recent decades has had contrasting effects on the opportunities for KIMS suppliers in Australia and Chile. In particular, the internationalisation of Chilean firms was facilitated neither by the outward global expansion of any Chilean mining company nor by the sourcing of services into the global networks of international companies that had subsidiaries in Chile. Only nuclei of KIMS capabilities within some of the Chilean subsidiaries of international companies were drawn into international markets.

6.4.2 The structure and organisation of KIMS suppliers

Four issues are addressed here. First, the general structure of the KIMS supplier sector at a global level is reviewed. Then, based on data from the survey of the sample of Chilean and Australian KIMS firms, three features of the KIMS supplier firms in Australia and Chile are examined: their degree of horizontal integration; their degree of specialisation; and the degree of internationalisation of their activities.

6.4.2.1 The structure of the global KIMS supplier industry

As noted earlier, before the 1970s, most of the services concerned with engineering, procurement and construction for mining investment projects were developed in-house by mining companies, with minor aspects of collaboration with external engineering and consultant firms. By the mid-2000s the roles had changed. But it is important to note that the emergence of external sourcing of a very large proportion of these services has come to shape an industry consisting of significantly different kinds of supplier firm. These can be grouped in three categories according to their size, but also their role in the industry:

i. *Large international engineering firms*: This group comprises a small group of very large international firms such as Bechtel, Fluor Daniels and Aker Kvaerner. Most of these firms started-up during the first half of the 20^{th} century and even before. They have worldwide operations, supply to different industrial sectors and their staff is about 20,000 and more. They usually participate in mining investment projects of over US$ 1 billon and carry out investment project engineering and the associated development or construction.

ii. *Medium size engineering firms*: These firms are focused on a narrower range of industries. Most of the firms in this group started up during the 1970s and 1980s; they have a global presence in mining projects worldwide and their staffs are between 300 and a few thousand people. They usually participate directly in mining investment projects that are in the range of US$ 100 to US$ 800 million. These firms frequently carry out investment project engineering as well as development or construction.

iii. *Small engineering and consultant firms*: These firms are much more focused in terms of the range of services offered and industry sector targeted. They started-up during the 1970s, 1980s and early 1990s, and have a staff of few hundred or less. Additionally, they usually participate directly in mining investment projects of US$ 10-100 million, and do not carry out development or construction activities.

This list of categories does not simply describe a structure of different kinds of company. To a large extent it also describes a hierarchical, or tiered, supply structure.

Over the recent decades the trend has been for mining companies to hire large international engineering services firms that offer a 'total solution'. Instead of dealing with large numbers of KIMS, contractors and others suppliers, mining companies prefer to work with only a few firms, which are also able to share the risk of the projects with them. Large engineering and project management firms, have the technical and financial capabilities to meet these preferences of the mining companies. They are global in scope, in much the same way as the senior mining companies. These large engineering services firms have therefore developed an increasingly important role in the selection of the products and services required in mining investment projects and operations. They are typically responsible for providing engineering services, and procurement and construction services. Mining companies usually retain an important role during the conceptual and basic engineering stages, working in close collaboration with engineering consultant firms.

However, the growth and consolidation of large multinational engineering companies, does not mean that there are no potential roles for direct supply from specialised KIMS consultant firms to mining companies (e.g. KIMS consultant services such as mine planning, blast engineering, tailing dam designing, and ore conveying engineering). These smaller and highly specialised firms keep playing an important role within the complex interaction and networking dynamic that characterises the current global mining sector. But mining companies' decision making about procurement has change as large engineering firms widen their influence. Highly specialised KIMS consultants need to build a close relationship with mining companies as well as with the large international engineering firms to have a better chance of participating in new projects or contracts. Specialised KIMS consultant learning and innovation possibilities is shaped by this 'dual user' relationship.

Most Chilean engineering firms are small consultant firms. Up to the year 2000 they were mostly focused on the local market. In Chile there are also medium size and large engineering firms, but all of these are international firms that set-up subsidiaries in Chile by hiring experts from Chilean suppliers and mining companies or by acquiring or merging with local firms.

In contrast, in Australia it is possible to find Australian engineering firms in all three interacting categories, and most have important international activities. This improves the opportunities for Australian engineering companies to participate in investment projects and operations on a global basis and therefore to exploit the potential for learning and innovation.

6.4.2.2 KIMS suppliers' horizontal integration

During the late 1970s and 1980s the KIMS supplier sector was characterised by a significant emergence of new small KIMS supplier firms, which maintained significant rates of growth over this period. This early growth was accompanied by substantial upgrading of the KIMS firms' technological capabilities. However, many of the new KIMS suppliers did not upgrade their managerial capabilities to match their growth, and continued using for many years managerial skills and systems that were similar to those they had used when they were still 'small groups of experts sharing an office'. During the 1980s and 1990s, these firms kept growing but many of them began to develop more robust management systems. Then in the late 1990s the KIMS sector started to consolidate and mergers and acquisitions became a more frequent means of growing and also learning.

Table 6.8 shows the evolution of mergers and acquisitions among the sample of surveyed Chilean and Australian KIMS firms. It shows the percentage of KIMS firms that merged with, acquired, or were acquired by other KIMS suppliers and how this processes have been evolving over the different stages in the development of the KIMS sector – Gestation, Emergence and Development, Internationalisation and Consolidation. In addition, the last column shows the share of KIMS firms that have merged, acquired or been acquired over the whole period since the emergence of the sector (1982-2005).

Although the frequency of mergers and acquisitions was broadly similar in the two countries during the late 1980s and 1990s (though slightly lower in Australia), their experiences diverged during the consolidation phase in the early 2000s when the frequency of merging and acquisition in Australia accelerated dramatically.

Table 6.8: Percentage KIMS Firms Merging with, Acquiring or been Acquired by Other KIMS

	Stages in the Development of the KIMS Sector					
	Gestation	*Emergence and Development*		*Internation-alisation*	*Consolidation*	
	Period					
	1981 and before	**1982-1987**	**1988-1993**	**1994-1999**	**2000-2005**	**1982-2005**
Chilean KIMS (N=10)	0%	0%	13%	22%	20%	50%
Australian KIMS (N=16)	0%	0%	10%	8%	60%	60%

Source: Own survey.

In the case of Australia, over recent years, mergers and acquisitions have been considered a key mechanism for acquiring the technological capabilities and production capacities required to keep growing. This mechanism operates on a worldwide basis. On the one hand, Australian KIMS firms acquire firms in other countries, and some of them have an active policy of worldwide screening to identify potential acquisitions. On the other hand, many Australian-owned KIMS suppliers – such as Geologics, Jaques, Tritronics, Aerodata, Prok, MIM Process Technologies, Warman, Elphinstone, ANI Arnall, Cram and Wheel & Rims Engineering (Roberts, 2006) – have been absorbed into bigger international corporations.

One implication is that space for the emergence and long term growth of new KIMS suppliers has shrunk. Specifically, if a new KIMS supplier emerges and shows important technological innovation potential; sooner or later it will be acquired by a larger KIMS firm. This change in the conditions facing new entrants to the industry can be illustrated particularly clearly in the case of firms supplying mining-related software (e.g. mine planning software, geological modelling software, project scheduling software, or mineral commercialisation software).

The production of engineering services and mining software are two closely related types of KIMS. This is because mining software is based on the integration of mining-specific knowledge (such as geology, geosciences, geo-statistics, mining engineering, and metallurgy) and computer science knowledge. Mining software and the related services are provided basically by three types of suppliers:

i. *Mining software firms*: These firms are mostly focused on the development of software, and their core business is in selling software products and in training engineers in consultants and mining companies how to use it. They keep a close relationship with mining companies, which request and support further developments.

ii. *Engineering consultant's internal units*: Leading engineering firms develop their own software to support their consultancy works. These firms usually have internal ICT units to upgrade their software and to integrate other commercially available software to their own platform. Besides offering KIMS consultancy they also might sell their own software if mining firms ask for it.

iii. *Large mining companies' internal units*: Some large mining companies have units dealing with geological modelling and mine planning that have very substantial software capabilities. However, most of these units have evolved into software users keeping strategic relationships with external software developers that have some elements of internal geological expertise that enable them to maintain a fertile interaction.

Australian KIMS suppliers started to use software-based tools in the 1970s and early 1980s. This 'early entry' provided an opportunity for some of them to become world leaders. As a result, by the early 2000s 60 per cent of the world's mining operations were using software developed by Australian firms (DTIR, 2002). But because of the consolidation of the global mining software sector, by 2006 only about 5-10 key players controlled the global market for mining software. Some of them are Australian mining software firms such as Maptek. But also some of the leading Australian mining software suppliers have been acquired by international corporations. For example, in 2006 Gemcom (from Canada) acquired Australia's second-biggest mine software group (Surpac Minex) and doubled its business size. However, in some cases such acquisitions have been associated with the continued innovative leadership of the acquired Australian firm for example, following its acquisition of Surpac Minex, Gemcom fostered the latter's R&D activity based in Australia in order to sustain the development of its key product lines.

However, while well established large firms may have expanded internationally or sustained a leading international role as subsidiaries of non Australian firms, the opportunities for entry and sustained long term growth by innovative new software suppliers have become much more constrained than they were in the 1970s and 1980s. For example, one of the Australian KIMS firms surveyed in the study was set-up in the late 1990s. It spent the first four years developing new geological software based on cutting edge data management technologies not previously used in geological software systems. After the development stage succeeded it was acquired by a much larger engineering consulting firm.

In contrast to the Australian KIMS firms, Chilean firms have taken a more passive approach with respect to looking for acquisitions or mergers as a basis for participating in the global consolidation of the KIMS sector. Consequently, acquisitions in Chile have usually taken place because foreign KIMS firms acquired Chilean ones. For instance, in Chile by 2006 international KIMS firms had acquired the three largest Chilean engineering firms (at least two of the acquirers were Australian KIMS).

In the specific case of the development of local mining software suppliers, there are no specialised Chilean suppliers. Local engineering consultants have their own ICT unit (or individual expert) for internal use, and they usually integrate commercially available software to upgrade their platforms. During the 1990s some Chilean KIMS consultants did develop 'original' software. However they ceased to maintain this effort and sold these developments to international software firms. By that stage in the development of the industry such Chilean

KIMS considered that the scale of resources required to develop and keep upgrading mining software was unaffordable or too risky.

Mining companies based in Chile (locally owned and international firms) have internal ICT units or experts. For example, since the 1980s Codelco has been using mining software tools, which incorporate their own minor adaptations. Also, over the 2000s mining companies have been developing software based applications in close collaboration with local universities, but locally owned suppliers have had no important participation in these developments.

6.4.2.3 KIMS suppliers' specialisation

The barriers to entry by new firms in the KIMS sector, and to sustained independent growth by existing smaller firms are not just related to overall scale. They are also influenced by the 'complexity' or diversity of production activities that are required to sustain a competitive presence in the industry. The survey of supplier firms in Australia and Chile therefore sought to identify the range of products and services they offered and the range of industries they supplied. The range of products and services was reflected in two ways: (i) by the range of KIMS categories[11] offered and (ii) by the range products that were not considered KIMS (contractor services, equipment, consumable inputs and others). The range of industries supplied was assessed simply in terms of whether the firms supplied exclusively to the mining industry or not.

The results are shown in Table 6.9a (the average number of KIMS categories supplied), Table 6.9b (the proportion of firms supplying non-KIMS products, and Table 6.9c (the proportion of firms exclusively supplying the mining sector rather than also other industries such as construction or defence).

[11] KIMS products were classified into 12 predefined categories, such as: (a) Mining engineering, (b) Processing and metallurgical engineering and design; (c) Tailing dam and waste rock system design and engineering. The full list is shown in Appendix 3, Table 11.

Table 6.9a: Average Number of KIMS Categories Offered

	Stages in the Development of the KIMS Sector				
	Gestation	*Emergence and Development*		*Internationa-lisation*	*Consolidation*
	Average Number of KIMS Categories Offered				
	1981 and before	**1982-1987**	**1988-1993**	**1994-1999**	**2000-2005**
Chilean KIMS Firm. Sample (N=10)	1.0	1.3	2.4	2.1	3.1
Australian KIMS Firm. Sample (N=16)	1.7	1.5	2.0	2.1	3.6

Table 6.9b: The Share of KIMS Suppliers that also Provide Non-KIMS Products

	Stages in the Development of the KIMS Sector				
	Gestation	*Emergence and Development*		*Internationa-lisation*	*Consolidation*
	Share of firms that also supply non-KIMS products				
	1981 and before	**1982-1987**	**1988-1993**	**1994-1999**	**2000-2005**
Chilean KIMS Firm Sample (N=10)	50%	50%	38%	44%	40%
Australian KIMS Firm Sample (N=16)	33%	25%	33%	45%	57%

Table 6.9c: Share of KIMS Firms that Supply Exclusively to the Mining Sector

	Stages in the Development of the KIMS Sector				
	Gestation	*Emergence and Development*		*Internationa-lisation*	*Consolidation*
	Share of Firms that supply exclusively to the Mining Industry				
	1981 and before	**1982-1987**	**1988-1993**	**1994-1999**	**2000-2005**
Chilean KIMS Firm Sample (N=10)	75%	67%	62%	33%	40%
Australian KIMS Firm. Sample (N=16)	75%	87%	78%	64%	54%

Source: Own survey.

The tables show that over time KIMS suppliers are becoming increasingly diversified organisations in all three senses – with one exception. The number of categories of KIMS products they offer has been growing; a significant proportion of KIMS suppliers also offer non-KIMS products and, although this has fallen a little in Chile, it has been rising particularly rapidly in Australia, mainly as the result of non-KIMS firms diversification into KIMS products. Finally a falling proportion of KIMS firms are specialised in supplying the mining industry, with a larger number diversifying into markets in other industries. In summary, these trends suggest that KIMS firms are becoming increasingly complex organisations. It seems likely that this adds to the barriers for the emergence and long-term growth of new small KIMS firms.

6.4.2.4 The International Activities of KIMS Suppliers

As mentioned in earlier in Chapter 5 and in Section 6.4.2.1, globalisation has shaped the level of learning and innovation possibilities that are open to KIMS suppliers. This has been evident since at least the 1970s as KIMS suppliers became increasingly international and used learning and innovation opportunities opened-up in foreign countries to upgrade and improve their capabilities. However, the degree of internationalisation of KIMS suppliers differs between countries, and in principle such differences between Chilean and Australian firms would contribute to difference in their learning and capability development.

But it is difficult to assess the various ways in which suppliers can engage in overseas activities. In the most clear-cut way, they can export services. But they may also have overseas operations undertaken by subsidiary companies located overseas, and they may even supply services to the overseas activities of mining companies, but via domestic transactions with those companies that are not reported as exports. Published information is not available about these forms of involvement in international projects by KIMS suppliers in Australia and Chile, and the research therefore relied mainly on the surveys of KIMS suppliers in Chile and Australia to illuminate the issue. It sought information about only two aspects of the internationalisation of the firms: their exports and the extent to which they had offices located in other countries. This was used to construct two variables as partial indicators of the broader spectrum of exposure to international learning opportunities.

i. Export intensity (the ratio of exports as a proportion of total sales);

ii. The proportion of Chilean and Australian firms with offices in ‘non-domestic’ regions.

Table 6.10 shows the export intensity of Chilean and Australian KIMS suppliers over four years – 1975, 1985, 1995 and 2005 which represents different points to cover the entire period of KIMS sector development. Actually 1975 represents the last part in the Gestation Stage; 1985 represents the last part in the Emergence and Development Stage; 1995 represents a mid-point in the

Internationalisation Stage; and 2005 represents the early part in the Consolidation Stage.

Both groups of suppliers, Chilean and Australian, have been increasing their exports over the last 20 years and in particular since the mid-1990s. However, since the 1990s the level of exports of Australian KIMS firms' has been growing much more rapidly than that of Chilean suppliers and their level of export-intensity was approximately three times higher in 2005.

Table 6.10: The Export Intensity of Leading KIMS Suppliers: 1975-2005

	Part in the Stages in the Development of the KIMS Sector			
	Last Part in the Gestation Stage	*Last Part in the Emergence and Development Stage*	*Mid-point in the Internationalisation Stage*	*Early Part in the Consolidation Stage*
	Year			
	1975	**1985**	**1995**	**2005**
	Average Export Intensity (% Sales)	**Average Export Intensity (% Sales)**	**Average Export Intensity (% Sales)**	**Average Export Intensity (% Sales)**
Sample of Chilean KIMS Suppliers Firms (N=10)	0 %	0%	13 %	17 %
Sample of Australian KIMS Suppliers Firms (N=16)	0 %	0%	10 %	48 %

Source: Own survey.

Other sources show similar differences between Chilean and Australian KIMS suppliers' internationalisation level. For instance, Lagos, *et al*. (2007) shows that in 2006, 26 per cent of the suppliers to the mining industry based in Chile exported. On the other hand, in 2004 74 per cent of the suppliers to the mining industry based in Australia exported (Tedesco and Curtotti, 2005).

Furthermore, at the time of the interviews (2006), most of the Australian KIMS firms expected that their international business would keep growing at a much faster pace than their purely domestic activities. Consequently, their investments and broader business strategies were in line with this trend. In contrast, up to 2006 most of the Chilean KIMS sample did not show a proactive commitment to international growth at even a similar rate to their local activities. Instead, exporting has frequently been a relatively passive response to requests, not a reflection of deliberate strategy and proactive effort.

Table 6.11 presents information about the location of the surveyed firms' offices in five geographical regions: Latin America, North America, Africa, Australasia and Europe. The information is organised with respect to the last two stages in the development of the KIMS sector – (i) 1995-1999, the second half of the stage of internationalisation that had started around the late 1980s, and (ii) 2001-2005, early years of the consolidation stage that has continued since then. The table shows that the Australian KIMS suppliers demonstrated two kinds of difference from their Chilean equivalents.

First, by the end of the internationalisation stage of the global industry the international spread of their offices was substantial in two senses: (i) the geographical scope of their non-domestic offices extended into all five of the regions covered, and (ii) the proportions of the sample of firms with such non-domestic offices were relatively high (between 30% and 50%) in all but one of the regions. In contrast, Chilean KIMS suppliers had offices in only two of the regions – Latin America (outside Chile) and North America, though relatively large proportions of the firms were involved in both regions.

Second, in the subsequent period the Australian firms further expanded their presence in all but one of the regions. This was so even in regions where they already had a substantial presence (Latin America, Africa and Australasia), but it was particularly striking in the North American region where their presence had been more limited in the earlier period. In contrast, the Chilean KIMS firms barely extended the geographical range of their international offices – only entering marginally into Europe, but not at all into the two other regions (Africa and Australasia) where they had held no presence in the earlier period. Nor did the Chilean firms expand their presence in the regions where they had already been established – Latin America and North America.

Thus, by the time of the phase of general internationalisation of the global KIMS sector from around the mid-1990s, Australian firms were among the leaders and established a substantial global presence across most regions. In contrast, Chilean KIMS firms had an important international presence only at their 'local' regional level in Latin America.

Table 6.11: The Non-domestic Locations of KIMS Suppliers' Offices

.	Part of the Stages in the Development of the KIMS Sector	
	2nd half of the Internationalisation Stage	*Early Consolidation Stage*
	Period	
	1995-1999	**2001-2005**
	Share of KIMS Firms With Offices in Latin America (Offices in Chile are excluded for the sample of Chilean Firms)	
Sample of Chilean KIMS Suppliers Firms (N=10)	56%	50%
Sample of Australian KIMS Suppliers Firms (N=16)	36%	47%
	Share of KIMS Firms With Offices in North America	
Sample of Chilean KIMS Suppliers Firms (N=10)	11%	10%
Sample of Australian KIMS Suppliers Firms (N=16)	42%	43%
	Share of KIMS Firms With Offices in Africa	
Sample of Chilean KIMS Suppliers Firms (N=10)	0%	0%
Sample of Australian KIMS Suppliers Firms (N=16)	42%	50%
	Share of KIMS Firms With Offices in Australasia (Offices in Australia are excluded for the sample of Australian Firms)	
Sample of Chilean KIMS Suppliers Firms (N=10)	0%	0%
Sample of Australian KIMS Suppliers Firms (N=16)	50%	60%
	Share of KIMS Firms With Offices in Europe	
Sample of Chilean KIMS Suppliers Firms (N=10)	0%	10%
Sample of Australian KIMS Suppliers Firms (N=16)	17%	40%

Source: Own survey.

6.5 Overview of the Potential for Learning and Innovation in the Chilean and Australian KIMS Sectors

In Chapter 3 it was argued that the potential for learning and innovation in the KIMS sector since its early gestation in the middle decades of the last century has been shaped by three key industry-level factors:

i. The scale and growth rate of mining production, primarily by domestic mining companies, both in the domestic and international industries;

ii. The complexity and challenges faced in achieving that growth; and

iii. Selected aspects of the industry's structure and organisation.

This chapter has analysed how these three factors have evolved to shape this potential in the Chilean and Australian KIMS sector over the second half of the 20th century. The analysis has been based on secondary data and on the interview-based survey of a sample of KIMS suppliers in Chile and Australia, firms which were considered to be leading KIMS firms by their peers and by executives of mining companies.

i Scale and growth

Table 6.12 below summarises the main features of the scale and growth of the mining industry at the global level and in the particular cases of Chile and Australia over the last five decades. At the global level, these features of the industry generated a high potential for learning and innovation in the KIMS supplier sector through all four stages of its development. During the initial two stages this was driven by the mining boom generated by demand for minerals for the ‘reconstruction’ of Europe and the emergence of Asian economies such as Japan. Later the boom was driven by the demand for minerals in China, India and other Asian economies. In the case of Australia, the potential for learning and innovation has matched this global pattern and has been very high through all the stages. Australia has kept a very high mineral production growth rate, with a high frequency of mining investment projects, becoming a major player in the production of a wide range of minerals. In addition, the Australian mining industry has become a globally organised industry, which made the potential for KIMS-related learning and innovation even larger.

In contrast, although Chile played an important role as a major copper producer over all the stages, its growth rate, and hence the frequency of investment projects, was relatively low up to the late 1980s. The industry therefore generated much more limited opportunities for KIMS-related learning and innovation over the first two stages of KIMS sector development – the key phase of change associated with the rejuvenation of the industry. The growth rate accelerated from the late 1980s, but this was just at the stage that the global KIMS sector entered the phases of internationalisation and later consolidation, while Codelco confined its activities to the domestic mining industry.

Table 6.12: Evolution of the scale and growth rate of mining production activity level

	Key features		
Stages in KIMS Sector Development	**International KIMS Sector**	**Australian KIMS Sector**	**Chilean KIMS Sector**
Gestation. (around 1940s to 1970s)	World mineral production growth rate is increasing significantly. For many minerals the growth rate is three times higher than in the previous four decades.	Australian mining output grows at a very significant rate – much higher that for world mineral production. Australia becomes a major producer of a wide range of minerals.	Chile continues as a major producer of copper. But its growth rate is below the world rate and its share of world copper production falls.
Emergence and Development (mid-1970s to early 1990s)	World mineral production output maintains the growth rate of the previous stage.	Australia strengthens its position as a major producer of a wide range of minerals. It maintains the growth rate of previous stage	Chilean mineral production remains focused on copper. Over the second part of this stage copper output growth rate increases and by the early 1990s accounts for 20% of world copper production.
Internationalisation (late 1980s to early 2000s)	World mineral production maintains the growth rate of the previous stage, and this rises even higher over the later part of the stage. Large mining companies develop worldwide mining operations.	Australia maintains mineral production growth rate of previous stage. Australian mining companies spread their operations worldwide.	Chilean production of copper grows at a very significant rate – with a high frequency of investment projects. By 2000 Chile is the largest copper producer (35% of world output) and state owned Codelco is the world's largest copper company. Its production is only locally based in Chile
Consolidation (late 1990s and continuing)	World mineral production again maintains the growth rate of the later part of the previous stage. Large mining companies consolidate as major producers with globally organised production systems.	Australia maintains a very high mineral production growth rate. Australian mining companies consolidate as major, globally organised producers.	Chile maintains its share of world cooper production (around 35%). International mining companies achieve a significant share of Chilean production. Codelco remains locally based.

Source: Own survey.

ii The complexity and challenges facing mining production

Table 6.13 summarises the contrast between Australia and Chile giving some examples.

Table 6.13: Evolution of the Complexity and Challenges of Mining Production Activity Level

	Key features regarding complexity and challenges of the mining production level and the impact in the potential for learning and innovation	
Stages in KIMS Sector Development	**Australian KIMS Sector**	**Chilean KIMS Sector**
Gestation (around 1940s to 1970s)	Mineral deposits were thought exhausted. This triggers learning efforts regarding exploration. Later on it was required to upgrade mining and processing technologies.	Copper deposits were large and with good ore quality (high grade). Significant improvements were not necessary to keep running the operations.
Emergence and Development (mid-1970s to early 1990s)	Minerals prices decline fosters learning and innovation, including new organisational changes.	To keep running the mining industry after nationalisation required capability as advanced user only
Internationalisation (late 1980s to early 2000s)	Higher environmental and health standards require cleaner and safer technologies.	Major production growth based on large and complex projects requires high level KIMS capabilities
Consolidation (late 1990s and continuing)	Shortages of water, energy, human capital and equipments are a key learning and innovation driving force.	Shortages of water, energy, human capital and equipment are a key learning and innovation driving force.

Source: Own survey.

Australia has shown at least since the 1960s a steady growth in terms of the complexity and challenges faced in the national and international growth of its mining industry. This has constantly pushed firms to maintain their learning and innovation efforts. In Australia, over every stage there were important challenges, which helped to keep a high level of learning and innovation efforts.

In contrast in Chile mining activity has gradually increased the complexity of the challenges that should be addressed to keep running profitably and increasing the production. During the initial stages up to the 1990s important learning and innovation efforts were not required to run a profitable activity. However that changed, during the 1990s mining production increased dramatically, generating learning opportunities and challenges that in the short term were beyond the capabilities of Chilean KIMS suppliers.

iii The structure and organisation of mining industry and KIMS supplier sectors

The structure and organisation of both the mining industry and the KIMS sector shaped the learning and innovation opportunities for KIMS suppliers, and consequently both were studied in this research. The structure and organisation of the mining industry has been analysed by focussing on three main features: (i) The general types of mining companies, and the implications of greater diversity for higher learning and innovation opportunities; (ii) the degree of vertical integration, and the extent to which vertically integrated organisation played a role as incubators and accumulators of KIMS capabilities; and (iii) mergers and acquisitions, and their role as opening learning and innovation opportunities by enlarging the geographical scope of the value chains they govern.

The structure and organisation of the KIMS supplier sector has been analysed by focusing on the following main features:

(i) Horizontal integration and the way larger KIMS firms lead to a more consolidated industry of big players that create higher barriers to entry;

(ii) the changing degree of KIMS specialisation, which has been transforming the sector into more diversified and complex organisations, generating additional barriers to entry and also more diverse learning opportunities; and

(iii) the degree of internationalisation of KIMS activities, represented by KIMS export intensity and the proportion of offices in 'non-domestic' regions, which play the role of maintaining a high exposure to new and diverse challenges.

Table 6.14: Changes in structure and organisation of mining industry and KIMS supplier sector

Stages in KIMS Sector Development	Key features regarding Industry's structure and organisation and the impact in the potential for learning and innovation	
Gestation (around 1940s to 1970s)	**Australian Mining Industry**	**Chilean Mining Industry**
	An ample range of mining companies have important in-house KIMS capabilities. Companies are "laboratories" and key reservoir supporting KIMS capabilities accumulation.	Production dominated by copper carried out by a reduced number of international mining companies focusing in production. There is not encouragement to accumulate higher level of KIMS capabilities.
	Australian KIMS Sector	**Chilean KIMS Sector**
	KIMS are part of mining companies, which are vertically integrated. There is a rich interaction between KIMS units and other internal units	Mining companies have low level of KIMS capabilities at the local level, there is a limited KIMS incubator effect.
Emergence and Development (mid-1970s to early 1980s)	**Australian Mining Industry**	**Chilean Mining Industry**
	An ample range of mining companies in terms of size and minerals exploited, opens up high diversity of challenges and learning opportunities	A small number large mining companies, mostly copper producers, generates low diversity of challenges and learning opportunities
	Australian KIMS Sector	**Chilean KIMS Sector**
	Vertical disintegration of mining companies leads to emergence of KIMS that spin-out of them.	Vertical disintegration of mining companies' leads to a small number of KIMS spun-out.
Internationa-lisation (late 1980s to late 1990s)	**Australian Mining Industry**	**Chilean Mining Industry**
	Internationalisation of mining companies helps internationalisation of KIMS suppliers.	No local mining company goes abroad.
	Australian KIMS Sector	**Chilean KIMS Sector**
	Australian KIMS firms participate in projects and operations at international level. The scope of Australian KIMS potential for learning and innovation is world mining industry.	Few Chilean KIMS firms are able to participate in projects and operations at international level. Additionally, international KIMS is crowding out local suppliers, limiting them from exploiting the local potential for learning.
Consolidation (early 2000s and continuing)	**Australian Mining Industry**	**Chilean Mining Industry**
	M&A of large mining companies opens up access to new operation and projects worldwide for KIMS that are part of their network of suppliers.	Local mining companies almost do not acquire assets in non-domestic market.
	Australian KIMS Sector	**Chilean KIMS Sector**
	Australian KIMS firms have acquired other suppliers or merged consolidating their international position. They are complex organisations that offer a wider range or product and serve several industries	KIMS experts participate at international level as employees of multinational mining companies and international KIMS suppliers. Chilean KIMS firms that were acquired by international KIMS, get access to wider scope of potential for learning and innovation. Locally owned KIMS supplies have to deal with first tier international KIMS to exploit the potential for learning and innovation.

Source: Own survey.

Table 6.14 summarises the evolution of the sector structure and organisation of mining companies and KIMS suppliers focusing on the most relevant features over the KIMS development stages in Chile and Australia.

The opportunities and barriers to participate or use the potential for learning and innovation derived from the changes in the structure and organisation of mining industry and KIMS sector have been evolving.

On the one hand Australia has a large and diverse mining industry, which comprises junior mining companies, medium size specialised mineral producer and very large multinational Mining Corporation. This diversity provides a wide range of challenges that enable the development of long term learning processes by tackling successive challenges of increasing complexity. Additionally, Australian mining companies at the early stages of KIMS development worked as incubator of KIMS capabilities and later on supported KIMS sector internationalisation. On the other hand, Chile has a fairly simple mining industry in term of the diversity of mining companies. Production is highly based on copper and carried out mostly by large mining companies. Additionally, Chilean mining companies at early stages (principally US companies, which controlled Chilean copper production) played a very poor role as incubators of KIMS capabilities, which later on led to a meagre emergence of KIMS suppliers spun-out from mining firms.

Chile and Australia represent also contrasting experiences regarding the KIMS sector structure and organisation and the related learning opportunities. In Australia, at the early stage of KIMS development the significant emergence of new and agile KIMS suppliers spun out from mining firms, were able to capture the significant learning and innovation opportunities that came along with Australian mining production boom. Later on KIMS internationalisation maintained an active learning process by capturing the opportunities that were emerging abroad. Additionally, during the early 2000s larger KIMS suppliers gained higher control of the KIMS value chain. This was a necessary basis for overcoming obstacles to participation in an industry that was rapidly consolidating at the global level. In contrast, the structure and organisation of the Chilean KIMS sector opened up less learning opportunities. It went through a very weak gestation stage and few new KIMS suppliers emerged as spin-offs from mining firms. Hence, the significant learning and innovation opportunities that accompanied the production growth of the 1990s were captured by international KIMS suppliers with higher capabilities. In addition, during the 2000s Chile had not developed large KIMS suppliers, and the Chilean KIMS sector therefore had greater difficulties in overcoming barriers to participation in the globally consolidating industry.

CHAPTER 7

EXPLOITING THE POTENTIAL FOR KIMS-RELATED LEARNING AND INNOVATION IN CHILE AND AUSTRALIA

7.1 Introduction

The previous chapter examined how industry-level factors evolved in Chile and Australia to shape the potential for KIMS-related learning and innovation. It indicated that the evolution of these industry-level factors was more favourable in Australia than in Chile. Consequently, Australian KIMS suppliers faced almost constantly between the 1950s and early 2000s a higher potential for learning and innovation than their Chilean equivalents. However, as outlined in Chapter 3 (Section 3.6), effective exploitation of a high potential for learning and innovation cannot be taken for granted. Positive influences from industry level factors are important, but they are not a sufficient condition for developing an internationally competitive KIMS capability. Positive learning and innovation efforts are also necessary.

This chapter examines the evolution of Chilean and Australian KIMS suppliers' effort to exploit the potential for learning and innovation over the different stages of KIMS sector development. This is based primarily on the interviews carried out with the KIMS suppliers (10 Chilean and 16 Australian).

More specifically, this chapter analyses the evolution of the following aspects of firm- level learning and innovation efforts (as outlined in Section 3.6):

i. The career paths and associated training efforts associated with the development of individual KIMS experts (Section 7.2);

ii. Efforts made by firms to enhance their innovation and engineering capabilities (Section 7.3);

iii. The learning opportunities arising from interactions between KIMS suppliers and mining companies (Section 7.4).

Finally, Section 7.5 summarises how KIMS firms' learning and innovation efforts have evolved in the two countries over the different stages of KIMS sector development.

7.2 The Career Paths and Training Efforts of KIMS Experts

Chapter 3 outlined how knowledge intensive firms rely heavily on the knowledge and skills of individual experts. This was elaborated during informal discussions with leading KIMS experts (four Chilean and six Australian). They emphasised that becoming what they described as "a full-range and experienced engineer" or KIMS consultant requires not only high technical skills but also the systematic building up of a deep base of practical experience in using them. Their own experience showed that this learning process can take around 20 years over which experts need to maintain a high level of exposure to training, new techniques and innovative technologies, as well as innovative activities and engagement with real problems of increasing complexity.

Consequently, differences in the way KIMS professionals acquire and keep upgrading their knowledge and enhancing their experience has an important influence in shaping KIMS firms' capacities to exploit the potential for learning and innovation. This chapter examines such differences between the two countries. The Australian experience is described first, then the Chilean experience is analysed. Finally there is a summary that contrasts the career development paths of KIMS experts in both countries.

7.2.1 The career paths and learning efforts of Australian KIMS experts

In Australia during the period 1950-1980 several universities offered programmes in geology, geosciences, mining engineering and other engineering programmes related to mining activities. Most of these programmes were part-time, enabling students to gain practical experience in mining companies which also enabled young professionals to try new technologies, such as ICTs, to solve or to analyse practical problems in the field, either in mining operations or during the development of mining investment projects.

After obtaining a university degree, training and structured experience accumulation processes continued as integral components of mining companies' graduate programmes within which young engineers were mentored by experienced professionals. Mining companies had very strong engineering capabilities in several areas, and young graduate engineers rotated and gained experience in different areas, learning to integrate different disciplines in order to address practical challenges arising in mining projects and operations. They were also encouraged to experiment and try different technologies using the mining companies' laboratories and research facilities, as well as real investment projects and operations. Moreover, because the rapid growth of mining production in Australia went along with an increasing complexity of mining investment projects, young engineers were involved in the design and development of difficult and technically challenging projects very early in their careers. Thus, during this period, mining companies were excellent training places for future KIMS consultants, many of whom later set-up their own KIMS consulting firms.

Subsequently however, during the 1980s, there was a gradual reduction in the use of such career development systems that integrated practical problem solving, formal training, and exposure to learning and innovation experiences. Mining companies stopped supporting universities, which in turn discontinued part-time programmes. Thus, education schemes based on a mutual enhancement between education in academia and the acquisition of practical skills and experience at mines or plants were discontinued. In addition graduate programmes at mining companies were weakened. As a result, the process of training 'full- range' engineers and experts was significantly weakened.

The consequences of this were not noticed immediately and over several years the industry was not aware of the 'disassembling' of the typical KIMS expert training and experience acquiring process. It was only around the late-1990s that the Australian KIMS sector and the whole mining industry became aware of the lack of experts and of suitable training processes – a problem that became more evident as senior experts started to retire and there were not enough replacement available.

In addition, after the 1980s mining-related studies were not attracting as many students as they used to. The image of mining as an environmentally unfriendly activity, combined with the reluctance of young professionals to work in isolated places where mining operations are usually located, shifted students' preferences away from pursuing mining-related degrees.

By around 2000 Australian KIMS suppliers and mining companies started to try and recreate career paths and training sequences similar to those that were in place in the 1970s. Engineering and KIMS consultants were setting up their own training programmes based on mentoring activities aiming to develop full-range engineers. KIMS firms started to use investment projects and operations to train young engineers to carry out different tasks while senior experts again acted as mentors to guide them. Some consultant firms used sequences of increasingly complex investment projects as a backbone for this type of training process – small investment projects were used as a basis for learning to integrate different disciplines and aspects of a project, and larger investment projects were used to deepen specific knowledge and experience of dealing with higher levels of complexity.

Around the 2000s, mining companies also reacted to the shortage of full-range engineers and KIMS experts, starting to strengthen their expert training schemes. For instance, BHP Billiton launched in 2007 a professional graduate development programme based on a two-year intensive training scheme that includes leadership development, technical training and experience, coaching and mentoring, and systematic rotations through different areas (source: www.bhpbilliton.com).

Over the 2000s KIMS expert training efforts have gradually gained more importance. However the level of effort has remained low compared to the 1970s, in particular regarding the linkage between formal training and practical problem-solving. For instance, during the 1970s companies started to interact with engineering students during their time at university, some years before they graduated. But during the early 2000s the interaction with young engineers started mostly after they graduated. Also, training resources (such as laboratories and senior mentors) in mining companies available for young engineers were much higher during the 1970s than during the 2000s.

7.2.2 The career paths and learning efforts of Chilean KIMS experts

The career development paths of KIMS experts in Chile have had important differences contrasted with Australia. Most of the expertise required to run mining and metallurgical operations and to develop mining investment projects up to the early 1970s was provided by foreign companies through their headquarters or central engineering units. Mining operations based in Chile maintained only routinely engineering capabilities at the local level, offering very limited skill development opportunities. Thus, before the 1970s Chile not only had a lower scale and growth rate of mining production than Australia, but in addition Chilean mining activities that were undertaken were not used to the same extent as in Australia as a basis for training in practice and as a means of accumulating experience by local experts.

After the nationalisation of the Chilean mining industry (early 1970s) a significant number of engineers and experts working in Chile left the country and only a few with the experience and knowledge required to run mining operations remained in Chile. For instance, in the field of geo-technologies Chile only had very incipient capabilities, involving just a small group of engineers with any significant knowledge and experience in the area. In particular, there were only three experts in rock mechanics, two of whom were pursuing postgraduate studies abroad. In soil mechanics, the picture was similar, with just a small group of experts working in the area, most of whom were lecturers at the university that carried out merely minor consulting work. Also, there was only a very small group of geologists. Besides this, there was no rock mechanics laboratory, nor any kind of research facility.

In that context, the Chilean government launched programmes to support engineering capability building. For instance the Mining and Metallurgy

Research Centre (CIMM) was created to build up a critical mass of specialised engineers and experts with capabilities to identify, transfer and adapt the best mining and metallurgical practices to the Chilean mining sector. But these programmes run for only a few years, and were then diminished because they were considered irrelevant for the development of the mining sector. At that time Chile was changing its economic model, implementing neoliberal market-oriented policies, which shaped the support given to efforts such as those developed by CIMM.

The implications of this change in policy, along with other difficulties faced during the 1970s by young Chilean engineers trying to pursue a career path towards becoming full-range KIMS experts are illustrated in Box 7.1. This is based on an interview in 2006 with a senior engineer who had been struggling to build his initial skill base in the 1970s.

Box 7.1: Constraints on career development in geo-technology in Chile during the 1970s: The experience of a young engineer

"… in the early 1970s I, at that age a young Chilean engineer, was one of the very few engineers with some geo-technological knowledge and experience. CIMM (Mining and Metallurgy Research Centre) contacted and invited me to collaborate in the development of an applied rock mechanics research unit and to pursue postgraduate studies at a leading university in a foreign country. CIMM with the collaboration of UNDP (United Nations Development Program) and the Mining School of Imperial College in the UK were working together sponsoring young engineer postgraduates' studies.

However, around the mid-1970s, when I was about to begin postgraduate studies at Imperial College, the government changed drastically the mining development policy, including CIMM's focus. Postgraduate studies were considered unnecessary. The focus of the new government can be summarised by the following statement of a high executive at the Chilean government: '*Engineers should just work at the operations and if a new challenge emerges that requires a 'new technology or knowledge' it would be acquired at the international market'*. Thus, sponsoring postgraduate studies was cancelled.

Despite this abrupt policy change, I worked out a way to pursue an MSc in soil mechanics at the Imperial College. Once there, I appreciated the distance that the Chilean mining industry was from the mining technology frontier.

In 1976 after finishing the MSc I went to work in Brazil. I found out that the Brazilian mining sector had very similar features to the Chilean in terms of a lack of local firms that offered a comprehensive package of geotechnical consulting services. These services were provided by international engineering firms such as Golder Associated (Canadian & US), Dames and Moore (US); Knight Piesold (British & South African), and CH2MHill (US), which were expensive and were contacted just for 'major' problems.

In the early 1980s I returned to Chile, inviting other experts with geo-technological expertise but in supplementary areas, to set-up a geo-technological services consulting firm able to offer a comprehensive range of geo-technological services…".

Source: Interview transcript (2006)

Over the 1980s Chilean engineers, who were working either in small KIMS supplier firms or in mining companies (mainly in Codelco), started to develop and foster KIMS capabilities and to build-up a stronger base of experience. An important feature of this phase was the way in which it was driven by the requirements of the mining industry’s expansion and upgrading. Because of the significant scale and accelerating growth of mining operations in Chile, and also because of the international isolation of Chile, young engineers were forced to address important technical challenges. This led to the formation of a group of highly skilled KIMS experts working in mining companies or in a small group of local engineering firms.

During the early 1990s KIMS experts continued to accumulate further experience by coping with the increasingly complex challenges associated with the rapid expansion of mining production. Most of the time challenges were addressed by integrating and adapting up-to-date technology, which was brought to Chile by international mining companies and international KIMS suppliers. This was reinforced by the fact that Codelco started to encourage engineers and experts working in its operations to present research proposal seeking solutions for production problems. Codelco’s engineers developed solutions based on their in-depth knowledge of what was going on at the international level in terms of mining technology developments and what the local practical problems were. However, during this 1990s period innovation was carried out neither as a continuous activity nor as part of a strategy of research and development. It was based on a reactive short-term, problem solving approach. Nevertheless, this reactive approach did lead to an important process of expert training and experience accumulation, comprising high exposure to both techniques and innovations and to real problems of long-term increasing complexity. Thus, during the 1990s the significant expansion of local mining production which was based on the development of large and complex copper mines speeded up the accumulation of experience and knowledge by KIMS experts in Chile.

In addition, during the 1990s undergraduate and postgraduate programmes in KIMS-related fields were fostered by Chilean Universities. Thus, while mining engineering departments were closed in Australia, Canada, UK, and the US during this decade, a new one was opened in Chile (Upstill and Hall, 2006). But, despite this reduction of the gap between Chile and Australia in terms of the number of universities offering KIMS and mining-related studies (e.g. geology, mining engineering and metallurgy), the gap remained important, at the postgraduate level. Table 7.1 shows that in 2005 the number of universities with mining related programmes was fairly similar in Australian and Chile (13 and 11 respectively). But only about half of the Chilean universities offered MSc programmes compared with nearly all in Australia (6 and 12 respectively); and only about one quarter of them offered PhD programmes, again compared with nearly all in Australia (3 and12).

Table 7.1: Number of Universities with Mining Related Programmes (2005)

Country	Number of Universities with mining related programmes	Numbers of Universities with mining related MSc Programmes	Numbers of Universities with mining related PhD Programmes
Chile	11	6 (55%)	3 (27%)
Australia	13	12 (92%)	12 (92%)

Around the early 2000s, mining companies increased their efforts to train the young KIMS experts they employed by widening the range of training activities – in particular setting-up important schemes such as internships and graduate programmes. But most Chilean KIMS suppliers did not engage in similar efforts for their young professionals. This contrasted with Australian KIMS suppliers that had started to get involved in similar kinds of expert training as the mining companies.

7.2.3 Summarising the contrast between Chile and Australia

The difference between Australia and Chile in the pattern of career paths development and training for KIMS professionals, combined with their exposure to challenges in accumulating practical experience can be illustrated in summary form by Figure 7.1. Using only a qualitative differentiation of relative positions along a spectrum from ‘Low’ to ‘High’, it plots change on two dimensions of the exposure to training and learning. One, the vertical axis, is about the opportunities for training and exposure to new technologies and innovation. The other, the horizontal axis, is about the qualitative characteristics of the industry-level problems to which young professionals were exposed. This is centred primarily on the increasing complexity of problems, as reflected in the frequency of new investment projects that typically bring with them challenges that are relatively complex in two senses – challenges concerned with relatively large-scale integration across sub-systems in new or substantially expanded mines and facilities, and challenges concerned with the absorption of new state of the art technologies.

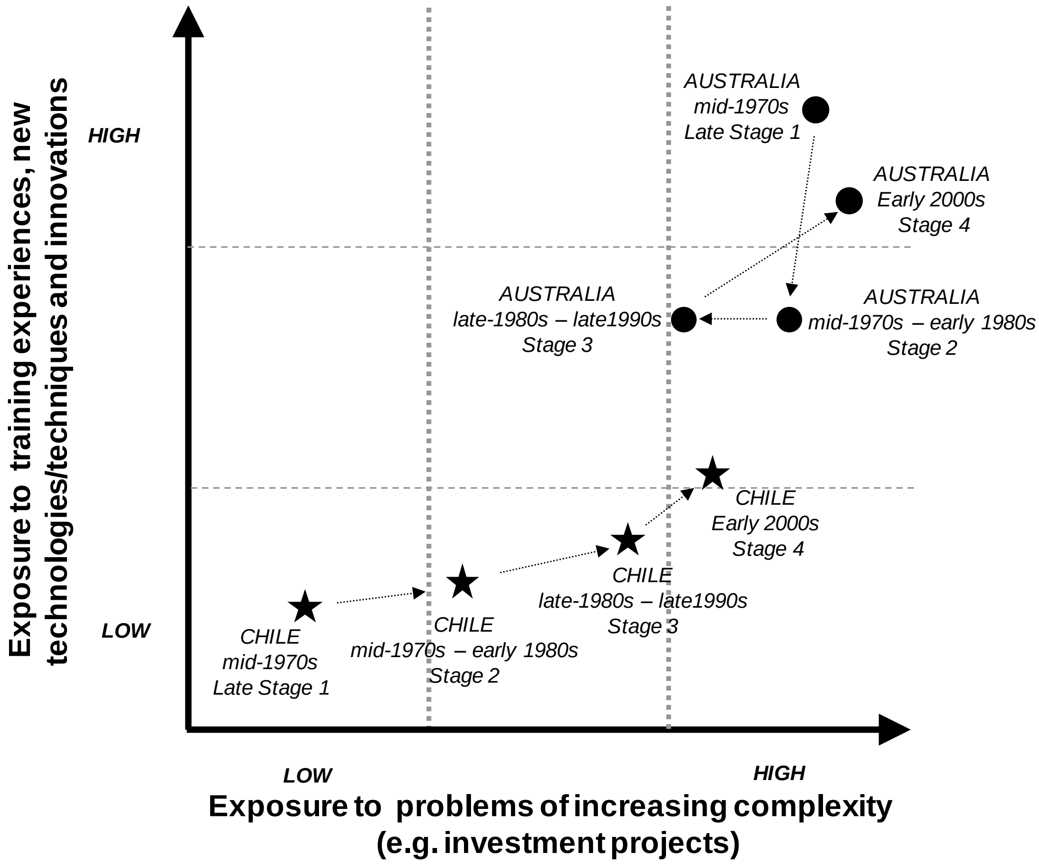


Figure 7.1: Contrasting Paths of Exposure to Training and Learning Opportunities for Young KIMS Experts in Chile and Australia

In Chile, during the period up to the mid-1970s (late in the KIMS sector Gestation Stage) there were no important training activities for KIMS experts, either at university level or as internal activities in firms. Also, the slow growth of mineral production, and the consequent low frequency of investment projects, provided very few opportunities for exposure to challenging problems – and in any case the most challenging activities, such as the engineering of new investment projects, were carried out by foreign KIMS experts. Chile was thus located in the bottom left-hand corner of Figure 7.1. In contrast, with a high rate of industry growth, and hence frequent investment projects at the frontiers of advancing technology, combined with high levels of training and learning activity in both universities and the mining companies, the opportunities for KIMS-related capability building in Australia were located in the top right-hand corner of the figure.

Later, during the stage of emergence and development of the KIMS sector (around the late 1970s and early 1980s), KIMS training activities in Chile remained low. However, driven by the nationalisation of the industry, local experts were engaged in addressing more complex production challenges, though these were primarily concerned with keeping existing operations running and increasing the rate of production. Thus the Chilean position in terms of learning opportunities moved a short distance to the right in Figure 7.1. In contrast, with the degradation of academic training and mentored firm-based learning in Australia, combined with the emerging disintegration of KIMS activities from mining companies to smaller KIMS firms, the position of learning opportunities moved ‘south’ in Figure 7.1 – while the exposure to relatively complex problems associated with the high growth of the industry was more or less maintained.

During the two stages of internationalisation and consolidation of the KIMS sector (the late-1980s to the early-2000s), the opportunities for Chilean KIMS experts to pursue career development paths leading to internationally competitive capabilities changed along both dimensions – reflected in the ‘north-east’ direction of change in Figure 7.1. Universities and mining companies improved their KIMS related training programmes, but KIMS suppliers did a much weaker effort. Additionally, the very significant expansion of the industry, based on large and highly complex investment projects, provided increasingly challenging learning opportunities. In Australia the path was less straightforward. During the internationalisation stage, KIMS suppliers maintained their exposure to difficult challenges. However this exposure was diminishing for students and young engineers. Then, during the sector’s later internationalisation phase, and especially in its consolidation phase, the complexity and frequency of available learning opportunities generated by the industry's growth both increased again. Combined with the renewed strengthening of opportunities for academic and firm-based training and learning, this moved Australia back into the top right-hand corner of Figure 7.1.

Thus the exposure of Chilean KIMS experts' to training experiences and real-world problems of rising complexity has been growing since the 1970s. This increasingly enabled young KIMS experts to pursue career development paths to become full-range professionals with capabilities to exploit in the Chilean mining sector and elsewhere the global potential for innovation and competitive expansion. However the process was very gradual and halting in the 1970s and remained very constrained in scope during the 1980s. It gathered pace during the 1990s, but even by the early 2000s the level of exposure to training and learning was still lower than in Australia.

The timing of these contrasting paths was important because it was during the earlier phases of the industry's development that opportunities for the entry of new firms into rapid growth in the emerging KIMS sector were particularly open. It was also during those earlier stages that the capability foundations were laid for KIMS firms to engage actively and positively in the subsequent phases of internationalisation and consolidation.

7.3 Firm-Level Efforts to Enhance Innovation and Engineering Capabilities

This section focuses in more detail on efforts to enhance KIMS innovation and engineering capabilities that were made at the firm level in Chile and Australia – and specifically by KIMS firms themselves.

Several types of capability-building effort are examined in order to provide a reasonably comprehensive coverage. But there is one significant omission. As explained in Chapter 3 one of the most important learning mechanisms for KIMS suppliers is 'doing' the engineering activities they carry out (process and product designing, integrating technologies, copying adapting and improving technologies, transferring solutions and so forth). But it is very difficult to distinguish or assess the learning-centred element of such 'doing', and the issue is only addressed incidentally. The other capability-building activities that are examined more systematically here are grouped according to whether the main source of the firms additional knowledge, was external (Section 7.3.1) or internal (Section 7.3.2).

7.3.1 Enhancing capabilities via external sources of knowledge

This section examines the importance that the sample of Chilean and Australian KIMS suppliers attached to using the following four learning mechanisms:

i. Hiring experts;

ii. Seeking, benchmarking and using best available technologies and practices;

iii. Attending seminars and conferences and reviewing literature;

iv. Formal training programmes (e.g. university first and post-graduate degrees).

Senior executives in the firms were asked during the interviews to assess the importance the firm had attached in practice to these mechanisms according to the following score:

5: Very Important
3: Important
0: No Importance

Information was sought covering the lifetimes of the firms, though all dates up to 1981 were collapsed into a single period. The data were compiled via the following steps, and acquired in the way described in Chapter 4 (Section 4.5):

i. *Assessing importance at the time of 'key events'*: the interviewees were asked to assess the importance of their use of these mechanisms at the time of each 'key event' in the firms history (see Chapter 4, Section 4.5.2, for an explanation of 'key events');

ii. *Grouping the event-linked assessments*: The interview responses referring to the dates of key events were grouped according to their timing in relation to the stages of KIMS sector development;

iii. *Computing the firm-specific average value by stage sector development*: If firms had multiple key events during any stages of sector development, the average ranking of importance across those events was calculated for each KIMS firm;

iv. *Computing the industry average value by stage of sector development*: The average value for each group of Chilean and Australian KIMS sample firms was calculated for each stage.

The results are presented in Table 7.2:

Table 7.2: The Importance of 'External' Learning Mechanisms in Chilean and Australian KIMS firms

Learning Mechanisms	**KIMS firms sample**	**Importance level of different learning means (Average Values)** (5: Very Important – 3: Important – 0: No Important)				
		Stages in the Development of the KIMS Sector				
		Gestation	*Emergence and Development*		*Internation-alisation*	*Consoli-dation*
		1975 back	1976-1980	1981-1985	1986-1999	2000-2005
Hiring experts	Chilean KIMS firms	1.5	1.4	2.2	2.6	2.8
	Australian KIMS firms	3.3	3.9	3.7	4.1	4.2
Seeking, benchmarking and using best available technologies and practises	Chilean KIMS firms	1.5	2.0	1.8	3.1	2.7
	Australian KIMS firms	4.0	4.7	4.7	4.7	4.4
Attending seminars & conferences and reviewing literature	Chilean KIMS firms	3.0	2.6	2.7	2.9	3.1
	Australian KIMS firms	3.0	3.2	3.8	4.0	3.6
Formal training programmes (e.g. university first and post-graduate degrees)	Chilean KIMS firms	0.0	0.5	0.5	2.0	2.0
	Australian KIMS firms	3.0	3.3	4.0	4.3	4.3
Sample Size (N)	Chile	3	6	7	8	10
	Australia	4	10	12	15	16

The table shows two clear patterns. First, the Chilean KIMS firms attached increasing importance to using three of the learning mechanisms over the period covered (there was little change in the case of using seminars, conferences, etc.). Second, the Australian firms also increased their use of these learning mechanisms over time. So, despite the rising trends in the Chilean KIMS supplier, they have consistently attached lower importance to every type of learning activity compared to Australian KIMS firms. Thus, in the case of most mechanisms, but especially with respect to formal academic training, the gap still remained wide at the end of the whole period in the early 2000s.

7.3.2 Enhancing capabilities via internal sources of knowledge

This section uses two indicators to examine the intensity of efforts made by KIMS supplier firms to strengthen their technological capabilities via mechanisms that involve the 'internal' generation of new knowledge. One, R&D expenditure (as a ratio to the value of a firm's sales) needs little explanation. The other, whether KIMS firms published in technical journals, merits brief comment. It is obviously not the publication of articles per se that 'measures' learning effort. Instead, the indicator is used to reflect whether the firms have undertaken internal knowledge search activities, perhaps wider than formally recorded R&D, that have yielded knowledge that merits some form of publication.

The information was collected and processed using the same procedure described in the previous section. The results are presented in Table 7.3.

Table 7.3: The Intensity of 'Internal' Learning in Chilean and Australian KIMS firms

		Stages in the Development of the KIMS Sector		
		Emergence and Development	***Internationa-lisation***	***Consolidation***
Indicators of Internal learning effort		**1980-1989**	**1990-1999**	**2000-2005**
R&D Expenditure as a proportion of the value of sales	Chilean suppliers	**2%**	**2%**	**3%**
	Australian suppliers	**7%**	**8%**	**9%**
Proportion of KIMS Suppliers that published in technical journals	Chilean suppliers	**33%**	**78%**	**60%**
(at least one publication every year)	Australian suppliers	**57%**	**88%**	**100%**
Sample of Chilean Suppliers (N)		**7**	**8**	**10**
Sample of Australian Suppliers (N)		**12**	**15**	**16**

The patterns in the results are clear-cut. As with the 'external' learning mechanisms, the disparity between the 'internal' mechanisms of the selected leading Australian and Chilean KIMS firms was wide in the 1980s. The intensity of R&D has risen over time in the Chilean firms. But the increase was relatively modest and was matched by increases on the part of the Australian firms, with the result that there had been little catching up or narrowing of the gap by the Chilean firms by the early 2000s.

The path was similar in the case of the publication-based indicator. The proportion of Chilean KIMS suppliers that published in technical journals was relatively low in the 1980s, but increased over the period. Again, however, that increase was matched by a rising proportion of Australian firms that published, and the gap between the two groups remained in place in the early 2000s. It is important to stress that this continuing difference reflected an explicit aspect of management. The managers of Australian KIMS suppliers encourage their experts to write technical papers by providing them with time and resources to prepare and present papers, and also by considering the publication and presentation of technical papers as an explicit component of formal personal performance assessments. Such managed approach to fostering publication was much less common among the Chilean firms.

7.4 Learning from Interactions between KIMS Suppliers and Mining Companies

It is well recognised that interactions along supply chains between suppliers and their customers can be an important source of learning and innovation. In addition, as outlined in Chapter 3, this is particularly relevant in the case of the KIMS sector since the sources of knowledge and skills required to develop and deliver knowledge-intensive services are usually located in both the user (a mining company) and the producer (a KIMS supplier). The interactions between them may play a key role in integrating and transferring the elements of knowledge to enhance learning processes and to speed up effective innovation.

However the learning intensity of “customer-client” interactions is highly variable and not every interaction is necessarily an important source of learning and stimulus for innovation. At one extreme these interactions may involve purely market-based transactions over nothing more than the sale of services derived from the use of the supplier’s existing capabilities, with no significant elements that enhance the knowledge-based capabilities of either party. But, moving away from that extreme, other kinds of interaction may involve intensive flows of knowledge that both stimulate innovation and enhance the capabilities to produce it, or even creating qualitatively new capabilities in some circumstances – for example via collaborative R&D.

This section reviews the position on that spectrum of interactions between KIMS users and suppliers in Chile and Australia. It uses two approaches to examine difference between the two industries, and changes over time within them:

- First, during both of the main phases of research general information was acquired about the quality of the interaction between KIMS suppliers and mining companies in Australia and Chile. This yielded loosely structured information that provides a basis for a general overview of the learning intensity of these interactions in the two countries;

- Second, more detailed information about the relationship was acquired during the interview survey of KIMS suppliers. This focused on the extent to which, in the view of those firms, mining companies had specifically encouraged learning and innovation in suppliers.

The results of the two approaches are reviewed separately below.

7.4.1 The learning intensity of interactions between KIMS suppliers and mining companies: a general overview

In Australia it is common to find knowledge flowing in both directions, from KIMS suppliers to mining companies as well as from mining companies to KIMS suppliers. For example, the flows from mining companies to suppliers do not consist merely of specifications for the service required. They commonly involve also broader understanding of the nature of problems being addressed, together with ideas about the possible directions in which innovative solutions might be developed. Similarly, flows from suppliers to mining companies may include more than information that is narrowly concerned with, or embodied in, the specific service provided. They may also include wider understanding about alternative solutions or future development possibilities.

These kinds of learning-rich relationship commonly arise because engineers within mining companies open spaces in their work activities for defining, in collaboration with KIMS suppliers firms, the nature of the problem or challenges their operations and projects are facing. To a significant extent the learning effort and potential is shaped by how the problem is framed or defined. Additionally, engineers within mining companies open spaces to collaborate with KIMS suppliers during the implementation of solutions that tackle new problems or challenges, enabling them to integrate their knowledge and know-how about operational constraints with the technical expertise and experience of the supplier.

It is likely that the origins of this kind of interaction reflect two features of the vertical disintegration of KIMS activities in the 1980s. On the one hand, that disintegration did not result in a complete absence of technologically creative competence in the mining companies. They continued to have strong technological capabilities at the heart of their interactions with suppliers. On the other hand, as experts left mining companies to set-up their own KIMS consultant organisations they maintained interactions with their peers in the mining companies with whom they had built strong trust relationships.

Nowadays, however, this kind of learning-rich relationship is built on more than just personal relationships and trust. Although those are critically important, significant elements of explicit management are now also involved. For example, Australian KIMS suppliers record and structure the knowledge arising through these relationships, and they analyse it in order to foresee types of product that are likely to be demanded in the short and long term. Such understanding about possible directions of market and technological development is then used to help in shaping suppliers' learning and innovation efforts.

These kinds of learning-rich interaction have been much less evident in Chile. In the 1970s and 1980s this probably reflected the different prior history of the industry – in particular the very limited accumulation of KIMS-related capabilities in the mining companies. This meant that they did not play a role as incubators of those capabilities during the gestation stage of the KIMS sector, and consequently very little of that sector emerged in Chile as a result of vertical dis-integration of KIMS activities from Chile-based mining companies. Thus the network of relationships and trust that was inherited from the past activities of mining companies by the Australian KIMS industry in the late-1970s and 1980s was at best very limited in the case of Chile. Even after nationalisation the constrained development of technological capabilities in Codelco continued to limit its internal basis for developing the kinds of interaction with KIMS suppliers that emerged in Australia.

Naturally through the later 1980s and 1990s there were networks of informal interaction between experts of mining companies (especially Codelco) and KIMS firms, and these involved knowledge flows in both directions. But this type of interaction depended heavily on specific personal relationships, and they tended to last only as long as the individuals remained in relevant positions in both the mining companies and KIMS suppliers.

More generally in Chile the knowledge flows associated with KIMS transactions now run only in one direction, from mining companies to the suppliers. But, in most cases they relate rather narrowly to the specific transactions, referring to the specifications and procedures to be met by the service suppliers. In contrast to the Australian experience, managed procedures are seldom set up by either the mining companies or the KIMS suppliers to develop richer knowledge-centred elements around their commercial transactions with the aim of fostering learning and innovation.

On the contrary, the interviews with KIMS suppliers in Chile suggested that since about 2000 the mining companies' management of their interactions with local KIMS suppliers was moving in the opposite direction: i.e. towards more narrowly bounded market transactions and away from fostering more learning-rich relationships. The companies have increasingly managed their procurement procedures by standardising services so that they can more easily be put out to a tender on a basis in which KIMS firms compete on price. This approach leads to transactional relationships that are easier to manage and control from a financial perspective. However, the interviewees in KIMS suppliers argue that it has also been pushing them towards the transformation of their services into standardised commodities that are executed on a routine basis with the lowest possible input of highly skilled (and expensive) KIMS expertise.

This relatively recent development therefore seems to be raising rather than lowering barriers to enriching the commercial transactions between suppliers and mining companies with significant elements of learning and innovation. It might even be destroying capabilities rather than fostering their development. Even if that is an overly negative perspective, it seems clear that the evolution of these interactions has not been moving towards the types of learning-rich transaction that are used in Australia to strengthen capabilities and foster understanding about markets and technology that underpins effective innovation.

7.4.2 KIMS firms' learning from interactions with customers: Specific encouragement from mining companies

As well as providing information that contributes to the general overview above, the interviewees in KIMS firms responded to more specific questions about whether they had been encouraged to learn and innovate by mining firms. The focus was on the extent to which mining companies encouraged KIMS suppliers to solve mining companies' technical challenges performance problems when the available solutions were unsatisfactory (for example, in desert conditions as in Chile, the degree of water recovery from tailing dams must be much higher in order to sustain rising production). This type of encouragement constitutes an active form of demand for KIMS firms to take an innovative approach ranging from technology transfer and adaptation to important engineering and R&D efforts. This type of encouragement usually involves knowledge flows in both directions. These flows start at very early stages, when the problem is defined or framed, and general solutions are outlined, and it continues up to the stage of problem solving and the implementation of solutions.

A contrary approach to tackling problems is to put out tenders in which the technical terms of a solution are already defined by the mining company, and the bidding process is largely concerned with identifying the lowest cost supplier, while the supplier tends to execute routine activities following "the instruction" defined in the technical terms. In this case knowledge flows and interaction are limited to understanding technical terms and general conditions.

The survey interviews sought to identify the extent to which KIMS suppliers had been engaged with the first of these types of interaction with mining company customers – asking both whether the firms had done so at particular times, and also in broad terms how frequently if they had – rarely, infrequently, commonly or very frequently. (Table 17 and List 17 in Appendix 3.1 were used as a guide to gather this kind of information.)

All the interviewees in both Chile and Australia agreed that second type of purely market-based transaction with mining companies were very common; but they differed widely about the incidence of the first type.

Table 7.4 shows the proportion of KIMS suppliers that have been involved in relationships in which they have been encouraged to tackle a challenging problem, by learning and innovating in collaboration with a mining company. It also provides a generalised assessment of the firms responses about the frequency with which this occurred.

Table 7.4: The Proportion of KIMS Suppliers Encouraged to Learn and Innovate by Mining Companies, and the Frequency this Occurred

Type of mining companies' encouragements to learn		*Stages in the Development of the KIMS Sector*			
		Gestation	*Emergence and Development*	*Internationalisation*	*Consolidation*
		Early 1970s back	**Mid 1970s – early 1980s**	**Late 1980s – late 1980s**	**Early 2000s**
Encouragement to solve mining companies' unsolved technical challenges.	Chilean KIMS sample	66% Rarely	75% Rarely	71% Infrequently	75% Infrequently
	Australian KIMS sample	100% Commonly	90% Commonly	100% Very frequently	100% Very frequently
Size of the Sample of Chilean KIMS		3	7	8	10
Size of the Sample of Australian KIMS		4	12	15	16

The table shows that mining companies in Australia consistently engaged leading KIMS suppliers in collaborative projects to solve challenging problems. 100 per cent of the surveyed firms indicated that this had occurred in nearly every stage since the 1970s, and most of them indicated that it occurred commonly or very frequently. In contrast, in Chile only two-thirds of the very small number of firms at that time engaged in this type of project before the mid-1970s, and this happened only rarely. The proportion rose to around 70-75 per cent in the period since then, but most interviewees indicated that this still happened very rarely until the mid-1980s and only infrequently in the subsequent periods. Much more usually, mining companies in Chile sought this type of solution in the international market from KIMS suppliers located abroad. Both groups of firms recognised the learning value of these kinds of projects, and the contrast between the two groups in their exposure to such learning opportunities must have been another significant influence on the different paths of capability development in the KIMS sector.

7.5 Overview of the Learning and Innovation Effort of Chilean KIMS

This section summarises the explanations earlier in this chapter about the main kinds of learning and innovation effort that were used to develop technological capabilities in the Australian and Chilean KIMS industries: the career paths and training activities of KIMS experts, firm-level efforts to enhance their innovation and engineering capabilities, and the learning-related dimensions of KIMS suppliers’ interactions with mining companies.

7.5.1 The career paths and training activities of KIMS experts

Table 7.5 presents the main difference between the two countries.

Consistently over the different stages of KIMS sector development the training institutions and programmes available for Chileans KIMS experts were much less developed than those in by Australia. Also until the latest stage in the sectors development hose training activities in Chile were organised in ways that provided young professionals with much more limited opportunities to connect their academic training with practical problems and new technologies in the operational contexts of mining activities.

Table 7.5: The Evolution of Career Paths and Training Activities for KIMS Experts in Chile and Australia – 1940s to early 2000s

Stages in KIMS Sector Development	Chilean KIMS Sector	Australian KIMS Sector
Gestation *(around 1940s to early1970s)*	▪ Low exposure of KIMS experts over the whole career path to training activities, new technologies and innovations and limited exposure to practical production problems of high complexity. ▪ Few engineering degrees in KIMS related fields available and most weak. ▪ No research centres and facilities in KIMS related fields. ▪ Very weak link between training activities and real problems.	▪ High exposure over the whole career path of KIMS expert to training activities, new technologies and innovations, linked to high exposure to practical production problems of increasing complexity. ▪ Numerous strong engineering degrees and post-graduate degree in KIMS related fields available and attracting young talents. Mining companies supporting these programmes. ▪ Strong R&D centres in KIMS related fields supported by mining companies. ▪ Strong link between training activities and real and practical problems.
Emergence and Development *(mid-1970s to early 1980s)*	▪ Emerging of a small group of KIMS experts with an important exposure to practical production problems. ▪ Universities' programmes in KIMS related field still weak but gradually improving. ▪ Weak link between training activities and real and practical problems.	▪ KIMS experts keep high exposure to innovations and practical problems. However this exposure is diminishing for students and young engineers. ▪ Universities' programmes weaken and failing to attract talents. Additionally mining companies' support shrinking. ▪ Link between training activities and real and practical problems weaken.
Internationalisation *(late 1980s to late 1990s)*	▪ KIMS experts keep high exposure to practical problems of increasing complexity. ▪ Universities' programmes in KIMS related field still weak but keep gradually improving. ▪ Link between training activities and real and practical problems is weak.	▪ Senior KIMS experts keep high exposure to innovations and practical problems. This is not the case for young KIMS experts. ▪ Universities' programmes and research centres' enhanced with governmental support. ▪ Deliberated link between training activities and real problems weaken.
Consolidation *(from early 2000s and continuing)*	▪ KIMS consultants keep high exposure to practical problems of increasing complexity. There is not a deliberated link between training and practical production problems. ▪ Mining companies set-up graduate programmes. However KIMS suppliers do not. ▪ No particular governmental support for KIMS related research activities. Increasing debate about policies for supporting the development of innovation capabilities for mining.	▪ Exposure to innovation and training and practical production problems increases for young experts. ▪ KIMS suppliers and mining companies enhancing graduate programmes and training activities. ▪ Governmental support for research activities increases.

But one must bear in mind that such limited interactions between the training of professionals and the practicalities of problems faced in mining were not simply reflections of the micro-level actors involved in managing those aspects of career path development. They were also constrained by the industry-level factors discussed in Chapter 6 – in particular the characteristics of the industry growth paths that influenced such things as the frequency of learning opportunities and the levels of complexity they involved.

7.5.2 Firm-level efforts to enhance their innovation and engineering capabilities

As indicated in Table 7.6, for both Australian and Chilean firms the paths of change were similar with respect to the use of both 'External' and 'Internal' mechanisms for strengthening the firms' capabilities. Consequently they do no need to be distinguished in describing the central feature of the history – i.e. that the efforts of Chilean KIMS firms to use these learning mechanisms to enhance their innovation and engineering capabilities were consistently much lower than those of the Australian firms.

There was an initial wide gap between the intensity with which the two groups of firms used the various learning mechanisms to deepen their capabilities. Over time the intensity of these various learning efforts increased among the Chilean firms, but it also increased among the Australian firms from their initially higher level; and the consequence was that a substantial gap persisted into the early 2000s. This is evident most tangibly in the fact that the R&D intensity of the Australian firms was still about three times the level in the Chilean firms – little different in relative terms from what it had been about 20 years earlier.

As in the earlier discussion of the opportunities for training and practice-based learning, the timing of the paths summarised in Table 7.6 relative to the stages of development in the global KIMS sector was probably very important. Because of the very different contexts in the global KIMS industry, developing intensive learning and capability deepening efforts in Chile after the end of the stage of KIMS sector emergence and development (around the mid-1990s) probably had different consequences from having done so at an earlier stage when entry to the industry was more open – a point that is taken up later in Chapter 8.

Table 7.6: The Changing Use of 'External' and 'Internal' Learning Mechanisms in Chilean and Australian KIMS Firms

<table>
<tr><th>Stages in KIMS Sector Development</th><th>Chilean KIMS Sector</th><th>Australian KIMS Sector</th></tr>
<tr><td>Gestation (around 1940s to early 1970s)</td><td>'External' Learning Mechanisms
▪ Limited learning and innovation efforts: low effort for hiring KIMS experts, seeking best available technologies and supporting formal training programmes.
'Internal' Learning Mechanisms
▪ Very minor level of research, innovation, engineering and other KIMS learning effort.</td><td>'External' Learning Mechanisms
▪ Significant learning and innovation efforts: important effort for hiring KIMS experts, seeking best available technologies and supporting formal training programmes.
'Internal' Learning Mechanisms
▪ Important research, innovation, engineering and other KIMS learning effort taken place mostly within mining companies or supported by them.</td></tr>
<tr><td>Emergence and Development (mid-1970s to early 1980s)</td><td>'External' Learning Mechanisms
▪ Low importance attached to:
- Hiring KIMS experts.
- Seeking and benchmarking best available technologies.
- Pursuing formal training programmes.
'Internal' Learning Mechanisms
▪ Limited internal knowledge generation:
- R&D expenditure: 2%
- Few firms publish technical articles (33%)</td><td>'External' Learning Mechanisms
▪ Important learning efforts:
- High effort for hiring KIMS experts.
- Very high effort seeking best available technologies and doing international benchmarking.
- High effort for pursing formal training programmes is important.
'Internal' Learning Mechanisms
▪ Important internal knowledge generation:
- R&D expenditure: 7%
- Most firms publish technical articles (57%)</td></tr>
<tr><td>Internationalisation (late 1980s to late 1990s)</td><td>'External' Learning Mechanisms
▪ KIMS suppliers increase learning and innovation efforts but it is still limited in terms of training:
- High effort for hiring KIMS experts
- High effort in seeking best available technologies
- Limited effort for pursing formal training programmes is limited
'Internal' Learning Mechanisms
▪ Despite publishing more technical articles, internal knowledge generation keep limited:
- R&D expenditure: 2%
- More firms publish technical articles (78%)</td><td>'External' Learning Mechanisms
▪ KIMS supplier make important learning and innovation efforts:
- Very high effort for hiring KIMS experts
- Very high effort seeking best available technologies and doing international benchmarking
- Very high effort for pursing formal training programmes is important.
'Internal' Learning Mechanisms
▪ Important internal knowledge generation:
- R&D expenditure: 8%
- Generally firms publish technical articles (88%)</td></tr>
<tr><td>Consolidation (early 2000s and continuing)</td><td>'External' Learning Mechanisms
▪ KIMS suppliers increase learning and innovation efforts and keep limited in terms of training:
- High effort for hiring KIMS experts.
- High effort in seeking best available technologies.
- Limited effort for pursing formal training programmes is limited.
'Internal' Learning Mechanisms.
▪ Internal knowledge generation improved in terms of R&D, but there is a drop regarding publishing technical papers:
- R&D expenditure: 3%
- Most firms publish technical articles, but there is a drop (60%)</td><td>'External' Learning Mechanisms
▪ KIMS supplier make important learning and innovation efforts:
- Very high effort for hiring KIMS experts.
- Very high effort seeking best available technologies and doing international benchmarking.
- Very high effort for pursing formal training programmes is important.
'Internal' Learning Mechanisms.
▪ Important internal knowledge generation:
- R&D expenditure: 9%
- All firms publish technical articles (100%)</td></tr>
</table>

7.5.3 The learning-related dimensions of KIMS suppliers' interactions with mining companies

Table 7.7 summarises the different ways in which the interaction between mining companies and KIMS suppliers has acted as a source of learning for the two groups of KIMS firms. Since the 1970s mining companies in Chile have developed less learning-rich forms of interaction and knowledge sharing with local KIMS suppliers than they have in Australia, and it has never become a common and systematic practise. Indeed, rather than coming to incorporate in their transactions with KIMS suppliers more open explorations of their problems and solutions, mining companies in Chile in the early 2000s were developing forms of transaction that pushed KIMS suppliers to develop more routine and standardised services which can be considered more as a commodities than creatively developed knowledge-intensive services. In Australia, in contrast, the development of learning-rich relationships emerged at a very early stage, linked to the vertical disintegration of the activity from the mining companies. These approaches have been strengthened over time to the extent that one of the main values of KIMS suppliers rests on their ability to offer creative solutions to mining companies' challenges – part of a self-reinforcing process that leads mining companies to continue or extend their demand for such interactive and collaborative innovation-intensive services.

Once again, history seems to have mattered considerably in shaping these contrasting paths of learning and capability development. KIMS firms that were able to establish a basis for such learning-rich relationships at an early stage on the development of the global KIMS industry were able to enter into a sequence of positive virtuous cycles of learning – improved innovative performance – deeper learning. For KIMS firms that could not establish that early basis for such learning-rich relationships, especially in the context of mining industry growth paths offering frequent and challenging learning opportunities, there were few virtuous learning-performance-learning cycles, as the KIMS industry became increasingly concentrated and internationalised – and possibly some that were destructively vicious.

Table 7.7: The Evolution of Interaction Between KIMS Suppliers and Mining Companies as a Learning Source

Stages in KIMS Sector Development	Chilean KIMS Sector	Australian KIMS Sector
Gestation *(around 1940s to early1970s)*	▪ Low levels of internal capabilities in mining companies lead to weak internal interaction between KIMS unit and operational units, which diminish the possibility for learning and innovation.	▪ Mining companies have an active internal innovation network. This lays the basis for learning-rich interactions in the next stage.
Emergence and Development *(mid-1970s to early 1980s)*	▪ There is no flow of knowledge between mining companies and KIMS suppliers. Few KIMS suppliers develop collaborative engineering activities with mining companies. ▪ Mining companies very rarely encourage KIMS firms to innovate to tackle their challenges.	▪ Knowledge flows from mining companies to KIMS suppliers and from KIMS suppliers to mining companies. Interaction is based on personal relationship. ▪ Mining companies commonly encourage KIMS firms to innovate to tackle their challenges.
Internationalisation *(late 1980s to late 1990s)*	▪ The interaction between mining company and KIMS suppliers interaction are mostly market-based transactional relationship. However, there is an informal peer interaction between experts working at mining firms and suppliers. ▪ Usually, mining companies do not encourage KIMS firms to innovate to tackle their challenges.	▪ Knowledge flows between mining companies and KIMS suppliers keep active and an important source of learning and innovation. ▪ Mining companies very frequently encourage KIMS firms to innovate to tackle their challenges.
Consolidation *(from early 2000s and continuing)*	▪ Learning-poor transactional interactions with mining companies and suppliers increase their predominance. ▪ Mining companies very infrequently encourage KIMS firms to innovate to tackle their challenges.	▪ Knowledge flows between mining companies and suppliers keep active and an important source of learning and innovation. There are system that support sustaining interaction as a long term effort. ▪ Mining companies very frequently encourage KIMS firms to innovate to tackle their challenges.

CHAPTER 8

KIMS LEARNING AND INNOVATION IN CHILE AND AUSTRALIA: AN INTEGRATED VIEW AND FINAL CONCLUSIONS

8.1 Introduction

Over recent decades an important set of knowledge-intensive mining services (KIMS) has emerged from within the activities of mining companies and become the core business of specialised supplier firms that constitute a distinct industry or sector. Many of these firms have become international corporations, creating a globally organised, knowledge-based industry. This process has been uneven across mining economies. One illustration of that unevenness is provided by the experience of Australia and Chile. While numerous KIMS suppliers emerged in Australia, with many of them gradually achieving international competitiveness, only a weak growth of locally owned KIMS firms has taken place in Chile. Although some of these developed a significant degree of strength in the local market, very few have developed international competitiveness. Among those that have, very few now remain as independent firms, the majority having been integrated into the activities of international KIMS firms, many with their origins in Australia.

The research reported in this thesis analysed the emergence and development of this knowledge intensive sector, concentrating in particular on its relatively weak development in Chile. The historical analysis was framed within the broad framework of 'technological rejuvenation' in an established and technologically mature industry developed by Perez (2001), and it focused on the technological learning and innovation processes that underpinned the accumulation of technological capabilities over time.

More specifically, the thesis addressed, and sought to explain, the relatively weak development of the Chilean KIMS sector, using the contrast with Australian experience as an external reference point to highlight what may be the more important features of the process in Chile.

The thesis has argued that two intertwined processes were particularly important in shaping the level of KIMS-related technological capabilities accumulated in Chile between the 1940s and 1970s period to the early years of the current decade. The first (Process 1) involved the evolution of a set of industry-level factors that shaped the potential for learning and innovation at the micro-level; the second (Process 2) centred on that micro level, and specifically on the efforts made by firms to exploit the potential for learning and innovation. This highly simplified model, as outlined briefly in Chapter 3, was developed on the basis of secondary sources and initial exploratory interviews with key informants in the industry, and the two component processes were analysed separately in Chapter 6 and Chapter 7.

The next section in this chapter (Section 8.2) provides an integrated overview of the learning and innovation dynamic generated by the interaction of these two processes in determining the level of KIMS technological capabilities accumulated over time. Section 8.3 then highlights the main contributions of this research, while noting some of the limitations. Section 8.4 draws some conclusions about policy to support and encourage the development of internationally competitive knowledge-based mining services sectors in developing countries. Finally, Section 8.5 outlines areas of further research.

8.2 An Integrated Overview of KIMS Learning and Innovation in Chile and Australia

This section pulls together the main threads of empirical analysis from Chapters 5, 6 and 7. In Section 8.2.1 the main stages in the global development of the KIMS sector are summarised. Then the subsequent sections provide summary answers to the three core research questions that were posed at the end of Chapter 3 – though they are answered here in a slightly different order.

Section 8.2.2 summarises the analysis of Industry level factors shaping the potential for learning and innovation (Chapter 6), so providing an answer to the research question:

> *How did the key industry-level factors and the interaction between them shape the potential for learning and innovation by KIMS firms in Chile and how did this contrast with Australian experience?*

Section 8.2.3 summarises the analysis of firm-level learning and its influence on capability development in KIMS supplier firms (Chapter 7), so providing an answer to the research question:

> *How did efforts by Chilean KIMS suppliers to exploit the potential for learning and innovation evolve over the period and shape the levels of capability actually accumulated, and how did this compare with experience in Australia?*

Finally, Section 8.2.4 reviews the outcome of the interaction between those two processes – the levels of capability achieved during the stages of the sector's development by 'leading' KIMS supplier firms in Chile and Australia. In doing so it provides an answer to the research question:

> *How have the levels of technological capabilities accumulated within KIMS suppliers in Chile changed since the 1970s, and what have been the main contrasts with experience in Australia?*

8.2.1 The global development of the KIMS sector

The emergence and development of the KIMS supplier sector has been a historical process occurring over at least half a century, starting around the late 1940s. For the purposes of this thesis, the process has been divided into four stages. The transitions from stage to stage involved gradual processes, and there are no precise years that mark the end of one and the start of the next. Nevertheless the core features of each are clearly distinct as summarised below.

- **Stage 1 *Gestation*** (From around the 1940s to the early 1970s)**:**

  During this stage the capabilities that will be the basis for KIMS sector emergence were accumulated mostly within mining companies. The industry was vertically integrated and consequently KIMS innovation and learning took place within or close to mining firms. Additionally, mining companies' activities, especially innovation projects, were mainly locally organised.

- **Stage 2 *Emergence and development*** (From mid-1970s to early 1980s)**:**

  During Stage 2 the mining industry entered a process of vertical disintegration, and many functions previously carried out within mining companies were outsourced. KIMS capabilities were spun-off from mining companies, from other kinds of company and from closely related technological programmes, or were created as start-ups drawing capabilities from those sources. Thus a highly diverse and fragmented sector of KIMS suppliers to the mining industry emerged. The interaction between mining companies and suppliers became a key learning and innovation driver and was frequently based on informal peer interaction.

- **Stage 3 *Internationalisation*** (From late 1980s to late 1990s)**:**

  During this stage KIMS suppliers expanded internationally, which enabled them to maintain active learning and innovation processes by accessing a wide range of investment projects and operations, which incorporated a high diversity of challenges. The mining industry thus became a globally organised industry. Both mining companies and suppliers participate in projects and operations worldwide.

- **Stage 4 *Consolidation*** (From early 2000s and still going on)**:**

  In this consolidation stage mergers and acquisitions were a pervasive trend. Large international KIMS suppliers were consolidating and gaining control of the KIMS global value chain. Internationalisation became a requirement to maintain high learning and innovation rates, and firms needed to keep a high frequency of participation in new investment projects and operations.

8.2.2 Industry-level factors shaping the potential for learning and innovation

Next Tables 8.1 and 8.2 summarise the evolution of the factors that shaped the potential for learning and innovation over the different stages of KIMS sector development. First, Table 8.1 focuses on the evolution of the scale and growth rate of mining production and in the related complexity and challenges.

Table 8.1: Industry Level Factors Shaping the Potential for Learning and Innovation, 1940s-2000s: Scale, Growth and Complexity

Stages in KIMS Sector Development	Scale and growth of mining production		Complexity and challenges faced	
	Australia	Chile	Australia	Chile
Gestation 1940s to early 1970s	Local production expanding rapidly - faster than world mining growth rate.	Local production expanding slowly – lower than world mining growth rate.	Growth faces technical challenges due to geological complexity and tighter regulations	Growth does not face important challenges. Production is based on large mines with high ore grade.
Emergence & Development Mid 1970s to early 1980s	Local production maintains high growth rate in wide range of minerals and starts in foreign countries.	Local production expands at a higher rate, above world growth. The focus is copper.	Geological complexity is growing and minerals prices declining, fostering learning.	Local ore quality keeps comparatively high. Nationalisation drives technical challenges to be tackled locally.
International-isation Late 1980s to late 1990s	Mining production maintains significant growth – in particular in international operations	Significant production expansion (over 100% increases). Chilean mining firms remain locally based	Australian ore bodies are old and regulations are tightening. Important challenges are addressed to keep production growth.	Important challenges are emerging. Growth relies on the development of large and complex projects and ore grade is decreasing
Consolidation Early 2000s still going on.	Mining companies' maintain significant growth – both locally and internationally	Overall production maintains significant growth. Chilean firms remain locally based	Besides tight regulations, other issues (e.g. safety energy and water) made mining highly complex.	Production expansion requires cutting edge technology (e.g. robotics)

By reviewing the evolution of scale and growth rate of mineral production and the related complexity and challenges (Table 8.1) it can be seen that the KIMS sector faced a much lower potential for learning and innovation in Chile than in Australia. In Australia production and complexity levels have been growing at an important pace since the 1940s – initially at local level and since the late 1980s locally and internationally. In Chile, however, production and complexity started to increase at a significant level much later – during the 1980s and in particular during the 1990s – and the opportunities and challenges were focused in the local industry.

Table 8.2 overviews the key features regarding the evolution of the structure and organisation of the mining industry, comprising mining companies and KIMS suppliers.

Table 8.2: Industry Level Factors Shaping KIMS Learning and Innovation, 1940s-2000s: The Structure and Organisation of the Mining Industry

Stages in KIMS Sector Development	Australia	Chile
Gestation 1940s to early 1970s	• Industry is vertically integrated, with substantial KIMS capabilities accumulated in domestic mining firms • Diversity of mining company types/sizes, plus multi-mineral production, reinforces strong scale/growth-driven demands for KIMS solutions. High diversity of learning and innovation opportunities	• Industry is vertically integrated, with limited KIMS capabilities accumulated in domestic mining firms. The industry is controlled by US companies • Few (US) companies control production in large mines with mono-mineral production (copper), reinforces low scale/growth-driven demands for KIMS solutions. Low diversity of learning and innovation opportunities
Emergence & Development Mid 1970s to early 1980s	• Large parts of mining companies' KIMS capabilities are vertically dis-integrated and substantial local KIMS sector emerges • Mining companies remain numerous and diverse, and production remains multi-mineral • Small KIMS suppliers' strong links with internationalising mining companies 'pulls' them into initial international operations	• Mining nationalisation (with Codelco emphasis on capability building), plus trend to vertical disintegration lead to emergence of a few local KIMS firms • Most mining production remains mono-mineral (copper) and controlled by few large companies • Operations of Chilean KIMS suppliers remain local.
Internationalisation Late 1980s to late 1990s	• High level of KIMS accumulated in mining firms and in suppliers. KIMS sector is diverse and gets a high degree of responsibility • KIMS sector become increasingly international • Mining production keeps been multi-mineral and diverse	• Medium level of KIMS accumulated in mining firms and suppliers. Locally owned KIMS firms are small and large international suppliers crowd them out • KIMS sector is mostly focused locally • Most mining activities remain based on copper and controlled by few large companies. Low diversity of users
Consolidation Early 2000s still going on	• KIMS sector consolidates through mergers and acquisitions, large players establish increasingly dominant control • Internationalisation is sustained • Mining remains a multi-mineral activity, with diverse types of producers	• International KIMS are getting a higher share and control of the local market • Locally owned KIMS are growing, there is some export effort, but not a clear trend • Copper mining remains the most important activity controlled by a few large players

The evolution of the structure and organisation of mining industry and KIMS sector was different in Chile compared to Australia generating a much more restricted possibility to exploit learning opportunities in the former. In Chile, the much lower capability accumulated within mining companies during the gestation stage led to the emergence of a smaller number of KIMS suppliers, which faced a narrower range of learning possibilities due to the small number of mining companies that controlled production, almost entirely focused in copper. Later, during the internationalisation stage, Chilean KIMS remained domestically focused, which limited learning and innovation opportunities. At the same time they started to face severe competition locally, generated by the arrival of international KIMS, many of which were Australian. During the consolidation stage, Chilean KIMS started to face additional barriers to exploit learning opportunities since the consolidation of the KIMS sector increased the control of first tiers suppliers – all of them globally organised companies and none Chilean – and frequently Chilean KIMS needed to deal with them to exploit the learning and innovation opportunities.

Finally, Table 8.3 shows an overall appraisal of the potential for learning and innovation shaped by the features described the previous two tables.

Table 8.3: Combined Effect of Industry-Level Factors on the Potential for KIMS Learning and Innovation, 1940s-2000s

Stages in KIMS Sector Development	Level of opportunities and potential for learning and innovation (L&I)	
	Australia	**Chile**
Gestation 1940s to early 1970s	***High potential for L&I***: High production scale, growth rate and challenges drive positive L&I. Mining firms enable L&I.	***Low potential for L&I***: Low production growth and limited challenges constrain L&I. Foreign owned mining firms import KIMS and develop little local KIMS capability.
Emergence & Development Mid-1970s to early 1980s	***High potential for L&I***: High production growth and challenges drive positive L&I. Mining firms enable emergence of KIMS firms, which stimulates further L&I.	***Medium potential for L&I***: Accelerating production growth and new challenges, plus nationalisation, stimulates KIMS L&I, principally within Codelco (the state owned company) and in few suppliers.
Internationalisation Late 1980s to Late 1990s	***High potential for L&I***: Production grows, challenges drive L&I, and KIMS firms exploiting global L&I web, which is fostered by mining companies internationalisation.	***High potential for L&I***: High growth of production along with important challenges drives local L&I opportunities, which is exploited by some international KIMS suppliers and few local KIMS.
Consolidation Early 2000s still going on	***High potential for L&I:*** Production grows, challenges drive L&I, and L&I web controlled by large mining and supplier firms globally organised	***High potential for L&I***: High growth of production, important challenges drive L&I, which is controlled by international firms that gained important control in an increasingly consolidated industry.

In Chile, only since the late 1970s have important learning and innovation opportunities emerged for the KIMS sector, principally driven by the very significant growth rate of mineral production in conjunction with increasing complexity and challenges. However, at the same time, the barriers to exploit these opportunities have been shaped by the evolution of the organisation and structure of the industry. Learning and innovation opportunities have become part of globally organised activity and the access to exploit them is importantly shaped by large companies that are part of an increasingly consolidated industry. In other words, the availability of more learning and innovation opportunities on their own does not guarantee the access to exploit them. Thus, in Chile, although learning and innovation opportunities have been growing, the access for exploiting them has been increasingly controlled by large and globally organised KIMS suppliers, which is not a common feature of Chilean KIMS firms.

In contrast, in Australia there have been important learning and innovation opportunities since the 1940s, at least 30 years earlier than in Chile. The exploitation of these opportunities had led to the emergence and development of KIMS suppliers with a higher level of technological and organisational capabilities. Australian KIMS suppliers have strengthened their capabilities and have become internationally organised companies able to overcome the barriers to exploit learning and innovation opportunities.

8.2.3 Firm-level learning and innovation effort to exploit the potential for learning and innovation

In this section, Tables 8.4 and 8.5 summarise the evolution of the effort carried out by KIMS firms to exploit the potential for learning and innovation that exists at industry level. Table 8.4 focuses on the evolution of the career path and training efforts of KIMS experts.

Table 8.4: Effort at the Micro-Level to Exploit the Potential for Learning and Innovation at the Industry-Level, 1940s-2000s: Career Path and Training Efforts of KIMS Experts

Stages in KIMS Sector Development	Australia	Chile
Gestation 1940s to early 1970s	- Mining attracts young professionals, which have the firm´s support to study in parallel they work - Several universities with degrees in geology, mining, and metallurgy - Mining companies open-up learning and training opportunities and support KIMS experts career development.	- Very few young talents choose mining industry to pursue a career - Few universities offering mining related degrees in mining related areas - Incipient efforts to develop expert training programmes within mining companies
Emergence & Development Mid 1970s to early 1980s	- Decreasing interest to pursue a career in mining and mining companies reduce their support to their young professionals to study - University enrolment in mining related areas fell down and many programmes are closed - KIMS experts training programmes that relied on mining companies support are 'disassembled' - KIMS suppliers training effort is low	- A small community of young KIMS experts and engineers is emerging - Incipient improvement of university degree programmes in mining related areas - Mining companies start internship programmes and training efforts - Very low training effort in KIMS supplier firms.
Internationalisation Late 1980s to late 1990s	- Young professionals' interest in pursuing a career in mining remains low, but there is some improvement - Universities strengthen mining studies and enrolment shows some recovery, but shortage of experts is a problem - Mining companies resume internal training and career development programmes - KIMS suppliers start internal training and career development programmes	- The industry is attracting more students and professionals - Universities strengthen mining related programmes. Enrolment keeps growing - Mining companies develop important formal training programmes - KIMS suppliers do some training effort, but it is low
Consolidation Early 2000s still going on	- Mining start again attracting young professionals and students, but it is not among the top career preferences - University enrolment and programmes keep growing, but shortage of experts becomes a critical problem - Mining firms strengthen internal training programme for young engineers and experts - KIMS suppliers strengthen internal training programme for young engineers and experts Early 2000s still going on	- Increasing number of young professionals and students joining the industry - Universities open new programmes in mining related areas and enrolment raises. Expert shortage becomes a problem - Mining firms foster training efforts for engineers - Only a few KIMS firms do some training effort

The Chilean KIMS experts' development process has been strengthening, but the gap with Australian career development and effort persisted over time. Over the different stages of KIMS sector development Chilean KIMS experts have been consistently exposed to lower training efforts and also to a lower level of connection between practical production problems and formal training activities

Table 8.5: Effort at the micro-level to exploit the potential for learning and innovation at the industry-level, 1940s-2000s: Use of 'External' and 'Internal' learning mechanism and use of interaction with mining companies as learning mean

Stages in KIMS Sector Development	Use of External and Internal learning and innovation mechanism		Interaction between KIMS suppliers and mining companies as a mean of learning	
	Australia	Chile	Australia	Chile
Gestation 1940s to early 1970s	**External Learning** Important effort regarding hiring experts, seeking best technologies and supporting training. **Internal learning** Important R&D and innovation effort	**External Learning** Low effort regarding hiring experts, seeking best technologies and supporting formal training. **Internal learning** Very minor R&D and innovation effort.	• Active internal learning networks within mining companies using opportunistic learning and innovation embodied in operations & projects.	• Low level of internal capabilities leads to weak internal learning network. Opportunistic learning barely occurred.
Emergence & Development Mid 1970s to early 1980s	**External Learning** High effort regarding hiring experts, seeking best technologies and supporting training. **Internal learning** - Important R&D and innovation effort (7%). - Most KIMS firms publish technical papers	**External Learning** Low effort regarding hiring experts, seeking best technologies and supporting training. **Internal learning** - Minor R&D and innovation effort (2%). - Few KIMS firms publish technical papers	• Mining company-KIMS supplier interaction is an important source of learning. It is based on personal relationships. • Mining companies encourage KIMS firms to innovate.	• Few KIMS suppliers develop some collaborative learning activity with mining companies. • Mining companies do not encourage KIMS firms to innovate.
Internationalisation Late 1980s to late 1990s	**External Learning** Very high effort regarding hiring experts and seeking best technologies and high effort supporting training. **Internal learning** - Important R&D (8%) - Majority of KIMS firms publish technical papers	**External Learning** High effort regarding hiring experts and seeking best technologies and limited effort supporting training. **Internal learning** - Minor R&D effort (2%) - Most KIMS firms publish technical papers.	• Mining company-KIMS supplier interaction web keep been an important source of learning • Mining companies encourage KIMS firms to innovate.	• Mostly market-based interaction between mining companies and KIMS suppliers. There is some informal peer interaction between experts working at mining firms and suppliers • Mining companies do not encourage KIMS firms to innovate.
Consolidation Early 2000s still going on	**External Learning** Very high effort regarding hiring experts, seeking best technologies and supporting training. **Internal learning** - Important R&D (9%) - All KIMS firms publish technical papers	**External Learning** High effort regarding hiring experts and seeking best technologies and limited effort supporting training **Internal learning** - Minor R&D effort (3%) - Most KIMS firms publish technical papers	• Mining company-KIMS supplier interaction web is international and an important source of innovation. Increasingly R&D is run under a collaborative scheme • Mining companies encourage KIMS firms to innovate.	• Market-based interaction between mining companies and KIMS suppliers increases its predominance • Mining companies usually do not encourage KIMS firms to innovate

than in Australia. The Australian KIMS expert development process was weakened during the 1980s. It was difficult to attract young professionals; mining companies and KIMS suppliers decreased training efforts and the exposure to practical problems, and university programmes declined – it resumed during the 1990s.

According to anecdotal information, gathered though informal conversations with mining industry experts, there is a new issue that is increasingly shaping the attractiveness to pursue a career in mining. This refers to how working in mining could have an effect on the quality of life of experts that chose to work in this industry, in particular in the quality of life of KIMS experts and their families. This is mainly because of the work shift systems usually applied in the industry and also because the quality of life that mining cities (the closest location to the mining operation) offer. Mining cities usually provide more limited choices regarding health, education and leisure services among others. This problem is diminishing the interest in pursuing mining related university careers in Australia as well as in Chile and could be a strategic enabler for the development of the KIMS sector.

Table 8.5 overviews the evolution of 'Internal' and 'External learning mechanisms and the interaction between KIMS firm and mining companies as a learning and innovation source.

Over the entire period analysed, Chilean KIMS suppliers have been increasing regarding their learning and innovation efforts, but consistently the effort level is much lower compared to Australia. Additionally, the interaction between suppliers and mining companies, which is a key source of learning and innovation for knowledge-based services, has not been exploited as a learning means and mining companies have not encouraged KIMS suppliers to learn and innovate by requesting them to find solutions to challenges and technical problems.

Table 8.6: Integrated Appraisal of the Effort at the Micro-Level to Exploit the Potential for Learning and Innovation (L&I) at the Industry-Level, 1940s-2000s

Stages in KIMS Sector Development	*Australia*	Chile
Gestation 1940s to early 1970s	***High L&I effort***: Active experts' development, high R&D& engineering effort, and active External L&I and interacting L&I web	**Low L&I effort**: Passive experts' development, very low R&D& engineering effort, and passive External L&I and interacting L&I web.
Emergence & Development Mid 1970s to early 1980s	***Medium L&I effort***: Weaken experts' development system, medium R&D& engineering effort. Resetting L&I web.	**Low L&I effort**: Passive but improving experts' development, low R&D& engineering effort. Setting L&I web.
Internationalisation Late 1980s to. late 1990s	***High L&I effort***: Resetting experts' development system, high R&D& engineering effort, and active External L&I and interacting L&I web	**Medium L&I effort**: Active experts' development, medium R&D& engineering effort. Restricted access to L&I web.
Consolidation Early 2000s still going on	***High L&I effort***: Difficulties with talent attraction, high R&D& engineering effort, and active External L&I and interacting L&I web.	**Medium L&I effort**: Active experts' development, medium R&D& engineering effort, restricted access to L&I web.

Table 8.6 shows a general integrated appraisal of the different learning and innovation efforts carried out by KIMS suppliers.

8.2.4 Outcomes of the interaction between industry-level and firm-level processes: KIMS suppliers capabilities

According to the learning dynamic model developed in Section 3.6 the integrated effect of industry level factors (summarised in Section 8.2.2) and KIMS suppliers' learning and innovation efforts (summarised in Section 8.2.3) determines the actual level of technological capabilities accumulated within these firms. This section provides an overview of this integrated effect of industry and firm level factors by presenting their evolution over the different stages of KIMS sector development and the effect on KIMS suppliers' capabilities.

Table 8.7 presents the evolution of the effect of the interacting factor on the level of KIMS suppliers' capability by presenting:

a) The level of technological capabilities accumulated in the firms of the samples of Chilean and Australian KIMS suppliers studied (10 and 16 firms respectively), which are considered leading KIMS suppliers at the respective countries.

The table shows in the shadowed columns the level of capabilities accumulated in KIMS suppliers at the end of each stage. Given that at the first stage (Gestation Stage) the mining industry was vertically integrated and most of the capabilities were within mining companies, for this stage it is also shown the level accumulated within mining companies beside the level of capabilities at KIMS firms.

Three different levels of technological capabilities are defined according to what was shown in Section 5.4: Lowest level: User; Intermediate level: Adaptor; and Highest level: Innovator.

b) The potential for learning and innovation at the micro-level shaped by the interacting industry level factors. Three levels of potential are defined and are shown in the upper part of each of the rows that represent the stages in KIMS sector development. The levels of potential defined are: Lowest level: Low potential for L&I; Intermediate level: Medium potential for L&I; and Highest level: High potential for L&I.

c) The learning and innovation effort carried out by KIMS suppliers to exploit the potential for learning and innovation shaped by industry level factors. Three levels of learning and innovation effort are defined and are shown in the lower part of each of the rows that represent the stages in KIMS sector development. The levels of effort defined are: Lowest level: Low level of effort of L&I; Intermediate level: Medium level of effort of L&I; and Highest level: High level of effort of L&I.

Additionally, Table 8.7 shows at its left side the period when technological rejuvenation was having a more pervasive effect and when barriers to exploiting innovation based on new technologies (mainly ICTs related innovation) were low.

Table 8.7 shows that over the entire period analysed (1940s to early 2000s), Chilean suppliers have shown consistently a lower learning and innovation effort than Australians. Only during the emergence and development stage was the effort level in both countries comparable. However, during this period the main driver of capability accumulation was the process of vertical dis-integration. As a consequence, during the emergence stage Australian KIMS suppliers became adaptors after exploiting the capabilities incubated mostly within mining companies during the previous period, which were later spun out into suppliers in a context of high potential for learning and innovation. In contrast, in Chile dis-integration during the emergence and development stage only led to the emergence of few KIMS suppliers that became users since the low level of capabilities incubated mostly within mining companies during the previous period were then spun out into suppliers in a context of medium potential for learning and innovation.

Table 8.7: The Evolution of KIMS Suppliers Technological Capability Level and of the Industry and Firm Level Factors That Shape It

	Stages in KIMS Sector Development	AUSTRALIA **_INDUSTRY LEVEL_** **_Process 1 Outcome_.** L&I potential shaped by Industry-level factors: *High potential.* *Medium potential.* *Low potential.* **+** **FIRM LEVEL** **_Process 2 Outcome_** L&I effort to exploit potential that exist at industry-level: *High L&I effort* *Medium L&I effort* *Low L&I effort*	**KIMS Technological Capability Level** at the end of the Stage:** *User* *Adaptor* *Innovator* *N = Sample Size*	CHILE **_INDUSTRY LEVEL_** **_Process 1 Outcome_** L&I potential shaped by Industry-level factors: *High potential* *Medium potential* *Low potential* **+** **FIRM LEVEL** **_Process 2 Outcome_** L&I effort to exploit potential that exist at industry-level: *High L&I effort* *Medium L&I effort* *Low L&I effort*	**KIMS Technological Capability Level** at the end of the Stage:** *User* *Adaptor* *Innovator* *N = Sample Size*
	Gestation* 1940s to early 1970s	**_High potential for L&I_** High production scale & growth Important challenges Mining firms enable L&I **+** **_High effort of L&I_** Active experts' development High 'External' & 'Internal' L&I Active L&I interaction web	AVERAGE CAPABILITY LEVEL OF KIMS SUPPLIERS SAMPLE: **Users** User 100% Adaptor 0% Innovator 0% N = 1 MINING FIRMS CAPABILITY LEVEL: **Innovators**	**_Low potential for L&I_** Low production growth Minor challenges Mining firms import KIMS **+** **Low effort of L&I** Passive experts' development, Low 'External' & 'Internal' L&I Passive L&I interacting web	AVERAGE CAPABILITY LEVEL OF KIMS SUPPLIERS SAMPLE: **Users** User 100% Adaptor 0% Innovator 0% N = 1 MINING FIRMS CAPABILITY LEVEL: **Users**
Pervasive Technological Rejuvenation	**Emergence & Development** Mid 1970s to early 1980s	**_High potential for L&I_** High production growth Important challenges Emergence of many KIMS firms **+** **_Medium effort of L&I_:** Weaken experts' development Medium 'External' & 'Internal' L&I Active L&I interaction web	AVERAGE CAPABILITY LEVEL OF KIMS SUPPLIERS SAMPLE: **Adaptors** User 37% Adaptor 50% Innovator 13% N = 9	**_Medium potential for L&I_** Accelerating production growth, New challenges Nationalisation stimulates L&I **+** **_Medium effort of L&I_** Increase experts' development, Medium 'External' & 'Internal' L&I Passive L&I interacting web	AVERAGE CAPABILITY LEVEL OF KIMS SUPPLIERS SAMPLE: **Users** User 83% Adaptor 17% Innovator 0% N = 6
	Internationali-sation Late 1980s to late 1990s	**_High potential for L&I_** High production growth Important challenges KIMS exploit global L&I web **+** **_High effort of L&I_** Resetting experts' development High 'External' & 'Internal' L&I Active L&I interaction web	AVERAGE CAPABILITY LEVEL OF KIMS SUPPLIERS SAMPLE: **Adaptors**. User 0%. Adaptor 69%. Innovator 31%. N = 14	**_High potential for L&I_** High production growth Important challenges International KIMS exploit L&I **+** **_Medium effort of L&I_** Active experts' development, Medium 'External' & 'Internal' L&I Restricted to L&I web	AVERAGE CAPABILITY LEVEL OF KIMS SUPPLIERS SAMPLE: **Adaptors** User 13% Adaptor 74% Innovator 13% N = 8
	Consolidation Early 2000s still going on	**_High potential for L&I_** High production growth Important challenges Large globally organised KIMS **+** **_High effort of L&I_** Difficulties with talent attraction, High 'External' & 'Internal' L&I Active L&I interaction web	AVERAGE CAPABILITY LEVEL OF KIMS SUPPLIERS SAMPLE: **Innovators** User 0% Adaptor 27% Innovator 73% N = 16	**_High potential for L&I_:** High production growth Important challenges International KIMS high control **+** **_Medium effort of L&I_** Active experts' development, Medium 'External' & 'Internal' L&I Restricted L&I web.	AVERAGE CAPABILITY LEVEL OF KIMS SUPPLIERS SAMPLE: **Adaptors** User 20% Adaptor 40% Innovator 40% N = 10

* At this stage the focus is on capability level accumulated in vertically integrated KIMS activities in mining companies.

** Technological capability level defined in Section 5.4.

During the next stages (Internationalisation and Consolidation), Australian KIMS suppliers increased learning and innovation efforts up to high level of effort in a context of high potential for learning and innovation. This fostered the level of capability accumulated within KIMS suppliers and they became innovators during the internationalisation stage able to profit from the opportunities opened by the rejuvenation process and remained as innovator during the consolidation stage.

In contrast in Chile, despite having high learning and innovation potential at the industry level, KIMS suppliers, which were pursuing just medium level of learning and innovation effort, became only adaptors. By the 1990s the tide had turned against small adaptors and only a massive active learning and innovation effort would have overcome the industry-level barriers, and Chilean KIMS suppliers were not in a position to do that.

Besides the differences between Chile and Australia in terms of learning and innovation effort and potential for learning and innovation, timing plays a very important role to understand these contrasting paths. Indeed, it was during the earlier phases of the industry's development that opportunities for the entry of new firms into rapid growth in the emerging KIMS sector were particularly open. It was also during those earlier stages that the capability foundations were laid for KIMS firms to engage actively and positively in the subsequent phases of internationalisation and consolidation. Australian KIMS suppliers made a higher learning effort and faced higher learning potential during these early stages than Chileans. Hence, Australian KIMS suppliers were in much better shape to overcome the barriers and sustain an active learning effort in an industry with high learning potential while Chilean KIMS were crowded out.

8.3 The Main Research Contributions and Some Limitations

8.3.1 The Contributions of the Research

The main contributions of this research are discussed here under two headings: (a) descriptive findings about technological learning in the KIMS supplier sector in a developing country context, and (b) the broad analytical framework and derived insights about factors that shape the learning process.

Technological learning in the KIMS sector in a developing country context

Over the last 20 years a very substantial literature has been developed around issues concerned with learning and the accumulation of innovation capabilities in manufacturing firms in developing countries. There have been repeated calls to widen the scope of such research to encompass the service sector, especially knowledge-intensive business services (KIBS) that have been the subject of increasing research interest in the advanced economies. However, although there has been some research about the general economic significance of the KIBS sector, and its role in implementing innovation in developing economies, there have been very few studies of how learning and capability accumulation take place in the sector, and these have focused primarily on software and related ICT services (e.g. Lema, 2009, 2010). As far as I am aware, there have been no studies of learning in knowledge-intensive service sectors supplying particular industries like mining. The research in this thesis about knowledge-intensive services for the mining industry (KIMS) contributes to this neglected area.

More specifically, the contribution incorporates two features that have been rare in the literature about learning and capability accumulation in developing countries. First, it sets that analysis in the context of a global history of the industry involved, the KIMS industry, and not merely in the context of localised country-specific history. That history involved the transition from the industry's origins in vertically integrated activities in mining companies, via vertical disintegration at national levels and then increasing internationalisation, to its consolidation into a tiered, international value chain with large diversified corporations at the apex. Second the research involved inter-country comparison – not merely between different developing economies, but between one of them (Chile) and an economy that even in the 1950s and 1960s already had many of the characteristics of an advanced economy, albeit one that also, like most developing countries of the time, had an economic structure that was heavily based on natural resources.

This combination resulted in a description of learning paths and processes that is dominated by diversity: both differences arising from change over time and differences between the two contexts. It also enables conclusions to be drawn about the rate of learning and capability deepening over the long term, albeit only in somewhat limited and relative terms.

There were common elements in the two paths. Central to the capability building process was the accumulation and upgrading of expert knowledge by individual professionals – the base of KIBS capabilities. Behind this lay career development and learning paths pursued by KIBS professionals within their employing firms as a basis not only for building initial technological capabilities, but for sustaining and further increasing them, and hence also for sustaining and increasing the competitiveness of KIMS firms. A common feature was also the key role that the KIMS users, mining companies, played in two ways: both as training centres, incubators and coordinators of key elements of the KIMS learning process, even after the vertical disintegration stage; and as key nodal points in a network of knowledge-centred user-producer interactions that helped to shape the learning process in supplier firms, especially after the disintegration stage. Finally, another common feature was the cumulative deepening of capabilities along lines that were very similar to those that have been described for manufacturing firms: running from capabilities to use and absorb technologies created elsewhere, via capabilities for incremental improvement and adaptation involving relatively unsystematic innovation, to more formally organised R&D-based innovation and the creation of significantly novel technology.

But cutting across those commonalities were several significant differences between the two countries in the details of those processes. At the start of the history, the intensity of efforts to support the career development paths of KIMS professionals was widely different between the two countries at the level of public organisational resources like universities and research centres and at the level of purposefully managed, firm-level activities. But most aspects of that difference persisted. Over the 40-50 year period, Chile did not ‘catch up’ in the intensity or ‘quality’ of those detailed learning activities. Similarly, the role of the mining company users of KIMS differed sharply, playing a much less supportive and positive role in Chile than in Australia. Again this was not just a feature of the early stages. Although that role changed over time in Chile after the nationalisation of the mining industry and its consolidation in a large local enterprise, it also changed in the case of the Australian industry where the mining companies played new roles in supporting learning by KIMS firms. Thus the difference persisted over the whole period. This was particularly so with respect to the learning-intensity and innovation-centred purposes of interactions between KIMS suppliers and their mining company customers.

For all these reasons, the cumulative paths of capability deepening in KIMS firms were different in the two countries. Australian firms moved much more quickly than their Chilean counterparts from being technology users and absorbers to being innovative technology creators. As a result, at least among the surveyed 'leading firms' in the two countries, a smaller proportion in Chile were active innovators by the early 2000s – some 40 years after the nationalisation of the domestic industry in 1971 provided a new base for the development of its technological capabilities.

However, the contribution of the thesis does not simply stop at these descriptions of difference and change in micro-level aspects of the long-term paths of learning and capability accumulation. There were further contributions associated with the identification of factors that contributed to those differences – based on the development of an original analytical framework.

The analytical framework and derived insights about the learning process

A key contribution of the thesis is the analysis of industry-level factors that interacted with the micro-level learning processes to shape the differing long-term paths of capability accumulation in the two KIMS industries. But the learning dynamic model that was used as a framework for this analysis was not drawn directly from the literature. It was developed specifically for this research and is an important output from it. As far as I am aware it is an original contribution to research in this field. This is particularly so, because its two main components (the industry level factors in Process 1 and the micro level factors in Process 2) are embedded in a yet broader perspective on the evolution of the global mining industry – its techno-organisational ‘rejuvenation’ along the lines suggested by Perez (2001).

It has been common for general reviews of learning and capability building in developing countries to suggest that industry-level factors are important in shaping micro-level processes and outcomes – for example Lall (1992). But it has been much less common for detailed empirical analyses to examine such factors. Instead, it has been more usual to jump from micro-level analysis to macro-level contexts concerned, for example, with policy regimes (e.g. protected import-substitution regimes versus liberalised regimes with higher levels of competition and open-ness to trade), or wider institutional systems (e.g. East Asian versus Latin American bureaucratic and political systems).

In contrast, this research incorporated industry-level factors in its analytical framework, and this yielded interesting insights – essentially propositions about the ways in which micro-level learning processes were influenced by:

- The scale and rate of growth of the KIMS-using industries in the two countries;
- The technological and organisational complexities and challenges facing the mining companies, both in domestic and international operations;
- The size-structure of the KIMS supplier industry;
- The degree of internationalisation of the KIMS industry.

The interacting combination of differences in these industry-level conditions (elements of Process 1) and in micro-level learning efforts (Process 2) seems to have played a major part in accounting for the different paths of development of KIMS sector capabilities in Chile and Australia – a central proposition emerging from this research.

But a further level of insight has been provided because these aspects of the analytical framework were set in the broader context of ideas about the techno-organisational ‘rejuvenation’ of mature industries. This is linked to the argument of Perez (2001) that such phases of rejuvenation not only open windows of opportunity for firms in developing countries to enter new technological fields and industries, but also that such windows of opportunity may close, or at least change their form, as the cycle of techno-organisational change at the global level moves towards an increasingly mature phase.

This argument about the way opportunities for latecomer firms in developing countries change over cycles of fundamental technological and organisational change has been advanced as a general proposition for many years – at least since the work of Perez and Soete (1988), though the argument had less specific reference to the rejuvenation of mature industries at that time. But there appears to have been no empirical examination of whether and how this opening and closing of windows for developing country firms operates in the case of specific mature industries. This thesis provides such an examination, albeit one that is necessarily exploratory.

The resulting argument is that the interaction of Processes 1 and 2 did not operate in the same way in different contexts independently of their historical timing relative to the global paths of fundamental techno-organisational change. On the contrary, differences between Australia and Chile in the timing of similar features of those two processes had different consequences with respect to the development of technological capabilities and the emergence and sustainability of internationally competitive KIMS firms.

In Australia, both industry-level and micro factors operated in the 1960s and 1970s to provide the mining industry with a base of KIMS-related capabilities for what Perez (2001) calls 'autonomous' exploitation of the window of opportunity that was being opened by the emergence of a new phase of fundamental technological and organisational change. Once established as innovative actors in the acceleration of this phase of technological change during the emergence of the specialised KIMS sector running into the 1980s, Australian firms were in a position to play a leading role in the internationalisation of the industry during the 1990s. This in turn reinforced their technological capabilities, as well as market positions. As a result they were then also in a strong position to play an active role in the consolidation of the industry in the early 2000s.

In contrast [to the Australian experience], industry-level and micro-level factors concerned with technological learning seriously constrained the development of KIMS-related capabilities in Chile in the period before the 1970s, and although these conditions changed somewhat in the 1970s, they still acted as a constraint on the emergence of strong, KIMS-related innovative capabilities in both the national mining company and local KIMS suppliers. By the late 1980s and increasingly by the mid-1990s, both sets of conditions changed to have broadly similar characteristics to those that had existed in Australia about 25 years earlier. By then however, the window of opportunity for developing country firms had radically changed. Chilean KIMS firms faced the competitive challenge of established international firms, including Australian companies, which had strong innovation-based positions in international markets – including the Chilean firms' home and nearby regional markets. By the early 2000s they faced the further challenge posed by the fact that those international KIMS firms were active leaders in the process of merger and acquisition that was contributing to the consolidation of the global KIMS industry. Those large diversified companies were coming to occupy the top tiers in the global value chain, while Chilean firms were being absorbed into the structure as local subsidiaries of international firms or as small independent companies – in either case occupying what were growth-constrained lower tier positions in the structure of the supply chain.

The significance of other factors needs to be considered in connection with this overall conclusion. It seems highly likely that factors other than those considered in the learning-related analysis in the thesis contributed to shaping the path of KIMS sector development in Chile – probably not only those outlined in Section 3.8 but also others. Interesting propositions about the influence of such factors merit further examination. However the argument here is that the path was already heavily constrained by the learning-related issues examined in the thesis.

At the very least the analysis in the thesis adds to the plausibility of the broad proposition put forward by Perez that, in the context of technological cycles at the global level, 'windows of opportunity' for developing countries to create new kinds of internationally competitive technological capabilities constitute 'moving targets' (Perez, 2001). Thus in the case of the KIMS industry in Chile in the early 2000s, the conclusion may be not so much that Chilean firms still had further to go to 'catch up' effectively in the global industry. Instead, it seems plausible that, because of the cumulative constraints that were faced, they had 'missed the bus' in the sense that the moving target of opportunity that had opened up around the 1970s and 1980s had passed them by without being fully exploited. Or at least, a more firmly based version of the argument is that, if the window of opportunity of the 1970s had not completely closed by around 2000, it had taken on a very different shape that was much more difficult to climb through. This seems to be a specific case that is consistent with Maloney's analysis of 'Missed Opportunities' during the resource-based growth of Latin America during the 20th century – an analysis that has at its core a view that Latin America failed to develop adequate human resources and innovative capacity in association with the expansion of resource-based production (Maloney, 2007).

8.3.2 Some limitations

The research design developed for this study involved a combination of choices:

- An analysis over a relatively long period of time during which key historical conditions were changing;
- a relatively high level of reliance on the acquisition of original non-documented types of information;
- a relatively wide range of explanatory variables, spanning both micro-level behaviour and meso-level structural conditions;
- and also a substantial element of comparison across two geographically distant contexts;
- and consequently a high level of reliance on small samples of survey informants, albeit selectively structured to concentrate on relatively homogeneous groups of 'leading firms'.

Each of these interconnected design choices within the overall strategy for this research can be contrasted with alternatives that are perhaps more common in doctoral research: shorter time-periods, a more limited range of variables, greater reliance on available information from documented records and data compilations, less demanding and expensive comparison between more localised contexts, and the use of primary data derived from larger samples of observations.

Such alternative approaches to design typically result in research with significant strengths in terms of the reliability of data and the rigour of analysis used to substantiate and test hypothesised relationships. Those two strengths are areas where the contrasting strategy used for the research reported in this thesis has resulted in limitations.

First, despite the considerable efforts made to achieve high reliability in the data derived from the two interview surveys, some degree of unreliability is inevitably likely to have resulted from the need for respondents to draw on recollections that extended, at least in some cases, over considerable periods of time. Such unreliability is unlikely to have been very significant with respect to the more basic 'factual' information – for example, the occurrence of particular types of innovative activity at particular times in the history of specific firms; or the previous employment backgrounds of the founders of new KIMS firms. On the other hand, it is probably greater with respect to more qualitative information or the subjective weight and interpretation respondents attached to events and 'facts' – for example, the 'significance' of knowledge inputs from external sources, the constraints on Chilean KIMS firms arising from recent changes in the mode of contracting for services by mining companies, or the extent to which personally experienced career paths were experienced more widely in the industry.

Nevertheless, there are no signs in the details of the data that such unreliability seriously undermines the validity of the main descriptive information used in the analysis. In any case, it is possible that any inaccuracy is much less in the case of the information about Chilean KIMS firms, the core focus of the study, than for their Australian counterparts from which much of the basis for 'benchmarking' comparison was derived. This is because the length of interviews was sometimes longer in the Chilean cases, the occurrence of multiple interviews about individual firms was a little higher, and the opportunities for cross-checking via other informants and documentary sources was a little greater. Moreover, some aspects of any inaccuracy have limited importance – especially those concerned with the inability to draw generalisations about the experience in the overall KIMS sectors in the two countries. Much of the interview-derived data refers explicitly to the sample of firms that were 'leading' with respect to technological capabilities and export performance. The intention was not to draw generalisable conclusions about the whole population of KIMS firms, but to focus essentially on the advanced 'frontier' of experience in the sector – especially in Chile.

Second, the heart of the thesis consists of a dense set of relationships that are put forward as providing causal explanations for the difference between Chile and Australia in the development of KIMS technological capabilities, and in particular for their limited development in Chilean KIMS suppliers. But the rigour with which those relationships are substantiated is limited and there was no basis for attempting any significant 'test' of their validity.

However, the thesis makes no claims to offer such forms of rigorous testing of these propositions. Instead, as emphasised in the preceding section, the concluding contributions of the research in terms of those relationships are put forward as hypotheses – propositions that, it is argued, seem interesting and plausible. Further, as suggested below, even in that form they may also be useful in considering issues about policy and management. Hopefully others will be encouraged to explore the issues further.

8.4 Policy Implications

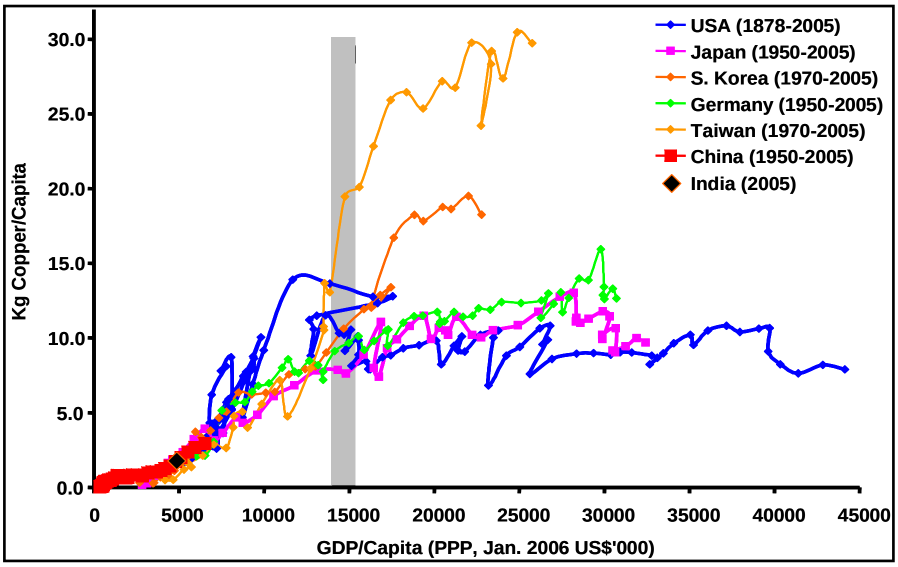
As noted in Chapter 1 the context for discussing policy issues arising from this thesis is deeply embedded in a wider discussion about the overall role of mining industries in developing countries: is that role developmentally positive or is it substantially negative as summarised by the idea of the 'resource curse'?

In recent years views about the answer to that question have been shifting to encompass arguments that there is no inherently fixed and generalisable answer. Instead it depends on several factors that are in principle amenable to modification by policy interventions. Among these arguments, considerable weight has been given to the view that the developmental outcomes of resource-intensive growth depend heavily on the extent to which the expansion of resource-based industries like mining is associated with the development of human capital and more knowledge-intensive economic activities. This for example is the core message of a World Bank study: *From Natural Resources to the Knowledge Economy* (De Ferranti *et al*. 2002). It is also the central message of Maloney's (2007) study of the ways in which resource-based growth in Latin America involved *Missed Opportunities* stemming in large part from the inadequate development of human capital and innovation capabilities.

Even in their exploratory and qualified form, the conclusions of this study of factors influencing the development of a strong, internationally competitive KIMS supplier industry can contribute to that strand of policy debate.

It is also the case that, with continuing expansion of global mining production, the importance of that debate will persist. Over the last decade mining production has experienced very rapid expansion. This trend is projected to continue at least over the next decade, driven by the sustained growth in global demand for commodities, particularly in China and India. This common view assumes that the consumption of commodities in such fast growing economies will continue to follow the same historical pattern as in other economies at similar stages of development. Graph 8.1 shows this historical relationship between commodity consumption and income level over various periods up to 2005 for the specific cases of copper. Extrapolating such relationship for China and India leads analysts to predict a continuing rise in global demand and production.

Graph 8.1: Copper Consumption Intensity per Capita



Source: Hernández, 2007.

The continuing expansion of mining production will open up important learning opportunities to foster the development of innovative and competitive KIMS supplier sectors in developing mining countries – especially in Latin America and Africa. In broad terms, the conclusions of this research suggest that debate about policy interventions to support the exploitation of those opportunities should take account not only of the recognised importance of basic education and training in universities and research centres. They should also take account of commonly neglected aspects of the learning process:

- the importance of sustained investment *by firms* in explicitly managed training and learning over the career development paths of KIMS professionals;

- the importance of *learning-intensive interactions*, and not just contractual supply relationships, between mining companies and KIMS suppliers.

In addition, debate should take into account three important features of the contemporary context for learning in these ways:

- the increasingly mature stage of the cycle of techno-organisational change in the industry, in particular the high degree of outsourcing of vertically disintegrated KIMS production;

- the high and rising level of consolidation in both the mining industry and the KIMS supplier sector;

- the pervasive internationalisation of both mining and KIMS companies, along with the importance of operating in international markets for the competitiveness of KIMS production.

In that context, debate about policy could usefully consider the following areas of intervention.

8.4.1 Mining companies

Despite the pervasive outsourcing of KIMS production, mining companies still play an important role in training experts, undertaking innovation and integrating technologies. Consequently the technological activities of mining companies associated with their investment projects and ongoing operations are at the core of the KIMS-related innovation and learning systems of mining industries – contributing not only to the spill-over of experienced personnel to KIMS firms, but also to the learning-intensity of links between mining companies and those firms. Thus, consideration might be given to policies that encourage both local and international mining companies to strengthen their internal technological capabilities and innovation activities in developing country operations, and to engage young professionals in learning roles in those activities.

8.4.2 International engineering companies

Since large international engineering companies have increased their control over the mining industry's global value chain, they have acquired an important role in the industry's investment projects and operations worldwide. Consequently, like mining companies, and perhaps to an even greater extent than them, they can play an important role in training professionals and shaping the learning and innovation process. Thus, consideration might be given to policies that encourage these international KIMS suppliers to make a greater use of their projects and operations in developing countries and elsewhere as part of training programmes for local KIMS professionals.

8.4.3 Universities and research centres

In order to provide effective support for KIMS sector development, universities and research centres need to do more than provide initial platforms of basic education and training. To a greater extent than seems common, they need to integrate their training with managed and systematic engagement with practice. Thus, consideration might be given to policies that encourage these organisations to develop stronger alliances with large KIMS suppliers and mining companies as a basis for much more extensive collaborative graduate and postgraduate programmes.

8.4.4 Learning-intensive user-producer interactions

It is common to think that fostering commercial customer-supplier links along supply chains contributes more or less automatically to knowledge flows and interactive learning between the contracting parties. However, the learning-intensity of such relationships is highly variable. Thus consideration might be given to policies that encourage more knowledge-rich relationships in KIMS supply chains.

8.4.5 Local KIMS suppliers

As a necessary complement to activities arising from the areas of policy intervention sketched above, the intensity of learning efforts on the part of local KIMS suppliers needs to be substantial. Thus where suitable measures do not exist to support KIMS firms in developing such learning and capability deepening activities, consideration might be given to policies that encourage such efforts. Such approaches would need to extend beyond conventional training and R&D subsidies to encompass a wider range of skills (e.g. management skills as well as ‘technical’), activities (e.g. a spectrum of engineering activities and not just R&D), and learning mechanisms (e.g. to acquire experience and not just to participate in conventional training programmes). Because of the importance of international activities and of learning associated with them, policy interventions might also include measures to encourage KIMS firms to acquire international experience and engage in international activities. Also, given the importance of the scale of KIMS firms and the diversity of their product portfolios, intervention might even extend to facilitating collaboration, alliances, and even joint-ventures or mergers among local KIMS suppliers.

8.5 Further Research

The exploratory research reported in this thesis presents only a preliminary view of the learning process and development of KIMS suppliers’ capabilities in merely two countries and a handful of KIMS firms in each. Moreover, as stressed earlier, the design of the research precluded rigorous testing of the key relationships identified. At the same time, the sketchy comments about policy immediately above rest on no research that was specifically directed at understanding the appropriateness, or even the feasibility, of the areas of intervention in any particular context. Further research could usefully push back some of those constraints. Possible directions of research can be conveniently sketched under three general headings, though these involve large potential overlaps: (a) widening the range of countries covered, (b) deepening the understanding of specific issues, and (c) extending the analysis to similar knowledge-intensive service sectors supplying other user industries.

8.5.1 Widening the range of country experience covered

Three kinds of widening would be useful.

- First, understanding the processes of learning and capability development in other advanced economies, in particular Canada, would not only help to identify whether Australian experience is seriously atypical. It would also be likely to identify a wider range of approaches to the details of organising and managing learning processes at the level of individuals, institutes like universities and research centres, firms and industries – issues that need to be explored more generally – as suggested below.

- Second, understanding the processes of learning and capability development in other Latin American mining economies like Peru, Brazil, Mexico and Argentina would help to identify regional similarities and differences, as well as possibilities for collaboration across countries in specific programmes and wider approaches to policy.

- Third, extending a similar analysis to Africa could be especially important. Not only is mining production expanding very rapidly in several African countries, but the dominance of mining within the structure of their economies is often particularly high, making issues about possible ‘resource curse’ effects more important than elsewhere. At the same time, the current situation facing local KIMS sector development in those countries within the contemporary global industry is fundamentally different from any of those examined in this study. With the exception of South Africa, no African countries are engaging in KIMS sector development in combinations of local and global situations that are anything like those of Chile in 1970 or at any stage since then. Learning from Chile may have some value, but may also be quite misleading, and understanding the specifics of African situations is a pre-requisite for thinking about areas and forms of policy intervention.

8.5.2 Deepening understanding of particular issues

Deeper understanding would be particularly useful in four areas.

- Effective ways of managing key aspects of training and learning during the career development of KIMS professionals are poorly understood, and research is needed to generate insights into good practice across different types of learning in different organisational locations and different socio-economic contexts.

- Deeper understanding is also needed about effective ways of developing and managing more learning-intensive interactions between different actors in the sectoral learning and innovation system, especially between users and producers at different stages in the KIMS value chain.

- Much greater understanding is needed about approaches to policy intervention in this area: what kinds of detailed mechanism are likely to be effective and feasible in different kinds of circumstance?

- Finally, greater understanding about a more general issue would be valuable. This thesis examined the relationship between 'windows of opportunity' for developing country firms to enter and establish leading positions in global industries and the constraints on their exploitation. But it did so only during what might be described as the 'middle decades' of the ICT-related techno-economic paradigm. But what happens after that? Are the late stages of such cycles as restrictive as has been suggested? Or do different kinds of new opportunity emerge? Do completely new kinds of opportunity arise as the mature phase of one paradigm begins to overlap with the early phase of a new paradigm? Is the effectiveness of exploitation of those overlapping opportunities linked, with successful exploitation in the old being a necessary basis for, or perhaps a constraint on, effectiveness in exploiting the new?

8.5.3 *Extending the analysis to similar knowledge-intensive service industries*

There is good reason to believe that many of the features of learning and capability accumulation to develop knowledge-intensive service industries to supply the mining industry are similar to those of other knowledge-intensive service suppliers to other industries such as transport, communications and other infrastructure sectors. Since these are particularly important segments of the economies of many developing countries, the opportunities for developing associated knowledge-intensive supplier sectors may be similarly important to those connected with mining – and perhaps giving rise to missed opportunities that are similar to those described for Chile in this study or to those described more generally by Maloney (2007) with respect to resource-intensive growth in Latin America.

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APPENDICES

APPENDIX 1: List of Interviewees during fieldworks in Chile and Australia

Interviewees during fieldwork in Chile:

1. Roberto Abeliuk, Manager, GHD Promina
2. Arthur Edward Anglin (Mike), Vice President – Base Metals, BHP Billiton
3. Elias Arze, Manager, ARA
4. Ricardo Badilla, Manager, Biosigma
5. Jorge Bande, Director, Codelco
6. Angus J. Brodie, Manager, SKM
7. José Campos, Manager, Alquimia Ingenieros
8. Francisco Carrasco J., Researcher, IM2
9. Rolando Carmona, Director, Drillco Tools
10. Luis Castelli, Director, Codelco
11. Orlando Castillo, Innova – Corfo, Chilean Government
12. José Castro, Manager, SKM
13. Rossana Cavalli, Engineer, AIC
14. Julio Cerna, Manager, Cerna Ingenieria
15. Christian Contador, Manager, ORICA-Chile
16. Fernando Cortés G, Director, Asociacion de Industriales de Antofagasta
17. Ricardo Cortes, Revista Mineria Chilena
18. Davor Cotoras, Manager, Biohidrica
19. Hugo Díaz, Manager, Modular Mining Systems
20. Alfonso Dulanto, Former Minister of Mining, Chilean Government
21. Michael Eamon, BHP Billiton
22. Víctor Encina M., Researcher, IM2
23. Patrick Esnouf, Former Presidente, Anglo American Latin America
24. Ernesto Ewertz Duhau, Corporacion de Bienes de Capital
25. Antonio Flores, Manager, Conymet-Duratray
26. Alejandro Font, Manager, GHD Promina
27. Jonkion Font Carmona, Engineer, IM2
28. Ramón Freire, Geologist, IM2
29. Fernando Fuentes, Manager, NCL
30. Juanita Gana, Codelco
31. Hans Göpfert, Engineer, Cadeidepe
32. Aron Grekin, Manager, Indec
33. Juan Carlos Guajardo Beltrán, Director, Cochilco
34. Diego Hernandez, Presidente Base Metals, BHP Billiton
35. Lincoyán Hernández, Manager, JRI
36. Javier E. Jullian Fuentes, Manager, Cadeidepe
37. Gustavo Lagos, Mining Centre, Catholic University
38. Cleve Lightfoot, BHP Billiton

39. Marcos Lima, Former Vicepresident, Codelco
40. Manuel Medel, Manager, Conymet-Duratray
41. Mauricio Medel Echeverría, Manager, Conymet-Duratray
42. Germán Morales, Manager, IM2
43. Juan Enrique Morales, Vicepresidente, Codelco
44. John O. Marsden, Senior Vice President, Phelps Dodge
45. Pedro Morales, Manager, Codelco
46. Rodrigo Moya, Engineer, BHP Billiton
47. Daniel Murillo, Manager, ORICA-Chile
48. Guillermo Olivares, Engineer, Cochilco
49. Carlos Orlandi, Manager, Enaex
50. Nancy Pérez, Manager, IM2
51. José Pesce, President, Metalica
52. Alejandro Plaza, BHP Billiton
53. Juan Rayo, Manager, JRI
54. Jaime Rauld, Director, Antofagasta Minerals
55. Juan Carlos Román, Director, Antofagasta Minerals
56. Juan Carlos Salas, Independent Consultant
57. Juan Daniel Silva, Engineer, Tricomin
58. Andrés Susaeta, Mining Engineer
59. Mauro Valdes, Vice President, BHP Billiton
60. Armando Valenzuela, Engineer, Cochilco
61. Francisco Valenzuela, Sales Manager, UDR
62. Luis Valenzuela, Manager, Arcadis-Geotecnica
63. Eugenio Varela, President, Corporacion de Bienes de Capital
64. Aquiles Vergara, Enaex
65. Pabla Viedma, Manager, Biohidrica
66. Francisco Walther, Director, Codelco

Interviewees during fieldwork in Australia:

1. Jenny Archibald, Director, Fractal Technologies
2. Ben Adair, Director, JKMRC
3. Mark Barley, CRC for Predictive Mineral Discovery (pmd*CRC)
4. Harry Bloch, Professor, Curtin Business School
5. Greg Carmody, Executive Officer, Austmine
6. Jock Cunningham, CSIRO Mining Automation
7. Robert D'Alessandro, Manager Engineering Global Supply, BHP Billiton
8. Richard Dewhirst, Manager, SKM Consulting
9. Gerry Doyle, Manager, Mincom
10. Phil Edmiston, Manager, Maptek
11. John Farrow, Manager, AJ Parker CRC for Integrate d Hydrometallurgy Solutions

12. Eduardo Feick, BHP Billiton
13. German Ferrando-Miguel, Environmental Scientist, Erthsystems
14. Markus Fietz, Manager, CSIRO Minerals
15. David Fittler, BHP Billiton
16. Stevan Green, CEO, Centre for Sustainable Resource Processing (CSRP)
17. Dan Greig, Geologist, GRD Minproc
18. Ron Grogan, Technical Director, AMMTEC
19. Wally Hay, BHP Billiton
20. Peter Hrstich, Manager, Ausenco
21. Keith Huggan, Manager, ABARE
22. Juan Jofre, Engineer, University of Melbourne
23. Peter Knights, Researcher, CRCMining
24. Christian Larsen, Director, Runge
25. Miles Larsen, Director, GRD Minproc
26. Don Larkin, Chief Executive Officer, AUSIMM
27. Manuel Legua, Mechanical Engineer, SKM Consulting
28. Eugene Louwrens, Manager, JKMineralogy
29. Peter McCarthy, Director, AMC Consultants
30. Bruce A McDonald, Manager, Encom
31. Joe Pease, Manager, Xstrata Technology
32. Larry Platt, Director, Advitech
33. David Pratt, Director, Encom
34. Tim Procter, Manager, Advitech
35. Colin Roberts, Manager, RSG Global
36. Paul Rakovich, BHP Billiton
37. John Rankin, Chief Scientist, CSIRO Minerals
38. Don Scott-Kemmis, Director, Innovation Management & Policy Program, ANU
39. John Slattery, Manager, UDR
40. Rick Stroud, Manager, Swonden
41. Peter R Taylor, Softrock Solutions
42. Leanna Tedesco, ABARE
43. Lyndal Thorburn, Director, Innovationdynamics
44. Allan Trench, Woodside Petroleum
45. Eduardo Valenzuela, Manager, SKM Consulting
46. Deming Whitman, CEO, AMIRA
47. Paul Williams, Manager, Australian Tailing Consulting – MPA

Table A2.19: Evolution of World Mine Production Value over the 20th Century for a Selected Group of Metals

		COPPER	IRON ORE	GOLD	NICKEL	ZINC	SILVER	LEAD	BAUXITE	TOTAL
Decade/ Period	**Year**	**Value of World Mine Production (98'US$)**	**Value of World Mine Production (98'US$)**	**Value of World Mine Production (98'US$)**	**Value of World Mine Production (98'US$)**	**Value of World Mine Production (98'US$)**	**Value of World Mine Production (98'US$)**	**Value of World Mine Production (98'US$)**	**Value of World Mine Production (98'US$)**	**Value of World Mine Production (98'US$)**
1st Decade 20th Century: 1900 - 1909	1900	3,465,000,000	2,674,000,000	4,593,400,000	204,380,000	910,100,000	2,106,000,000	1,498,000,000	6,512,000	15,457,392,000
	1901	3,682,000,000	2,674,000,000	4,700,500,000	273,600,000	918,000,000	2,044,400,000	1,647,000,000	7,526,000	15,947,026,000
	1902	2,664,000,000	2,674,000,000	5,141,400,000	231,800,000	1,094,000,000	1,619,200,000	1,796,000,000	8,704,000	15,229,104,000
	1903	3,158,800,000	2,674,000,000	5,456,000,000	163,200,000	1,262,800,000	1,670,400,000	1,945,000,000	11,340,000	16,341,540,000
	1904	3,366,000,000	2,674,000,000	5,786,000,000	168,000,000	1,258,000,000	1,737,400,000	2,094,000,000	7,581,000	17,090,981,000
	1905	4,491,900,000	3,712,000,000	6,325,000,000	249,600,000	1,584,000,000	1,929,600,000	9,693,000,000	11,289,000	27,996,389,000
	1906	5,574,800,000	3,800,000,000	6,688,000,000	256,000,000	1,760,000,000	2,000,700,000	2,392,000,000	12,663,000	22,484,163,000
	1907	5,551,700,000	5,940,000,000	6,603,800,000	277,100,000	1,623,600,000	2,120,100,000	2,085,300,000	17,216,000	24,218,816,000
	1908	3,943,200,000	4,469,000,000	7,348,000,000	268,200,000	1,301,400,000	1,959,200,000	2,176,000,000	17,739,000	21,482,739,000
	1909	4,388,400,000	4,914,000,000	7,557,000,000	272,000,000	1,705,000,000	1,980,000,000	1,802,000,000	22,000,000	22,640,400,000
2nd Decade 20th Century: 1910 - 1919	1910	4,290,000,000	6,106,000,000	7,303,400,000	346,500,000	1,701,000,000	2,070,000,000	1,870,000,000	25,632,000	23,712,532,000
	1911	4,361,000,000	4,655,000,000	7,409,400,000	378,000,000	1,969,000,000	2,112,000,000	1,887,000,000	28,050,000	22,799,450,000
	1912	6,200,000,000	4,983,000,000	7,261,500,000	418,500,000	2,524,600,000	2,373,200,000	1,972,000,000	26,535,000	25,759,335,000
	1913	5,607,480,000	6,177,300,000	6,940,000,000	492,660,000	1,906,170,000	2,264,230,000	1,840,000,000	34,981,100	25,262,821,100
	1914	4,464,880,000	3,374,800,000	6,563,700,000	441,000,000	1,454,850,000	1,540,560,000	1,687,406,667	14,702,800	19,541,899,467
	1915	6,550,800,000	3,410,400,000	6,962,560,000	570,860,000	3,838,000,000	1,512,720,000	1,534,813,333	25,487,400	24,405,640,733
	1916	13,291,200,000	4,976,200,000	6,370,500,000	627,900,000	3,951,360,000	1,690,500,000	1,382,220,000	29,862,600	32,319,742,600
	1917	11,711,700,000	5,637,400,000	5,048,000,000	545,160,000	2,252,500,000	1,864,480,000	1,229,626,667	48,719,000	28,337,585,667
	1918	8,422,700,000	4,749,800,000	3,970,860,000	464,576,000	1,613,100,000	2,087,600,000	1,077,033,333	35,255,800	22,420,925,133
	1919	3,757,320,000	3,322,000,000	3,322,000,000	192,192,000	1,042,550,000	1,866,600,000	924,440,000	31,920,900	14,459,022,900
3rd Decade 20th Century: 1920 - 1929	1920	3,011,260,000	4,178,800,000	2,722,590,000	268,821,000	954,800,000	1,439,130,000	1,181,880,000	42,347,000	13,799,628,000
	1921	1,417,320,000	1,992,900,000	3,002,940,000	87,568,000	438,480,000	980,720,000	739,935,000	17,013,000	8,676,876,000
	1922	2,563,600,000	3,348,800,000	3,121,690,000	96,052,000	890,600,000	1,384,360,000	1,185,840,000	26,567,900	12,617,509,900
	1923	3,937,000,000	4,460,800,000	3,517,900,000	235,116,000	1,253,490,000	1,522,350,000	1,674,000,000	56,160,000	16,656,816,000

		COPPER	IRON ORE	GOLD	NICKEL	ZINC	SILVER	LEAD	BAUXITE	TOTAL
	1924	3,794,400,000	3,510,000,000	3,753,280,000	222,390,000	1,301,520,000	1,527,250,000	2,122,800,000	48,952,000	16,280,592,000
	1925	4,467,600,000	3,593,800,000	3,652,380,000	252,280,000	1,880,200,000	1,583,550,000	2,650,800,000	55,338,000	18,135,948,000
	1926	4,288,400,000	3,580,500,000	3,678,220,000	246,792,000	2,115,000,000	1,443,870,000	2,403,400,000	52,716,000	17,808,898,000
	1927	4,088,800,000	4,001,400,000	3,725,280,000	249,090,000	1,831,800,000	1,350,900,000	2,156,000,000	76,516,000	17,479,786,000
	1928	5,380,300,000	4,054,200,000	3,816,990,000	390,831,000	1,727,200,000	1,427,560,000	2,217,600,000	83,433,000	19,098,114,000
	1929	7,507,500,000	5,065,200,000	3,842,790,000	413,805,000	1,795,200,000	1,315,440,000	2,318,400,000	93,095,000	22,351,430,000
4th Decade 20th Century: 1930 - 1939	1930	4,604,600,000	4,331,800,000	4,192,560,000	410,294,000	1,247,400,000	928,800,000	1,824,000,000	76,284,000	17,615,738,000
	1931	2,772,000,000	3,010,700,000	5,379,300,000	300,201,000	774,728,000	607,392,000	1,272,600,000	59,225,000	14,176,146,000
	1932	1,381,680,000	1,280,160,000	5,986,760,000	200,342,000	540,258,000	548,910,000	874,650,000	59,400,000	10,872,160,000
	1933	2,121,000,000	4,040,160,000	8,485,100,000	447,721,000	999,040,000	752,940,000	1,112,800,000	81,620,000	18,040,381,000
	1934	2,982,400,000	3,864,000,000	11,437,600,000	672,324,000	1,187,200,000	1,126,120,000	1,236,000,000	114,912,000	22,620,556,000
	1935	3,495,000,000	4,360,800,000	12,289,200,000	711,306,000	1,379,400,000	1,688,050,000	1,476,600,000	150,096,000	25,550,452,000
	1936	4,334,400,000	5,287,000,000	13,596,000,000	845,270,000	1,689,100,000	1,346,400,000	1,793,400,000	239,701,000	29,131,271,000
	1937	7,671,500,000	6,784,000,000	13,970,000,000	1,048,800,000	2,396,100,000	1,416,960,000	2,501,710,000	297,000,000	36,086,070,000
	1938	5,193,900,000	4,795,200,000	15,210,000,000	1,026,950,000	1,675,600,000	1,331,200,000	2,040,000,000	340,560,000	31,613,410,000
	1939	6,177,000,000	7,160,400,000	15,990,000,000	1,104,100,000	1,980,000,000	1,220,100,000	2,262,000,000	362,390,000	36,255,990,000
5th Decade 20th Century: 1940 - 1949	1940	7,104,000,000	5,977,200,000	16,637,000,000	1,258,600,000	2,396,100,000	1,122,670,000	2,348,780,000	343,298,000	37,187,648,000
	1941	7,266,400,000	6,446,000,000	12,960,000,000	1,386,720,000	2,909,700,000	1,017,500,000	2,204,024,000	446,030,000	34,636,374,000
	1942	6,863,500,000	6,133,500,000	12,208,000,000	1,113,900,000	2,966,600,000	949,160,000	2,059,268,000	553,432,000	32,847,360,000
	1943	6,550,000,000	5,705,700,000	9,228,800,000	1,110,550,000	3,147,600,000	867,680,000	1,914,512,000	911,400,000	29,436,242,000
	1944	6,027,000,000	5,054,700,000	8,211,300,000	1,025,210,000	3,160,300,000	769,160,000	1,769,756,000	435,000,000	26,452,426,000
	1945	5,085,100,000	4,001,400,000	7,696,200,000	929,450,000	2,425,500,000	766,080,000	1,625,000,000	218,148,000	22,746,878,000
	1946	4,592,400,000	3,865,400,000	8,015,200,000	790,890,000	2,304,000,000	849,580,000	1,534,700,000	251,136,000	22,203,306,000
	1947	7,284,600,000	4,693,700,000	7,335,000,000	789,600,000	2,704,000,000	882,180,000	3,091,600,000	296,408,000	27,077,088,000
	1948	7,337,200,000	5,737,800,000	7,045,920,000	810,870,000	3,413,800,000	875,840,000	3,712,200,000	353,628,000	29,287,258,000
	1949	6,291,600,000	6,801,500,000	6,719,080,000	881,840,000	3,183,200,000	885,630,000	3,178,400,000	337,430,000	28,278,680,000
6th Decade 20th Century: 1950 - 1959	1950	7,639,800,000	8,333,200,000	6,645,240,000	971,500,000	4,450,500,000	1,017,520,000	3,247,200,000	340,288,000	32,645,248,000
	1951	8,466,000,000	9,996,000,000	6,189,830,000	982,080,000	5,852,800,000	1,111,590,000	3,856,000,000	424,010,000	36,878,310,000
	1952	8,506,700,000	11,315,700,000	5,928,440,000	1,128,580,000	5,672,100,000	1,125,600,000	4,036,300,000	514,560,000	38,227,980,000

		COPPER	IRON ORE	GOLD	NICKEL	ZINC	SILVER	LEAD	BAUXITE	TOTAL
	1953	10,166,000,000	14,027,000,000	5,901,120,000	1,593,900,000	3,898,200,000	1,152,300,000	3,384,700,000	558,900,000	40,682,120,000
	1954	10,560,000,000	16,605,000,000	6,590,950,000	1,766,880,000	3,803,800,000	1,107,220,000	3,760,000,000	665,820,000	44,859,670,000
	1955	14,616,000,000	16,236,000,000	6,496,420,000	2,127,100,000	4,785,000,000	1,218,000,000	4,100,400,000	799,220,000	50,378,140,000
	1956	17,728,000,000	18,170,000,000	6,601,500,000	2,217,040,000	5,535,800,000	1,228,500,000	5,064,000,000	868,560,000	57,413,400,000
	1957	12,672,000,000	20,311,200,000	6,640,200,000	2,711,280,000	4,599,000,000	1,222,300,000	4,474,400,000	1,004,500,000	53,634,880,000
	1958	10,463,200,000	18,913,500,000	6,678,000,000	2,063,040,000	3,776,000,000	1,203,660,000	3,548,500,000	1,052,880,000	47,698,780,000
	1959	13,102,600,000	20,808,600,000	7,130,300,000	2,596,350,000	4,258,200,000	1,126,330,000	3,480,000,000	1,150,380,000	53,652,760,000
7th Decade 20th Century: 1960 - 1969	1960	15,444,800,000	23,959,800,000	7,425,600,000	2,867,200,000	4,851,300,000	1,178,520,000	3,465,500,000	1,335,840,000	60,528,560,000
	1961	14,846,700,000	24,948,800,000	7,576,800,000	3,393,400,000	4,851,100,000	1,193,940,000	3,130,900,000	1,522,920,000	61,464,560,000
	1962	15,487,400,000	24,079,200,000	7,856,100,000	3,395,070,000	4,926,600,000	1,445,850,000	2,886,500,000	1,906,430,000	61,983,150,000
	1963	15,615,600,000	25,627,000,000	8,053,400,000	3,139,140,000	5,160,600,000	1,703,820,000	3,353,600,000	2,001,640,000	64,654,800,000
	1964	16,687,500,000	29,033,400,000	8,242,700,000	3,398,360,000	6,327,100,000	1,685,140,000	3,997,400,000	2,187,700,000	71,559,300,000
	1965	18,733,200,000	29,621,700,000	8,409,600,000	3,833,500,000	7,154,600,000	1,722,150,000	4,941,000,000	2,187,900,000	76,603,650,000
	1966	18,274,200,000	30,337,200,000	8,236,000,000	3,600,880,000	7,245,000,000	1,726,400,000	4,759,500,000	2,328,040,000	76,507,220,000
	1967	18,983,000,000	29,281,000,000	7,852,600,000	4,247,540,000	7,211,600,000	1,951,290,000	4,333,700,000	2,796,420,000	76,657,150,000
	1968	21,342,600,000	31,166,100,000	8,697,600,000	4,875,570,000	6,958,000,000	2,764,880,000	4,123,700,000	2,709,400,000	82,637,850,000
	1969	25,662,480,000	32,156,300,000	8,613,000,000	5,016,100,000	7,636,200,000	2,354,280,000	4,730,400,000	2,999,220,000	89,167,980,000
8th Decade 20th Century: 1970 - 1979	1970	31,712,500,000	33,528,400,000	7,281,600,000	7,473,200,000	7,753,200,000	2,236,104,000	4,915,500,000	2,959,360,000	97,859,864,000
	1971	27,460,620,000	34,628,000,000	7,743,000,000	7,516,600,000	7,893,600,000	1,839,502,000	4,292,700,000	3,061,530,000	94,435,552,000
	1972	28,906,800,000	36,643,800,000	10,202,600,000	7,393,100,000	8,268,800,000	1,974,490,000	4,450,500,000	3,290,430,000	101,130,520,000
	1973	33,292,120,000	39,592,800,000	15,525,000,000	8,804,000,000	9,535,700,000	2,928,430,000	4,606,800,000	3,238,400,000	117,523,250,000
	1974	39,980,100,000	45,977,600,000	21,250,000,000	9,779,000,000	15,143,600,000	4,635,556,000	5,723,600,000	6,614,760,000	149,104,216,000
	1975	28,880,900,000	53,127,800,000	18,840,000,000	11,067,600,000	15,210,000,000	4,059,615,000	4,953,600,000	4,607,680,000	140,747,195,000
	1976	31,893,180,000	58,075,400,000	13,915,000,000	11,246,400,000	13,314,600,000	3,940,920,000	5,387,400,000	5,270,940,000	143,043,840,000
	1977	29,383,200,000	56,599,300,000	15,488,000,000	11,095,200,000	12,076,800,000	4,115,880,000	6,206,200,000	5,577,390,000	140,541,970,000
	1978	26,390,000,000	58,697,100,000	18,876,000,000	7,435,400,000	10,003,500,000	4,641,660,000	6,435,600,000	5,337,900,000	137,817,160,000
	1979	33,552,750,000	62,487,600,000	26,862,000,000	9,055,200,000	11,081,500,000	8,649,720,000	9,126,000,000	4,890,600,000	165,705,370,000
9th Decade 20th Century:	1980	31,816,800,000	60,766,200,000	47,580,000,000	9,581,700,000	9,698,500,000	14,038,400,000	6,512,000,000	4,629,480,000	184,623,080,000
	1981	25,592,320,000	57,571,800,000	33,920,000,000	7,768,200,000	10,472,000,000	6,789,440,000	4,824,000,000	4,324,710,000	151,262,470,000

		COPPER	IRON ORE	GOLD	NICKEL	ZINC	SILVER	LEAD	BAUXITE	TOTAL
1980 - 1989	1982	20,549,380,000	50,999,300,000	27,336,000,000	5,048,730,000	8,765,900,000	4,964,550,000	3,274,050,000	4,369,430,000	125,307,340,000
	1983	21,011,210,000	56,092,000,000	31,220,000,000	5,148,450,000	9,357,200,000	7,282,990,000	2,619,700,000	3,698,900,000	136,430,450,000
	1984	18,064,530,000	51,978,300,000	26,572,000,000	5,789,770,000	10,953,600,000	5,381,480,000	2,832,000,000	4,072,240,000	125,643,920,000
	1985	17,881,620,000	50,368,500,000	23,715,000,000	6,130,020,000	9,126,000,000	3,919,520,000	2,162,820,000	3,696,380,000	116,999,860,000
	1986	17,190,100,000	43,977,600,000	28,336,000,000	4,916,040,000	8,550,000,000	3,399,500,000	2,336,040,000	3,616,200,000	112,321,480,000
	1987	21,498,160,000	38,377,500,000	36,520,000,000	6,183,540,000	9,562,700,000	4,526,200,000	3,910,200,000	3,068,600,000	123,646,900,000
	1988	31,932,640,000	37,713,000,000	36,278,000,000	18,088,000,000	12,389,100,000	4,484,150,000	3,864,600,000	3,204,460,000	147,953,950,000
	1989	34,324,880,000	41,612,000,000	32,562,000,000	17,272,500,000	16,231,600,000	3,813,000,000	3,876,000,000	3,635,900,000	153,327,880,000
10th Decade 20th Century: 1990 - 1999	1990	31,123,600,000	37,845,500,000	33,572,000,000	10,811,400,000	14,657,500,000	3,208,780,000	4,246,200,000	3,842,000,000	139,306,980,000
	1991	26,917,050,000	34,416,000,000	30,240,000,000	9,857,600,000	10,105,300,000	2,424,240,000	2,881,840,000	4,029,300,000	120,871,330,000
	1992	26,051,970,000	30,710,000,000	29,154,000,000	8,211,300,000	10,875,000,000	2,193,280,000	2,876,800,000	3,486,000,000	113,558,350,000
	1993	21,618,220,000	27,732,300,000	29,868,000,000	5,540,160,000	7,946,500,000	2,199,600,000	2,285,200,000	3,454,000,000	100,643,980,000
	1994	25,574,000,000	27,478,400,000	30,736,000,000	6,496,040,000	8,460,000,000	2,618,000,000	2,525,600,000	2,989,200,000	106,877,240,000
	1995	32,620,000,000	30,591,000,000	29,659,000,000	9,152,000,000	9,609,600,000	2,638,790,000	2,704,580,000	2,811,200,000	119,786,170,000
	1996	27,478,000,000	30,600,000,000	29,770,000,000	8,257,400,000	8,751,600,000	2,618,340,000	3,270,400,000	3,264,300,000	114,010,040,000
	1997	27,542,500,000	32,528,000,000	26,705,000,000	8,025,600,000	10,857,600,000	2,635,050,000	3,255,000,000	3,050,000,000	114,598,750,000
	1998	20,981,400,000	32,760,000,000	23,725,000,000	5,463,400,000	8,554,100,000	3,061,600,000	3,056,940,000	2,792,100,000	100,394,540,000
	1999	20,966,400,000	26,724,000,000	22,641,700,000	6,879,600,000	9,154,000,000	2,904,000,000	2,901,360,000	2,721,900,000	94,892,960,000
21st Century: 2000 - 2006	2000	24,301,200,000	26,108,000,000	22,092,700,000	10,552,200,000	10,173,200,000	2,751,200,000	2,912,000,000	2,978,400,000	101,868,900,000
	2001	21,358,300,000	23,504,000,000	20,956,000,000	7,329,800,000	7,947,720,000	2,438,100,000	2,764,320,000	2,931,800,000	89,230,040,000
	2002	20,590,400,000	25,506,000,000	23,128,500,000	8,275,500,000	6,577,440,000	2,479,000,000	2,499,770,000	2,649,600,000	91,706,210,000
	2003	22,796,800,000	32,606,000,000	26,520,000,000	11,686,100,000	7,612,800,000	2,557,600,000	2,684,700,000	2,681,500,000	109,145,500,000
	2004	36,660,600,000	42,478,000,000	27,459,000,000	16,541,000,000	9,580,800,000	3,506,600,000	3,265,500,000	3,084,600,000	142,576,100,000
	2005	48,096,040,438	57,733,782,645	29,799,424,246	18,500,101,095	12,187,666,386	3,819,026,116	3,697,000,842	3,701,769,166	177,534,810,935
	2006	88,871,287,129	72,508,250,825	40,401,175,743	30,528,094,059	26,320,132,013	5,766,336,634	4,665,742,574	4,089,108,911	273,150,127,888

Table A2.20: Evolution of Geographical Location of Copper Mining

Share of Production by Region

Region	1929	1951	1961	1971	1981	1991	2001	2005
WORLD TOTAL (Tonnes)	1,956,214	2,631,774	5,332,417	7,333,653	8,190,700	9,090,004	13,648,763	15,010,416
NORTH AND CENTRAL AMERICA	57.25%	44.61%	34.62%	35.00%	30.08%	30.11%	17.18%	14.42%
SOUTH AMERICA	19.63%	15.84%	17.17%	15.64%	17.59%	24.35%	41.67%	44.31%
EUROPE (Without USSR/Russia)	5.07%	5.34%	5.70%	7.17%	8.35%	9.44%	6.57%	5.92%
USSR/Russia	3.90%	9.65%	12.40%	10.22%	11.48%	9.90%	3.96%	4.40%
AFRICA	8.44%	21.24%	22.16%	21.51%	17.68%	9.85%	3.86%	4.56%
ASIA	5.04%	2.67%	5.74%	7.58%	9.34%	10.58%	18.72%	18.92%
OCEANIA	0.67%	0.64%	2.21%	2.89%	4.84%	5.77%	8.06%	7.48%

Share of Production by Country

		1929		1951		1961		1971		1981		1991		2001		2005
Rkg	Country	%	Country	%	Country	%	Country	%	Country	%	Country	%	Country	%	Country	%
1st	USA	46.26%	USA	32.00%	USA	24.09%	USA	22.88%	USA	18.78%	Chile	19.96%	Chile	34.72%	Chile	35.45%
2nd	Chile	16.39%	Zambia	14.87%	Zambia	13.09%	Chile	11.89%	Chile	13.20%	USA	17.94%	USA	9.81%	USA	7.59%
3rd	Congo, DR	7.01%	Chile	14.43%	Chile	12.55%	Canada	10.84%	USSR	11.48%	USSR	9.90%	Indonesia	7.68%	Indonesia	7.09%
4th	Canada	5.75%	USSR	9.65%	USSR	12.40%	Zambia	10.80%	Canada	8.44%	Canada	8.92%	Australia	6.56%	Peru	6.73%
5th	Mexico	4.42%	Canada	9.31%	Canada	9.08%	USSR	10.22%	Zambia	7.18%	Zambia	4.30%	Peru	5.29%	Australia	6.20%
6th	Japan	3.86%	Congo, DR	7.29%	Congo, DR	6.73%	Zaire	6.72%	Zaire	6.78%	Peru	3.93%	Canada	4.64%	China	5.33%
7th	Spain	3.26%	Mexico	2.56%	Peru	4.51%	Peru	3.53%	Peru	4.18%	Poland	3.52%	China	4.30%	Russia	4.40%
8th	Peru	2.87%	Japan	1.62%	Australia	2.21%	Philippines	3.27%	Philippines	3.69%	Australia	3.52%	Russia	3.96%	Canada	3.96%
9th	Germany	1.48%	South Africa	1.28%	Japan	2.20%	Australia	2.89%	Poland	3.59%	China	3.34%	Poland	3.47%	Poland	3.41%
10th	USSR	1.33%	Peru	1.23%	China	1.82%	South Africa	2.61%	Australia	2.82%	Mexico	3.21%	Kazakhstan	3.44%	Zambia	2.90%
11th	South Africa	1.12%	Yugoslavia	1.22%	Philippines	1.18%	Japan	2.01%	Mexico	2.81%	Zaire	2.61%	Mexico	2.72%	Mexico	2.86%
12th	Norway	0.89%	Cyprus	0.87%	Mexico	1.12%	China	1.65%	South Africa	2.55%	Indonesia	2.33%	Zambia	2.25%	Kazakhstan	2.68%
13th	Yugoslavia	0.78%	Cuba	0.75%	South Africa	1.07%	Yugoslavia	1.56%	China	2.44%	PN Guinea	2.25%	PN Guinea	1.49%	Iran	1.33%
	All Other 21	4.58%	All Other 21	2.92%	All Other 36	7.95%	All Other 45	9.13%	All Other 43	12.06%	All Other 37	14.26%	All Other 33	9.66%	All Other 34	10.08%

Ranking and Share of Australian and Chilean Production

	Australia (15)	0.67%	Australia (15)	0.64%	Australia (8)	2.21%	Australia (9)	2.89%	Australia (10)	2.82%	Australia (8)	3.52%	Australia (4)	6.56%	Australia (5)	6.20%
	Chile (2)	16.39%	Chile (3)	14.43%	Chile (3)	12.55%	Chile (2)	11.89%	Chile (2)	13.20%	Chile (1)	19.96%	Chile (1)	34.72%	Chile (1)	35.45%

Table A2.21: Evolution of Geographical Location of Iron Ore Mining

Share of Production by Region

Region	1929	1951	1961	1971	1981	1991	2001	2005
WORLD TOTAL (Tonnes)	201,175,000	294,103,000	486,887,677	762,948,887	828,282,052	955,552,000	1,049,438,618	1,544,062,062
NORTH AND CENTRAL AMERICA	38.04%	41.86%	18.33%	16.56%	15.71%	11.09%	8.00%	6.33%
SOUTH AMERICA	0.92%	2.38%	8.22%	10.64%	14.97%	19.36%	22.14%	20.39%
EUROPE (Without USSR/Russia)	51.09%	32.37%	31.90%	18.37%	9.47%	5.22%	7.87%	6.49%
USSR/Russia	3.90%	16.32%	23.40%	25.77%	28.35%	20.83%	7.89%	6.27%
AFRICA	2.17%	2.73%	3.29%	7.57%	7.45%	4.89%	4.65%	3.57%
ASIA	3.32%	3.49%	13.71%	13.14%	13.77%	26.13%	32.00%	39.85%
OCEANIA	0.36%	0.85%	1.14%	7.96%	10.28%	12.50%	17.44%	17.10%

Share of Production by Country

		1929		1951		1961		1971		1981		1991		2001		2005
Rkg	Country	%	Country	%	Country	%	Country	%	Country	%	Country	%	Country	%	Country	%
1st	USA	36.88%	USA	40.25%	USSR	23.40%	USSR	25.77%	USSR	28.35%	USSR	20.83%	China	20.68%	China	27.23%
2nd	France	25.22%	USSR	16.32%	USA	14.42%	USA	10.42%	Brazil	11.44%	China	18.43%	Brazil	19.19%	Brazil	18.19%
3rd	United Kingdom	6.67%	France	11.97%	France	13.25%	Australia	7.88%	Australia	9.90%	Brazil	15.75%	Australia	17.29%	Australia	16.96%
4th	Sweden	5.70%	Sweden	5.23%	China	6.95%	France	7.09%	USA	8.69%	Australia	12.26%	India	8.22%	India	10.00%
5th	USSR	3.90%	United Kingdom	5.11%	Sweden	4.69%	China	6.97%	China	7.72%	India	6.03%	Russia	7.89%	Russia	6.27%
6th	Luxembourg	3.76%	Germany	4.60%	Germany	4.08%	Canada	5.54%	Canada	6.08%	USA	5.92%	Ukraine	5.21%	Ukraine	4.50%
7th	Spain	3.25%	Luxembourg	1.91%	India	3.73%	Brazil	5.42%	India	4.84%	Canada	3.81%	USA	4.40%	USA	3.56%
8th	Germany	3.08%	Canada	1.44%	Canada	3.67%	Sweden	4.36%	South Africa	3.31%	South Africa	3.03%	South Africa	3.31%	South Africa	2.56%
9th	Bhutan	1.33%	India	1.41%	United Kingdom	3.34%	India	4.35%	Sweden	2.72%	Venezuela	2.22%	Canada	2.78%	Canada	1.84%
10th	India	1.23%	Chile	1.11%	Venezuela	2.90%	Liberia	2.97%	France	2.53%	Sweden	2.02%	Sweden	1.86%	Sweden	1.51%
11th	Algeria	1.09%	China	1.02%	Brazil	2.03%	Venezuela	2.58%	Liberia	2.30%	Mexico	1.36%	Venezuela	1.61%	Venezuela	1.30%
12th	Austria	0.94%	Algeria	0.96%	Peru	1.74%	Chile	1.43%	Venezuela	1.82%	Mauritania	1.07%	Kazakhstan	1.51%	Kazakhstan	1.26%
13th	Chile	0.90%	Australia	0.84%	Luxembourg	1.48%	South Africa	1.33%	Mauritania	1.02%	Korea, Dem. PR of	1.05%	Iran	1.41%	Iran	1.18%
	All Other 27	6.04%	All Other 31	7.83%	All Other 50	14.30%	All Other 44	13.88%	All Other 40	9.28%	All Other 34	6.23%	All Other 28	4.64%	All Other 26	3.65%

Ranking and Share of Australian and Chilean Production

	Australia (21)	0.00%	Australia (13)	0.84%	Australia (17)	1.08%	Australia (3)	7.88%	Australia (3)	9.90%	Australia (4)	12.26%	Australia (3)	17.29%	Australia (3)	16.96%
	Chile (13)	0.90%	Chile (10)	1.11%	Chile (14)	1.39%	Chile (12)	1.43%	Chile (17)	0.91%	Chile (14)	0.91%	Chile (15)	0.84%	Chile (16)	0.51%

Table A2.22: Evolution of Geographical Location of Gold Mining

Share of Production by Region

Region	1931	1951	1961	1971	1981	1991	2001	2005
WORLD TOTAL (Kilograms)	694,526	1,041,968	1,468,086	1,446,153	1,283,003	2,169,506	2,533,140	2,430,106
NORTH AND CENTRAL AMERICA	25.08%	20.88%	13.86%	8.66%	9.09%	22.40%	21.00%	17.08%
SOUTH AMERICA	2.59%	3.01%	1.94%	1.14%	5.89%	8.59%	12.66%	16.36%
EUROPE (Without USSR/Russia)	1.17%	0.90%	1.48%	0.72%	1.19%	2.74%	0.90%	0.79%
USSR/Russia	7.62%	28.36%	25.00%	14.41%	20.42%	11.98%	6.03%	6.71%
AFRICA	53.42%	39.63%	52.56%	70.58%	53.24%	30.67%	23.59%	20.98%
ASIA	6.62%	3.85%	2.60%	2.77%	7.33%	9.58%	21.54%	23.89%
OCEANIA	3.51%	3.46%	2.61%	1.71%	2.83%	14.04%	14.29%	14.19%

Share of Production by Country

		1929		1951		1961		1971		1981		1991		2001		2005
Rkg	Country	%	Country	%	Country	%	Country	%	Country	%	Country	%	Country	%	Country	%
1st	Sudan	52.40%	South Africa	34.38%	South Africa	48.61%	South Africa	67.51%	South Africa	51.20%	South Africa	27.71%	South Africa	15.58%	South Africa	12.13%
2nd	Canada	12.07%	USSR	28.36%	USSR	25.00%	USSR	14.41%	USSR	20.42%	USA	13.55%	USA	13.22%	Australia	10.82%
3rd	USA	9.91%	Canada	13.11%	Canada	9.48%	Canada	4.82%	China	4.12%	USSR	11.98%	Australia	11.06%	USA	10.74%
4th	USSR	7.62%	USA	5.66%	USA	3.32%	USA	3.22%	Canada	4.06%	Australia	10.80%	China	7.18%	China	9.22%
5th	Mexico	2.79%	Australia	2.67%	Australia	2.28%	Ghana	1.50%	USA	3.34%	Canada	8.14%	Indonesia	6.56%	Peru	8.55%
6th	Japan	1.94%	Ghana	2.09%	Ghana	1.81%	Australia	1.45%	Brazil	2.91%	China	5.53%	Canada	6.32%	Russia	6.71%
7th	India	1.48%	Zimbabwe	1.45%	Zimbabwe	1.21%	Philippines	1.37%	Philippines	1.83%	Brazil	4.12%	Russia	6.03%	Indonesia	5.88%
8th	Korea, Dem.	0.93%	Colombia	1.29%	Philippines	0.90%	Zimbabwe	1.08%	Australia	1.43%	PN Guinea	2.80%	Peru	5.45%	Canada	4.91%
9th	Colombia	0.87%	Mexico	1.18%	Colombia	0.85%	Japan	0.55%	PN Guinea	1.31%	Colombia	1.61%	Uzbekistan	3.37%	Uzbekistan	3.47%
10th	Philippines	0.81%	Philippines	1.17%	Japan	0.62%	Colombia	0.41%	Colombia	1.28%	Poland	1.38%	Ghana	2.77%	PN Guinea	2.82%
11th	Brazil	0.52%	Congo, DR	1.05%	Mexico	0.57%	Zaire	0.37%	Dominican R	0.99%	Chile	1.33%	PN Guinea	2.65%	Ghana	2.74%
12th	Indonesia	0.45%	Nicaragua	0.75%	Congo, DR	0.50%	Korea, Dem.	0.34%	Chile	0.97%	Ghana	1.21%	Brazil	1.69%	Tanzania	1.87%
13th	China	0.43%	India	0.68%	Nicaragua	0.48%	Brazil	0.34%	Zimbabwe	0.90%	Philippines	1.19%	Chile	1.68%	Mali	1.82%
	All Other 21	2.93%	All Other 53	5.22%	All Other 52	3.46%	All Other 46	2.64%	All Other 49	5.23%	All Other 58	8.64%	All Other 65	16.44%	All Other 6	18.32%

Ranking and Share of Australian and Chilean Production

	Australia (?)	?	Australia (5)	2.67%	Australia (5)	2.28%	Australia (6)	1.45%	Australia (8)	1.43%	Australia (4)	10.80%	Australia (3)	11.06%	Australia (2)	10.82%
	Chile (24)	0.10%	Chile (16)	0.52%	Chile (25)	0.12%	Chile (21)	0.14%	Chile (12)	0.97%	Chile (11)	1.33%	Chile (12)	1.68%	Chile (14)	1.66%

Table A2.23: Evolution of Geographical Location of Nickel Mining

Share of Production by Region

Region	1929	1951	1961	1971	1981	1991	2001	2005
WORLD TOTAL (Tonnes)	68,487	167,000	444,769	773,899	884,737	985,36	1,280,59	1,448,996
NORTH AND CENTRAL AMERICA	89.36%	75.33%	64.56%	49.95%	31.38%	26.41%	23.43%	21.83%
SOUTH AMERICA	0.00%	0.00%	0.03%	0.50%	0.94%	4.17%	8.52%	12.54%
EUROPE (Without USSR/Russia)	1.23%	0.05%	1.79%	2.60%	5.14%	4.19%	2.24%	2.22%
USSR/Russia	0.00%	19.76%	20.57%	18.52%	21.68%	28.42%	21.30%	20.70%
AFRICA	0.00%	0.68%	0.80%	3.84%	7.70%	6.45%	5.22%	5.42%
ASIA	1.50%	0.00%	0.20%	3.11%	12.22%	11.75%	14.08%	16.72%
OCEANIA	7.90%	4.01%	12.04%	21.48%	20.95%	18.62%	25.20%	25.20%

Share of Production by Country

		1929		1951		1961		1971		1981		1991		2001		2005
Rkg	Country	%	Country	%	Country	%	Country	%	Country	%	Country	%	Country	%	Country	%
1st	Canada	88.82%	Canada	74.91%	Canada	57.74%	Canada	41.92%	Canada	22.01%	USSR	28.42%	Russia	21.30%	Russia	20.70%
2nd	N Caledonia	7.75%	USSR	19.76%	USSR	20.57%	USSR	18.52%	USSR	21.68%	Canada	19.51%	Australia	16.01%	Canada	13.69%
3rd	India	1.50%	N Caledonia	4.01%	N Caledonia	12.04%	N Caledonia	15.90%	N Caledonia	10.72%	N Caledonia	11.62%	Canada	15.15%	Australia	12.84%
4th	Norway	0.78%	South Africa	0.68%	Cuba	4.04%	Australia	5.58%	Australia	10.23%	Indonesia	7.27%	N Caledonia	9.19%	Indonesia	10.19%
5th	USA	0.55%	USA	0.41%	USA	2.77%	Cuba	5.55%	Indonesia	6.71%	Australia	7.00%	Indonesia	7.97%	N Caledonia	7.73%
6th	Greece	0.46%	Finland	0.05%	Albania	0.82%	Indonesia	3.11%	Cuba	5.29%	Cuba	3.38%	Cuba	5.67%	Colombia	6.14%
7th	Australia	0.15%			South Africa	0.72%	USA	2.43%	Philippines	4.02%	China	3.09%	Colombia	4.14%	Brazil	5.12%
8th					Finland	0.59%	South Africa	2.00%	South Africa	3.63%	Dominican R	2.95%	China	3.98%	Cuba	4.97%
9th					Poland	0.36%	Zimbabwe	1.82%	Dominican R	2.57%	South Africa	2.81%	Brazil	3.55%	China	4.97%
10th					Indonesia	0.17%	Greece	1.66%	Botswana	2.27%	Botswana	2.38%	South Africa	2.85%	Dominican R	3.17%
11th					Morocco	0.07%	Finland	0.57%	Greece	2.14%	Colombia	2.09%	Dominican R	2.61%	South Africa	2.93%
12th					Myanmar	0.03%	Brazil	0.50%	Zimbabwe	1.79%	Brazil	2.08%	Philippines	2.12%	Botswana	1.95%
13th					Germany	0.03%	Poland	0.31%	USA	1.51%	Greece	1.96%	Botswana	1.75%	Philippines	1.56%
	All Other	-	All Other	-	All Other 2	0.04%	All Other 5	0.12%	All Other 10	5.44%	All Other 8	5.44%	All Other 6	3.70%	All Other 8	4.04%

Ranking and Share of Australian and Chilean Production

	Australia (7)	0.15%	Australia (n.a)	n.a.	Australia (n.a)	n.a.	Australia (4)	5.58%	Australia (4)	10.23%	Australia (5)	7.00%	Australia (2)	16.01%	Australia (3)	12.84%
	Chile (n.a)	n.a.	Chile (n.a)	n.a.	Chile (n.a)	n.a.	Chile (n.a)	n.a.	Chile (n.a)	n.a.	Chile (n.a)	n.a.	Chile (n.a)	n.a.	Chile (n.a)	n.a.

Table A2.24: Evolution of Geographical Location of Zinc Mining

Share of Production by Region

Region	1943	1951	1961	1971	1981	1991	2001	2005
WORLD TOTAL (Tonnes)	2,018,000	2,300,000	4,204,250	6,721,181	5,848,200	7,258,424	9,119,732	10,083,167
NORTH AND CENTRAL AMERICA	59.08%	48.44%	31.98%	36.44%	27.94%	28.36%	26.14%	19.18%
SOUTH AMERICA	3.19%	6.40%	6.15%	7.70%	11.63%	13.20%	15.16%	15.72%
EUROPE (Without USSR/Russia)	17.74%	19.50%	22.94%	19.63%	22.04%	16.46%	10.22%	9.13%
USSR/Russia	4.46%	6.43%	11.54%	11.76%	13.51%	6.54%	1.80%	1.84%
AFRICA	1.78%	7.01%	7.01%	4.53%	4.43%	2.64%	2.58%	4.21%
ASIA	4.38%	2.88%	11.25%	11.72%	11.58%	18.69%	27.47%	36.36%
OCEANIA	7.14%	8.60%	9.14%	8.22%	8.86%	14.11%	16.63%	13.56%

Share of Production by Country

		1929		1951		1961		1971		1981		1991		2001		2005
Rkg	Country	%	Country	%	Country	%	Country	%	Country	%	Country	%	Country	%	Country	%
1st	USA	33.46%	USA	26.87%	USA	12.18%	Canada	22.92%	Canada	18.74%	Canada	15.93%	China	18.57%	China	25.04%
2nd	Canada	16.41%	Canada	13.45%	Canada	11.62%	USSR	11.76%	USSR	13.51%	Australia	14.11%	Australia	16.63%	Australia	13.56%
3rd	Germany	11.82%	Australia	8.60%	USSR	11.54%	USA	8.24%	Australia	8.86%	China	10.33%	Canada	11.68%	Peru	11.92%
4th	Mexico	9.21%	Mexico	7.83%	Australia	9.14%	Australia	8.18%	Peru	8.53%	Peru	8.65%	Peru	11.59%	USA	7.42%
5th	Australia	7.14%	USSR	6.43%	Mexico	7.77%	Peru	5.75%	USA	5.34%	USA	7.53%	USA	9.23%	Canada	6.61%
6th	USSR	4.46%	Peru	4.40%	Peru	5.03%	Japan	5.62%	Japan	4.14%	USSR	6.54%	Mexico	4.70%	India	4.78%
7th	Japan	4.05%	Italy	4.38%	Japan	4.86%	Mexico	4.79%	Mexico	3.53%	Mexico	4.37%	Kazakhstan	3.78%	Mexico	4.72%
8th	Spain	1.84%	Congo, D.R.	3.86%	Poland	4.03%	Poland	3.50%	Spain	3.11%	Spain	3.60%	Irish Republic	3.27%	Irish Republic	4.42%
9th	Italy	1.81%	Poland	3.75%	Italy	3.88%	Germany	2.57%	Sweden	3.09%	Korea, Dem.	2.76%	India	2.35%	Kazakhstan	3.61%
10th	Peru	1.53%	Germany	3.27%	Congo, DC	2.92%	Korea, Dem.	2.44%	China	2.74%	Irish Republic	2.58%	Spain	1.82%	Namibia	2.44%
11th	Sweden	1.40%	Spain	3.22%	China	2.88%	Zaire	1.97%	Poland	2.51%	Poland	2.37%	Russia	1.80%	Sweden	2.14%
12th	Congo, DC	0.94%	Japan	2.80%	Germany	2.72%	Italy	1.91%	Korea, Dem.	2.39%	Sweden	2.22%	Sweden	1.71%	Russia	1.84%
13th	Argentina	0.88%	Yugoslavia	1.71%	Korea, Dem.	2.62%	China	1.80%	Irish Republic	2.06%	Japan	1.83%	Poland	1.67%	Brazil	1.70%
	All Other 11	2.84%	All Other 23	8.68%	All Other 29	18.44%	All Other 37	18.54%	All Other 38	21.45%	All Other 34	17.17%	All Other 29	11.20%	All Other 26	9.80%

Ranking and Share of Australian and Chilean Production

	Australia (5)	7.14%	Australia (4)	8.60%	Australia (4)	9.14%	Australia (4)	8.18%	Australia (3)	8.86%	Australia (2)	14.11%	Australia (2)	16.63%	Australia (2)	13.56%
	Chile (n.a)	n.a.	Chile (n.a)	n.a.	Chile (42)	0.005%	Chile (44)	0.04%	Chile (48)	0.03%	Chile (29)	0.43%	Chile (26)	0.36%	Chile (25)	0.29%

Table A2.25: Evolution of Geographical Location of Silver Mining

Share of Production by Region

Region	1930	1951	1961	1971	1981	1991	2001	2005
WORLD TOTAL (Kilograms)	8,019,206	6,180,266	7,367,919	9,170,749	11,252,663	15,672,000	18,999,798	20,411,089
NORTH AND CENTRAL AMERICA	72.29%	55.86%	46.90%	43.54%	37.06%	35.42%	30.89%	25.96%
SOUTH AMERICA	9.13%	12.34%	17.78%	17.11%	18.91%	19.50%	24.22%	25.35%
EUROPE (Without USSR/Russia)	4.65%	7.38%	9.59%	9.25%	13.63%	12.84%	10.47%	9.48%
USSR/Russia	0.12%	12.08%	10.55%	13.23%	12.85%	14.04%	2.11%	5.39%
AFRICA	4.04%	3.97%	4.14%	3.43%	4.84%	4.31%	2.28%	2.18%
ASIA	5.83%	2.84%	5.49%	6.05%	5.73%	5.49%	19.14%	19.38%
OCEANIA	3.94%	5.53%	5.54%	7.40%	6.99%	8.40%	10.89%	12.26%

Share of Production by Country

		1929		1951		1961		1971		1981		1991		2001		2005
Rkg	Country	%	Country	%	Country	%	Country	%	Country	%	Country	%	Country	%	Country	%
1st	Mexico	40.88%	Mexico	22.04%	Mexico	17.03%	Canada	15.61%	Mexico	14.63%	Mexico	14.64%	Mexico	14.53%	Peru	15.64%
2nd	Canada	10.25%	USA	20.08%	USA	14.73%	USA	14.10%	Peru	12.97%	USSR	14.04%	Peru	14.07%	Mexico	14.18%
3rd	Peru	6.01%	USSR	12.08%	Peru	14.42%	USSR	13.23%	USSR	12.85%	USA	11.84%	China	10.60%	China	12.25%
4th	Bolivia	2.75%	Canada	11.64%	Canada	13.25%	Peru	13.02%	USA	11.25%	Peru	11.29%	Australia	10.37%	Australia	11.79%
5th	Myanmar	2.73%	Peru	7.53%	USSR	10.55%	Mexico	12.43%	Canada	10.03%	Canada	8.54%	USA	9.16%	Chile	6.86%
6th	Japan	2.18%	Australia	5.43%	Australia	5.51%	Australia	7.36%	Australia	6.61%	Australia	7.53%	Chile	7.10%	Poland	6.18%
7th	Germany	2.13%	Bolivia	3.59%	Japan	3.36%	Japan	3.83%	Poland	5.69%	Poland	5.74%	Canada	6.95%	USA	6.01%
8th	Spain	1.03%	Germany	2.70%	Germany	2.82%	Germany	2.31%	Chile	3.21%	Chile	4.33%	Poland	6.48%	Canada	5.49%
9th	Indonesia	0.81%	Japan	2.32%	Spain	1.91%	Bolivia	1.82%	Japan	2.49%	Bolivia	2.40%	Kazakhstan	4.96%	Russia	5.39%
10th	South Africa	0.41%	Congo, D.C	1.91%	Bolivia	1.65%	France	1.80%	South Africa	2.09%	Morocco	1.89%	Bolivia	2.16%	Kazakhstan	3.98%
11th	Czechoslov.	0.35%	Honduras	1.60%	Honduras	1.50%	Sweden	1.32%	Bolivia	1.77%	Korea	1.69%	Russia	2.11%	Bolivia	2.06%
12th	Chile	0.28%	Yugoslavia	1.53%	Congo, DC	1.46%	Honduras	1.24%	Spain	1.48%	Sweden	1.53%	Indonesia	1.83%	Indonesia	1.60%
13th	France	0.25%	Czechoslov.	0.81%	Yugoslavia	1.46%	South Africa	1.15%	Sweden	1.48%	Spain	1.33%	Sweden	1.61%	Sweden	1.52%
	All Other 29	1.29%	All Other 48	6.74%	All Other 42	10.35%	All Other 37	10.79%	All Other 42	13.46%	All Other 39	13.22%	All Other42	8.08%	All Other 43	7.05%

Ranking and Share of Australian and Chilean Production

	Australia (?)	?	Australia (6)	5.43%	Australia (6)	5.51%	Australia (6)	7.36%	Australia (6)	6.61%	Australia (6)	7.53%	Australia (4)	10.37%	Australia (4)	11.79%
	Chile (12)	0.28%	Chile (19)	0.49%	Chile (16)	0.91%	Chile (17)	0.93%	Chile (8)	3.21%	Chile (8)	4.33%	Chile (6)	7.10%	Chile (5)	6.86%

Table A2.26: Evolution of Geographical Location of Lead Mining

Share of Production by Region

Region	1930	1951	1961	1971	1981	1991	2001	2005
WORLD TOTAL (Tonnes)	1,786,178	1,916,545	2,899,106	4,125,854	3,355,800	3,314,000	3,099,540	3,336,479
NORTH AND CENTRAL AMERICA	56.83%	37.85%	25.12%	32.21%	8.08%	28.06%	24.05%	19.80%
SOUTH AMERICA	1.59%	7.53%	8.46%	7.59%	28.23%	7.65%	10.42%	10.70%
EUROPE (Without USSR/Russia)	25.06%	21.91%	22.50%	20.07%	18.95%	14.17%	10.28%	6.74%
USSR/Russia	0.35%	6.70%	14.83%	13.36%	12.66%	11.47%	0.45%	1.09%
AFRICA	1.31%	19.76%	8.19%	5.92%	8.87%	5.32%	4.77%	3.53%
ASIA	4.77%	1.05%	9.43%	8.92%	11.63%	15.86%	25.54%	35.15%
OCEANIA	10.10%	5.22%	11.48%	11.92%	11.57%	17.47%	24.49%	22.99%

Share of Production by Country

		1929		1951		1961		1971		1981		1991		2001		2005
Rkg	Country	%	Country	%	Country	%	Country	%	Country	%	Country	%	Country	%	Country	%
1st	USA	35.66%	USA	18.37%	USSR	14.83%	USA	15.46%	USA	13.28%	Australia	17.47%	Australia	24.49%	China	30.66%
2nd	Mexico	13.43%	South Africa	11.92%	Australia	11.48%	USSR	13.36%	USSR	12.66%	USA	14.39%	China	21.81%	Australia	22.99%
3rd	Australia	10.10%	Australia	11.92%	USA	9.96%	Australia	11.88%	Australia	11.57%	USSR	11.47%	USA	15.05%	USA	13.08%
4th	Spain	7.99%	Mexico	11.76%	Mexico	7.60%	Canada	11.57%	Canada	9.89%	China	10.62%	Peru	9.34%	Peru	9.57%
5th	Canada	7.73%	Canada	7.49%	Canada	6.94%	Peru	4.88%	Peru	5.74%	Canada	8.34%	Canada	4.97%	Mexico	4.03%
6th	Germany	5.48%	USSR	6.70%	Peru	5.72%	Mexico	4.62%	China	4.77%	Peru	6.03%	Mexico	3.81%	Canada	2.38%
7th	Belgium	4.64%	Peru	4.30%	Yugoslavia	4.05%	Yugoslavia	3.66%	Mexico	4.69%	Mexico	5.06%	Sweden	2.77%	Irish Rep.	2.16%
8th	Myanmar	4.56%	Yugoslavia	4.11%	China	3.76%	Bulgaria	2.94%	Yugoslavia	3.53%	Sweden	2.75%	Morocco	2.48%	India	1.87%
9th	Poland	2.00%	Morocco	3.57%	Morocco	3.70%	China	2.94%	Morocco	3.46%	Yugoslavia	2.72%	Poland	1.70%	Sweden	1.81%
10th	Italy	1.27%	Germany	2.76%	Bulgaria	3.35%	Korea, Dem.	2.35%	Korea, Dem.	2.98%	Korea, Dem.	2.41%	South Africa	1.64%	Morocco	1.59%
11th	France	1.14%	Spain	2.11%	Spain	3.34%	Sweden	2.34%	South Africa	2.95%	South Africa	2.30%	Irish Rep.	1.44%	Poland	1.53%
12th	Peru	1.09%	Italy	2.10%	Sweden	2.68%	Morocco	2.30%	Bulgaria	2.86%	Morocco	2.22%	Kazakhstan	1.21%	Kazakhstan	1.36%
13th	Tunisia	1.06%	Namibia	2.05%	Namibia	2.66%	Namibia	2.11%	Sweden	2.51%	Poland	1.92%	Spain	1.15%	South Africa	1.26%
	All Other 17	3.84%	All Other 36	10.84%	All Other 39	19.92%	All Other 39	19.59%	All Other 36	19.12%	All Other 33	12.29%	All Other 26	8.15%	All Other 22	5.71%

Ranking and Share of Australian and Chilean Production

	Australia (5)	10.10%	Australia (5)	11.92%	Australia (4)	11.48%	Australia (5)	11.88%	Australia (5)	11.57%	Australia (1)	17.47%	Australia (1)	24.49%	Australia (2)	22.99%
	Chile (n.a)	n.a	Chile (23)	0.41%	Chile (39)	0.09%	Chile (44)	0.03%	Chile (47)	0.01%	Chile (40)	0.03%	Chile (33)	0.04%	Chile (31)	0.03%

Table A2.27: Evolution of Geographical Location of Bauxite Mining

Share of Production by Region

Region	1929	1951	1961	1971	1981	1991	2001	2005

WORLD TOTAL (Tonnes)	2,148,949	10,781,854	28,434,522	60,176,941	85,541,000	107,916,000	140,215,886	176,101,013
NORTH AND CENTRAL AMERICA	17.29%	17.42%	30.78%	26.06%	16.46%	10.71%	8.96%	8.13%
SOUTH AMERICA	18.53%	43.83%	20.20%	17.99%	13.50%	16.50%	17.39%	19.52%
EUROPE (Without USSR/Russia)	63.73%	25.20%	21.67%	17.31%	14.65%	6.31%	2.87%	2.52%
USSR/Russia	0.00%	7.88%	13.85%	6.54%	5.38%	4.63%	3.43%	3.64%
AFRICA	0.00%	1.25%	6.72%	4.71%	13.92%	15.86%	12.85%	11.27%
ASIA	0.43%	4.38%	6.73%	6.89%	6.23%	8.45%	16.14%	20.88%
OCEANIA	0.03%	0.05%	0.06%	20.50%	29.86%	37.53%	38.37%	34.05%

Share of Production by Country

		1929		1951		1961		1971		1981		1991		2001		2005
Rkg	Country	%	Country	%	Country	%	Country	%	Country	%	Country	%	Country	%	Country	%
1st	France	31.01%	Suriname	24.78%	Jamaica	23.06%	Australia	20.50%	Australia	29.86%	Australia	37.53%	Australia	38.37%	Australia	34.05%
2nd	Hungary	18.11%	Guyana	18.87%	USSR	13.85%	Jamaica	20.03%	Jamaica	13.66%	Guinea	14.33%	Guinea	12.35%	Brazil	12.51%
3rd	USA	17.29%	USA	17.42%	Suriname	11.60%	Suriname	10.81%	Guinea	12.99%	Jamaica	10.70%	Brazil	9.55%	Guinea	10.92%
4th	Suriname	9.77%	France	10.43%	Guyana	8.22%	USSR	6.54%	Brazil	6.75%	Brazil	9.65%	Jamaica	8.82%	China	10.22%
5th	Italy	8.97%	USSR	7.88%	France	7.58%	Guyana	6.31%	USSR	5.38%	USSR	4.63%	India	6.20%	Jamaica	8.02%
6th	Guyana	8.75%	Hungary	6.81%	Guinea	6.02%	France	5.13%	Suriname	4.79%	India	4.39%	China	6.17%	India	7.00%
7th	Yugoslavia	4.81%	Yugoslavia	4.20%	Hungary	4.65%	Greece	4.61%	Yugoslavia	3.80%	Suriname	2.96%	Russia	3.43%	Russia	3.64%
8th	India	0.43%	Indonesia	3.65%	USA	4.25%	Hungary	3.36%	Greece	3.76%	China	2.41%	Venezuela	3.27%	Venezuela	3.35%
9th	Germany	0.34%	Greece	1.83%	Yugoslavia	4.20%	USA	3.25%	Hungary	3.41%	Guyana	2.04%	Suriname	3.13%	Kazakhstan	2.73%
10th	Greece	0.29%	Italy	1.61%	Greece	3.81%	Guinea	3.22%	India	2.25%	Greece	1.98%	Kazakhstan	2.63%	Suriname	2.70%
11th	UK	0.11%	Ghana	1.22%	Dominican R	2.56%	Yugoslavia	3.15%	France	2.15%	Hungary	1.89%	Guyana	1.43%	Greece	1.39%
12th	Spain	0.05%	India	0.63%	Malaysia	2.29%	India	2.44%	Guyana	1.97%	Venezuela	1.85%	Greece	1.36%	Guyana	0.95%
13th	Romania	0.04%	Brazil	0.18%	India	1.62%	Iran	1.99%	USA	1.77%	Yugoslavia	1.77%	Indonesia	0.88%	Indonesia	0.61%
	All Other 1	0.03%	All Other 7	0.48%	All Other 13	6.30%	All Other 13	8.66%	All Other 13	7.48%	All Other 13	3.86%	All Other 12	2.42%	All Other 12	1.89%

Ranking and Share of Australian and Chilean Production

	Australia (14)	0.03%	Australia (19)	0.05%	Australia (22)	0.05%	Australia (1)	20.50%	Australia (1)	29.86%	Australia (1)	37.53%	Australia (1)	38.37%	Australia (1)	34.05%
	Chile (n.a)	n.a	Chile (n.a)	n.a	Chile (n.a)	n.a	Chile (n.a)	n.a	Chile (n.a)	n.a	Chile (n.a)	n.a	Chile (n.a)	n.a	Chile (n.a)	n.a

Table A2.28: Share of Value Mine Production by Country: 8 Metals (Copper – Iron Ore – Gold – Nickel – Zinc – Silver – Lead – Bauxite)

	Country	1951	Country	1961	Country	1971	Country	1981	Country	1991	Country	2001	Country	2005
1	USA	25.37%	USSR	18.45%	USSR	16.54%	USSR	20.31%	USSR	14.71%	Australia	13.87%	China	15.27%
2	USSR	14.38%	USA	14.32%	USA	13.15%	South Africa	13.58%	Australia	10.57%	China	11.40%	Australia	12.75%

	Country	1951	Country	1961	Country	1971	Country	1981	Country	1991	Country	2001	Country	2005
3	Canada	10.44%	Canada	10.16%	Canada	12.34%	USA	8.69%	USA	10.32%	Chile	9.17%	Chile	10.23%
4	South Africa	8.23%	South Africa	7.00%	South Africa	6.50%	Canada	8.02%	China	8.89%	USA	8.14%	Brazil	7.37%
5	Mexico	3.98%	France	4.90%	Australia	6.14%	Australia	7.17%	South Africa	8.71%	Russia	6.48%	Russia	6.80%
6	Chile	3.72%	Chile	4.04%	Chile	4.37%	Brazil	5.24%	Canada	8.38%	Brazil	6.30%	USA	5.94%
7	Australia	3.66%	Zambia	3.81%	Zambia	3.66%	China	4.68%	Brazil	6.31%	Canada	5.92%	Peru	4.76%
8	Zambia	3.62%	China	3.45%	China	3.14%	Chile	3.05%	Chile	5.08%	South Africa	5.07%	Canada	4.51%
9	France	3.34%	Peru	2.90%	France	2.55%	Peru	2.44%	Peru	2.19%	Peru	4.38%	Indonesia	3.98%
10	Congo, D.C	2.48%	Australia	2.80%	Peru	2.53%	Mexico	1.99%	India	2.13%	Indonesia	4.07%	India	3.86%
11	Germany	2.06%	Congo ,D.R	2.23%	Zaire	2.41%	India	1.98%	Mexico	2.00%	India	2.75%	South Africa	3.38%
12	Sweden	1.87%	Sweden	2.14%	Brazil	1.95%	Sweden	1.49%	Poland	1.48%	Mexico	2.04%	Mexico	2.00%
13	Peru	1.71%	Germany	2.01%	Sweden	1.89%	Zambia	1.36%	Indonesia	1.35%	Kazakhstan	1.98%	Kazakhstan	1.64%
14	United Kingdom	1.33%	Mexico	1.84%	India	1.57%	Zaire	1.35%	P. New Guinea	1.22%	Ukraine	1.40%	Ukraine	1.48%
15	Yugoslavia	1.16%	Japan	1.47%	Mexico	1.45%	Philippines	1.35%	Sweden	1.13%	Poland	1.22%	Poland	1.20%
16	Japan	1.12%	India	1.46%	Japan	1.44%	Poland	1.13%	Zambia	0.97%	P. New Guinea	0.98%	Sweden	0.92%
17	Spain	1.00%	United Kingdom	1.17%	New Caledonia	1.40%	France	1.08%	New Caledonia	0.93%	Sweden	0.96%	Colombia	0.88%
18	Italy	0.97%	Venezuela	1.02%	Philippines	1.28%	Yugoslavia	0.92%	Philippines	0.78%	Uzbekistan	0.91%	Iran	0.85%
19	Poland	0.73%	Spain	0.97%	Yugoslavia	1.14%	Spain	0.88%	Venezuela	0.75%	Iran	0.78%	P. New Guinea	0.82%
20	Morocco	0.69%	Yugoslavia	0.90%	Poland	1.02%	Liberia	0.85%	Zaire	0.73%	New Caledonia	0.73%	Zambia	0.79%
21	India	0.56%	Brazil	0.82%	Liberia	0.96%	Korea, Dem.	0.74%	Yugoslavia	0.72%	Argentina	0.69%	New Caledonia	0.78%
22	Bolivia	0.52%	New Caledonia	0.75%	Venezuela	0.84%	Venezuela	0.67%	Korea, Dem.	0.69%	Venezuela	0.69%	Uzbekistan	0.77%
23	Luxembourg	0.49%	Poland	0.69%	Korea, Dem.	0.79%	P. New Guinea	0.67%	Colombia	0.60%	Ghana	0.65%	Venezuela	0.69%
24	Namibia	0.45%	Korea, Dem.	0.67%	Spain	0.74%	New Caledonia	0.67%	Spain	0.59%	Guinea	0.57%	Argentina	0.55%
25	Philippines	0.41%	Italy	0.57%	Bulgaria	0.65%	Indonesia	0.64%	Guinea	0.54%	Colombia	0.55%	Cuba	0.51%
26	Ghana	0.40%	Philippines	0.54%	Germany	0.59%	Japan	0.62%	Iran	0.45%	Zambia	0.54%	Ghana	0.46%
27	China	0.38%	Malaysia	0.53%	Jamaica	0.57%	Zimbabwe	0.42%	Portugal	0.39%	Philippines	0.51%	Philippines	0.44%
28	Brazil	0.34%	Luxembourg	0.52%	Cuba	0.50%	Dominican Rep.	0.42%	Jamaica	0.35%	Cuba	0.46%	Mongolia	0.40%
29	Algeria	0.32%	Bulgaria	0.51%	United Kingdom	0.42%	Jamaica	0.39%	Turkey	0.34%	Mali	0.37%	Irish Republic	0.36%
30	Zimbabwe	0.28%	Jamaica	0.49%	Zimbabwe	0.42%	Bulgaria	0.39%	Korea, Republic	0.32%	Mongolia	0.36%	Guinea	0.36%
31	Austria	0.27%	Morocco	0.43%	Romania	0.37%	Greece	0.38%	Ghana	0.32%	Irish Republic	0.35%	Dominican Rep.	0.32%
32	Suriname	0.27%	Finland	0.40%	Namibia	0.36%	Mauritania	0.37%	Japan	0.32%	Bolivia	0.32%	Tanzania	0.32%
33	Argentina	0.25%	Namibia	0.35%	Mauritania	0.35%	Guinea	0.37%	Greece	0.31%	Turkey	0.31%	Mali	0.30%
34	Colombia	0.24%	Algeria	0.33%	Finland	0.34%	Cuba	0.33%	Mauritania	0.31%	Jamaica	0.30%	Botswana	0.26%

	Country	1951	Country	1961	Country	1971	Country	1981	Country	1991	Country	2001	Country	2005
35	Tunisia	0.23%	Austria	0.30%	Greece	0.32%	Colombia	0.31%	France	0.30%	Tanzania	0.28%	Mauritania	0.23%
36	Guyana	0.21%	Cuba	0.28%	Norway	0.31%	Germany	0.30%	Dominican Rep.	0.28%	Spain	0.27%	Bolivia	0.22%
37	Cyprus	0.20%	Zimbabwe	0.28%	Suriname	0.31%	Finland	0.29%	Cuba	0.28%	Mauritania	0.26%	Namibia	0.22%
38	Finland	0.19%	Turkey	0.26%	Irish Republic	0.29%	Romania	0.27%	Bolivia	0.26%	Greece	0.24%	Bulgaria	0.21%
39	Czechoslovakia	0.19%	Czechoslovakia	0.26%	Indonesia	0.29%	Turkey	0.26%	Irish Republic	0.25%	Bulgaria	0.23%	Turkey	0.21%
40	Norway	0.19%	Ghana	0.25%	Italy	0.28%	Namibia	0.22%	Botswana	0.24%	Morocco	0.23%	Congo, D.C.	0.18%
41	Cuba	0.17%	Suriname	0.25%	Angola	0.25%	Norway	0.22%	Mongolia	0.23%	Kyrgyzstan	0.22%	Greece	0.18%
42	Nicaragua	0.14%	Norway	0.23%	Turkey	0.25%	Bolivia	0.19%	Bulgaria	0.21%	Zimbabwe	0.22%	Jamaica	0.17%
43	Turkey	0.13%	Liberia	0.23%	Austria	0.23%	Ghana	0.19%	Finland	0.20%	Dominican Rep.	0.21%	Morocco	0.17%
44	New Caledonia	0.13%	Cyprus	0.18%	Iran	0.20%	Irish Republic	0.18%	Romania	0.20%	Guyana	0.18%	Portugal	0.16%
45	Venezuela	0.11%	Guyana	0.18%	Morocco	0.19%	Botswana	0.18%	Zimbabwe	0.17%	Botswana	0.17%	Zimbabwe	0.16%
46	Hungary	0.11%	Greece	0.17%	Bolivia	0.19%	Algeria	0.18%	Morocco	0.16%	Portugal	0.15%	Suriname	0.13%
47	Sierra Leone	0.10%	Argentina	0.17%	Luxembourg	0.19%	Korea, Republic	0.17%	Namibia	0.16%	Japan	0.14%	New Zealand	0.12%
48	Greece	0.09%	Guinea	0.17%	Guyana	0.18%	Morocco	0.16%	Norway	0.15%	New Zealand	0.14%	Kyrgyzstan	0.11%
49	Malaysia	0.08%	Colombia	0.16%	Algeria	0.17%	Mongolia	0.16%	New Zealand	0.15%	Romania	0.11%	Korea, Dem.	0.11%
50	Romania	0.08%	Romania	0.16%	Argentina	0.16%	Malaysia	0.16%	Ecuador	0.14%	Suriname	0.11%	Laos	0.10%
51	Honduras	0.07%	Hungary	0.14%	Hungary	0.14%	Austria	0.15%	Thailand	0.12%	Namibia	0.11%	Japan	0.10%
52	Guatemala	0.07%	Bolivia	0.12%	Sierra Leone	0.13%	Hungary	0.15%	Malaysia	0.12%	Korea, Dem.	0.10%	Finland	0.09%
53	Bulgaria	0.06%	Sierra Leone	0.12%	Ghana	0.13%	New Zealand	0.14%	Argentina	0.10%	Honduras	0.09%	Guyana	0.08%
54	P. New Guinea	0.05%	Tunisia	0.11%	Czechoslovakia	0.12%	Suriname	0.14%	Suriname	0.10%	Serbia & Mont.	0.08%	Myanmar	0.07%
55	Fiji	0.05%	Nicaragua	0.11%	Swaziland	0.12%	Argentina	0.13%	Albania	0.09%	Finland	0.08%	Vietnam	0.06%
56	Tanzania	0.05%	Albania	0.09%	Korea, Republic	0.12%	Greenland	0.13%	Guyana	0.09%	Vietnam	0.07%	Honduras	0.06%
57	New Zealand	0.04%	Uganda	0.09%	Cyprus	0.10%	Czechoslovakia	0.12%	Austria	0.09%	Congo, D.R	0.06%	Spain	0.06%
58	Saudi Arabia	0.04%	Myanmar	0.07%	Guinea	0.09%	Albania	0.11%	Italy	0.08%	Uganda	0.06%	Saudi Arabia	0.05%
59	Indonesia	0.04%	Iran	0.07%	Uganda	0.09%	Italy	0.10%	Czechoslovakia	0.08%	Tunisia	0.05%	Romania	0.05%
60	Central African	0.03%	Korea, Republic	0.07%	Honduras	0.09%	Iran	0.09%	Algeria	0.07%	Sudan	0.05%	Egypt	0.05%
61	El Salvador	0.02%	Angola	0.06%	Tunisia	0.09%	Egypt	0.08%	Germany	0.07%	Macedonia	0.05%	Malaysia	0.05%
62	Portugal	0.02%	Honduras	0.06%	Malaysia	0.09%	Guyana	0.07%	Hungary	0.07%	Myanmar	0.05%	Thailand	0.05%
63	Irish Republic	0.02%	Dominican Republic	0.06%	Haiti	0.07%	Honduras	0.06%	Burkina Faso	0.07%	Malaysia	0.05%	Algeria	0.05%
64	Egypt	0.02%	Guatemala	0.04%	Dominican Rep.	0.06%	United Kingdom	0.05%	Egypt	0.06%	Austria	0.05%	Austria	0.04%
65	Liberia	0.02%	Indonesia	0.04%	Israel	0.05%	Nicaragua	0.04%	Saudi Arabia	0.06%	Egypt	0.05%	Armenia	0.04%
66	Taiwan	0.02%	Haiti	0.04%	Albania	0.05%	Taiwan	0.03%	Honduras	0.06%	Armenia	0.05%	Ecuador	0.04%

	Country	1951	Country	1961	Country	1971	Country	1981	Country	1991	Country	2001	Country	2005
67	Ethiopia	0.02%	Greenland	0.04%	Colombia	0.05%	Tunisia	0.03%	Mali	0.06%	Fiji	0.04%	Serbia & Mont.	0.04%
68	Myanmar	0.02%	Israel	0.04%	Nicaragua	0.05%	Myanmar	0.03%	Tanzania	0.05%	Guatemala	0.04%	Pakistan	0.03%
69	Hong Kong	0.02%	Irish Republic	0.04%	Portugal	0.03%	Sierra Leone	0.02%	Liberia	0.04%	Algeria	0.04%	Sudan	0.03%
70	Thailand	0.01%	Tanzania	0.03%	New Zealand	0.03%	Thailand	0.02%	Sierra Leone	0.04%	Georgia	0.04%	Burundi	0.03%
71	Angola	0.01%	Egypt	0.03%	Myanmar	0.02%	Luxembourg	0.02%	Ethiopia	0.04%	French Guiana	0.04%	Nicaragua	0.02%
72	Kenya	0.01%	Portugal	0.03%	Egypt	0.02%	Fiji	0.02%	Greenland	0.03%	Ethiopia	0.04%	Niger	0.02%
73	Ecuador	0.01%	Fiji	0.02%	Taiwan	0.02%	Portugal	0.02%	Oman	0.03%	Nicaragua	0.04%	Georgia	0.02%
74	Switzerland	0.01%	Mauritania	0.02%	Fiji	0.01%	Haiti	0.01%	Fiji	0.03%	Ivory Coast	0.03%	Korea, Republic	0.02%
75	Belgium	0.01%	Taiwan	0.02%	Hong Kong	0.01%	Congo, D.R	0.01%	Vietnam	0.02%	Saudi Arabia	0.03%	Ethiopia	0.02%
76	Iran	0.01%	P. New Guinea	0.01%	Ecuador	0.01%	Costa Rica	0.01%	Myanmar	0.02%	France	0.03%	Tunisia	0.02%
77	French Guiana	0.01%	Ethiopia	0.01%	P. New Guinea	0.00%	Israel	0.01%	Tunisia	0.02%	Norway	0.03%	Fiji	0.02%
78	Korea, Republic	0.00%	Thailand	0.01%	Ethiopia	0.00%	Mali	0.01%	Nicaragua	0.01%	Ecuador	0.03%	Norway	0.02%
79	Burkina Faso	0.00%	Hong Kong	0.01%	Belgium	0.00%	Vietnam	0.01%	Ivory Coast	0.01%	Tajikistan	0.03%	Tajikistan	0.01%
80	Cameroon	0.00%	Belgium	0.01%	Congo, D.R	0.00%	Ethiopia	0.01%	Nigeria	0.01%	Hungary	0.02%	French Guiana	0.01%
81	Panama	0.00%	New Zealand	0.01%	Thailand	0.00%	Guatemala	0.01%	Rwanda	0.01%	Uruguay	0.02%	Greenland	0.01%
82	Madagascar	0.00%	Switzerland	0.01%	Mozambique	0.00%	Ecuador	0.00%	Costa Rica	0.01%	Kenya	0.01%	Uruguay	0.01%
83	Nigeria	0.00%	Ecuador	0.01%	Gabon	0.00%	El Salvador	0.00%	Mozambique	0.00%	Slovakia	0.01%	Macedonia	0.01%
84	Sudan	0.00%	Burkina Faso	0.00%	El Salvador	0.00%	French Guiana	0.00%	United Kingdom	0.00%	Thailand	0.01%	Ivory Coast	0.01%
85	Mozambique	0.00%	Gabon	0.00%	Guatemala	0.00%	Central African	0.00%	Madagascar	0.00%	Laos	0.01%	Burkina Faso	0.01%
86	Eritrea	0.00%	Kenya	0.00%	Costa Rica	0.00%	Kenya	0.00%	Panama	0.00%	Germany	0.01%	Germany	0.01%
87	Botswana	0.00%	French Guiana	0.00%	Cambodia	0.00%	Rwanda	0.00%	Central African	0.00%	Bosnia & Herz.	0.01%	Hungary	0.01%
88	Dominican Rep.	0.00%	Eritrea	0.00%	Denmark	0.00%	Solomon Islands	0.00%	Gabon	0.00%	Cyprus	0.01%	Slovakia	0.01%
89	Uganda	0.00%	Cambodia	0.00%	Kenya	0.00%	Mozambique	0.00%	Sudan	0.00%	Italy	0.01%	Bosnia & Herz.	0.01%
90	Swaziland	0.00%	Costa Rica	0.00%	French Guiana	0.00%	Denmark	0.00%	Guatemala	0.00%	Korea, Republic	0.01%	Guatemala	0.00%
91	Costa Rica	0.00%	Sudan	0.00%	Nigeria	0.00%	Nigeria	0.00%	Solomon Islands	0.00%	Oman	0.01%	Kenya	0.00%
92			Mozambique	0.00%	Uruguay	0.00%	Gabon	0.00%	Burundi	0.00%	Senegal	0.00%	Cameroon	0.00%
93			Swaziland	0.00%	Solomon Islands	0.00%	Tanzania	0.00%	Kenya	0.00%	Cameroon	0.00%	Senegal	0.00%
94			Pakistan	0.00%	Madagascar	0.00%	Cameroon	0.00%	Congo, DR	0.00%	Burundi	0.00%	Albania	0.00%
95			Rwanda	0.00%	Tanzania	0.00%	Sudan	0.00%	Pakistan	0.00%	Madagascar	0.00%	Costa Rica	0.00%
96			Nigeria	0.00%	Niger	0.00%	Pakistan	0.00%	Cameroon	0.00%	Burkina Faso	0.00%	Gabon	0.00%
97			Cameroon	0.00%	Cameroon	0.00%	Madagascar	0.00%	Georgia	0.00%	Eritrea	0.00%	Panama	0.00%
98			Madagascar	0.00%	Pakistan	0.00%	Burundi	0.00%	Belize	0.00%	Costa Rica	0.00%	Italy	0.00%

	Country	1951	Country	1961	Country	1971	Country	1981	Country	1991	Country	2001	Country	2005
99			Botswana	0.00%	Mali	0.00%			Nepal	0.00%	United Kingdom	0.00%	United Kingdom	0.00%
100			Central African	0.00%							Pakistan	0.00%	France	0.00%
101											Gabon	0.00%	Eritrea	0.00%
102											Niger	0.00%	Nigeria	0.00%
103											Mozambique	0.00%	Azerbaijan	0.00%
104													Bhutan	0.00%
105													Mozambique	0.00%

Table A2.29: Copper Mine Production [tonnes (metal content)]

Country	1929	1951	1961	1971	1981	1991	2001	2005
Albania			2,866	7,716	15,500	3,700		1,696
Armenia							16,460	16,400
Austria	2,081	1,838	2,320	3,219				
Azerbaijan								
Belgium								
Bosnia & Herzegovina								
Bulgaria	2,000		21,605	55,115	62,000	47,200	97,100	94,900
Cyprus	5,900	22,811	34,817	23,563			4,600	
Czechoslovakia	1,359			5,467	5,200	2,600		
Denmark								
Finland	4,565	18,400	41,336	34,521	38,500	11,732	11,600	15,500
France	596		443	364	100	166		
Georgia							11,500	6,000
Germany	28,983	1,669	33,061	4,105	13,400			
Greece					100			
Greenland								
Hungary				1,433				
Irish Republic			7,202	14,321	3,500			
Italy	883	144	2,930	1,872	800			
Luxembourg								
Macedonia							6,800	6,000
Netherlands								
Norway	17,317	14,003	16,952	26,333		17,393		
Poland			14,220	109,348	294,000	320,000	474,000	511,799
Portugal	4,000		686	4,808	2,900	158,900	82,965	89,500
Romania	143			17,306	2,700	26,400	19,185	14,868
Russia							540,000	660,000
USSR	26,000	254,000	661,380	749,564	940,000	900,000		
Serbia and Montenegro							31,000	12,900
Slovakia								
Spain	63,700	7,560	22,078	41,352	50,900	8,322	9,800	2,459

Country	1929	1951	1961	1971	1981	1991	2001	2005
Sweden	1,128	14,447	22,098	36,721	50,700	81,650	74,269	87,068
Switzerland								
Turkey		11,850	35,045	23,621	31,900	41,797	56,820	30,067
Ukraine								
United Kingdom	69				700	300		
Yugoslavia	15,200	32,011	46,062	114,693	110,900	138,000		
EUROPE	**175,497**	**394,661**	**965,102**	**1,275,442**	**1,623,800**	**1,758,160**	**1,436,099**	**1,549,157**
	9.0%	15.0%	18.1%	17.4%	19.8%	19.3%	10.5%	10.3%
Algeria	25	120	807	728	200			
Angola		1,100	1,127					
Botswana					17,800	20,600	19,209	26,704
Burkina Faso								
Burundi								
Cameroon								
Central African Republic								
Congo, Democratic Republic	137,178	191,959	358,885	503	200		34,100	98,000
Egypt								
Eritrea								
Ethiopia								
Gabon								
Ghana								
Guinea								
Ivory Coast								
Kenya				88				
Liberia								
Madagascar								
Mali								
Mauritania								
Morocco	75	28	2,111	3,827	6,900	15,800	5,357	4,000
Mozambique				503	200			
Namibia	5,915	12,355	30,620	38,930	46,100	31,700	15,003	10,157
Niger								

Country	1929	1951	1961	1971	1981	1991	2001	2005
Nigeria								
Rwanda								
Senegal								
Sierra Leone								
South Africa	21,909	33,731	57,036	191,338	208,700	184,556	141,900	103,907
Sudan								
Swaziland								
Tanzania		137	122				3,600	3,700
Tunisia								
Uganda			16,250	20,734				
Zaire				493,111	555,100	237,500		
Zambia		391,373	697,909	791,782	588,000	390,600	306,909	435,500
Zimbabwe		95	16,802	35,646	24,600	14,400	492	2,570
AFRICA	**165,102**	**558,898**	**1,181,669**	**1,577,190**	**1,447,800**	**895,156**	**526,570**	**684,538**
	8.4%	21.2%	22.2%	21.5%	17.7%	9.8%	3.9%	4.6%
Belize								
Canada	112,545	244,912	484,007	795,231	691,300	811,100	633,531	594,812
Costa Rica								
Cuba	14,982	19,700	6,063	3,638	2,900	2,000	1,000	
Dominican Republic				551				
El Salvador								
Guatemala					700			
Haiti			4,224	8,047				
Honduras					500	1,000		
Jamaica								
Mexico	86,554	67,351	59,920	76,732	230,500	292,100	371,123	429,042
Nicaragua			7,627	4,450				
Panama								
USA	904,962	842,162	1,284,350	1,677,902	1,538,200	1,631,000	1,338,600	1,140,000
NORTH AND CENTRAL AMERICA	**1,119,979**	**1,174,125**	**1,846,190**	**2,566,551**	**2,464,100**	**2,737,200**	**2,344,254**	**2,163,854**
	57.3%	44.6%	34.6%	35.0%	30.1%	30.1%	17.2%	14.4%
Argentina			669	551	100	400	191,667	185,720

Country	1929	1951	1961	1971	1981	1991	2001	2005
Bolivia	7,188	4,846	2,529	9,128	2,600	100		
Brazil			2,094	6,197	13,900	37,900	32,734	133,325
Chile	320,630	379,725	669,353	871,613	1,081,100	1,814,300	4,739,000	5,320,500
Colombia				68	100	3,640	2,000	1,200
Ecuador		2	122	686	800	100		
French Guiana								
Guyana								
Peru	56,115	32,304	240,649	258,671	342,100	357,200	722,035	1,009,898
Suriname								
Uruguay								
Venezuela								
SOUTH AMERICA	**383,933**	**416,877**	**915,416**	**1,146,914**	**1,440,700**	**2,213,640**	**5,687,436**	**6,650,643**
	19.6%	15.8%	17.2%	15.6%	17.6%	24.4%	41.7%	44.3%
Bhutan								
Cambodia								
China	3,469	6,000	97,002	121,253	200,000	304,000	587,000	800,000
Hong Kong								
India	7,200	7,388	10,692	13,081	25,200	50,430	38,177	25,409
Indonesia					62,500	211,692	1,048,700	1,063,849
Iran				1,219	2,000	84,300	146,300	200,000
Israel			7,598	12,303	4,400			
Japan	75,469	42,756	117,145	147,059	51,500	12,414	744	1,000
Kazakhstan							469,500	401,700
Korea, Dem. P.R. of			7,275	15,432	15,000	15,000	12,000	12,000
Korea, Republic of		6	387	2,155	500	5		
Kyrgyzstan								
Laos								30,500
Malaysia				259	28,600	25,605		
Mongolia					71,800	90,100	133,500	129,000
Myanmar			138	97	800	4,592	25,800	34,500
Nepal						4		
Oman						14,000		

Country	1929	1951	1961	1971	1981	1991	2001	2005
Pakistan								17,700
Philippines		12,712	63,032	240,067	302,300	148,347	20,321	16,320
Saudi Arabia						900	1,000	668
Taiwan	6,100		2,712	2,866	500			
Tajikistan								
Thailand								
Uzbekistan							70,000	103,500
Vietnam							1,600	3,100
ASIA	**98,685**	**70,339**	**305,981**	**555,791**	**765,100**	**961,389**	**2,554,642**	**2,839,246**
	5.0%	2.7%	5.7%	7.6%	9.3%	10.6%	18.7%	18.9%
Australia	13,018	16,874	118,059	211,661	231,300	320,000	896,000	930,000
Fiji								
New Caledonia								
New Zealand				104				
Papua New Guinea					165,400	204,459	203,762	192,978
Solomon Islands								
OCEANIA	**13,018**	**16,874**	**118,059**	**211,765**	**396,700**	**524,459**	**1,099,762**	**1,122,978**
	0.7%	0.6%	2.2%	2.9%	4.8%	5.8%	8.1%	7.5%
WORLD TOTAL	**1,956,214**	**2,631,774**	**5,332,417**	**7,333,653**	**8,190,700**	**9,090,004**	**13,648,763**	**15,010,416**
Unit Value in [US$ 1998]	3,850	3,400	3,630	4,623	3,328	2,885	1,559	3,206

Table A2.30: Iron Ore Mine Production [tonnes (metal content)]

Country	1929	1951	1961	1971	1981	1991	2001	2005
Albania			346,438	393,680	581,662	750,000		
Armenia								
Austria	1,891,381	2,370,000	3,577,567	4,040,141	2,954,568	2,120,000	1,843,275	2,047,950
Azerbaijan								7,300
Belgium	155,670	79,000	111,215	90,546				
Bosnia & Herzegovina							264,000	
Bulgaria		43,000	404,506	2,907,327	1,698,729	800,000	324,800	
Cyprus								
Czechoslovakia	1,807,663	1,962,000	3,190,776	1,558,973	1,873,917	1,738,000		
Denmark				14,763	7,874			
Finland			271,639	850,349	1,191,866			
France	50,731,100	35,201,000	64,518,247	54,111,316	20,921,139	7,472,000	36,587	
Georgia								
Germany	6,191,232	13,515,000	19,866,077	5,170,987	1,563,894	120,000	407,002	362,106
Greece		53,000	282,465		1,356,228	2,024,000		
Greenland								
Hungary	251,711	400,000	585,599	665,319	408,443			
Irish Republic								
Italy	715,171	553,000	1,196,787	661,382	119,088			
Luxembourg	7,571,206	5,625,000	7,224,028	4,365,911	415,332			
Macedonia								
Netherlands	900							
Norway	746,112	332,000	1,620,977	3,928,926	3,936,800	2,209,000	395,000	713,000
Poland	659,568	901,000	2,310,902	2,012,689	101,373			
Portugal	8,507	21,000	226,366	95,467	55,115	11,000		
Romania	90,014	478,000	1,682,982	3,358,090	2,232,166	1,400,000	221,000	220,788
Russia							82,800,000	96,800,000
USSR	7,849,000	48,000,000	113,946,739	196,645,128	234,819,294	199,000,000		
Serbia and Montenegro								
Slovakia							435,492	258,500
Spain	6,546,648	2,389,000	5,872,721	7,099,035	8,296,806	3,920,000	55,058	

Country	1929	1951	1961	1971	1981	1991	2001	2005
Sweden	11,467,551	15,383,000	22,853,124	33,289,581	22,496,844	19,328,000	19,486,000	23,255,000
Switzerland	88,445	86,000	83,657					
Turkey		226,000	734,213	2,014,657	2,843,354	5,335,000	4,434,621	3,889,934
Ukraine							54,700,000	69,456,000
United Kingdom	13,427,742	15,014,000	16,257,016	9,907,941	707,640	59,000	510	500
Yugoslavia	427,946	581,000	2,116,030	3,608,077	4,643,456	2,574,000		
EUROPE	**110,627,567**	**143,212,000**	**269,280,073**	**336,790,287**	**313,225,587**	**248,860,000**	**165,403,345**	**197,011,078**
	55.0%	48.7%	55.3%	44.1%	37.8%	26.0%	15.8%	12.8%
Algeria	2,196,182	2,823,000	2,777,412	3,048,067	3,370,885	2,344,000	1,291,000	1,878,800
Angola			786,376	5,965,236				
Botswana								
Burkina Faso								
Burundi								
Cameroon								
Central African Republic								
Congo, Democratic Republic	50,000							
Egypt			408,443	457,653	1,881,790	2,144,000	1,843,027	2,500,000
Eritrea								
Ethiopia								
Gabon								
Ghana								
Guinea			524,579					
Ivory Coast								
Kenya					13,779			
Liberia		171,000	3,149,440	22,664,158	19,086,591	1,100,000		
Madagascar								
Mali								
Mauritania			290,339	8,191,497	8,431,641	10,246,000	10,300,000	10,700,000
Morocco	1,061,424	1,470,000	1,416,264	603,315	70,862	99,000	7,976	
Mozambique								
Namibia	28,697							
Niger								

Country	1929	1951	1961	1971	1981	1991	2001	2005
Nigeria						398,000		8,000
Rwanda								
Senegal								
Sierra Leone		1,159,000	1,641,646	2,467,389				
South Africa	38,270	1,421,000	3,836,412	10,166,786	27,431,622	28,958,000	34,757,159	39,542,072
Sudan			4,921					
Swaziland				2,776,428				
Tanzania								
Tunisia	977,000	923,000	822,791	906,448	383,838	295,000	206,500	206,400
Uganda								
Zaire								
Zambia	3,613							
Zimbabwe	3,406	52,000	375,964	492,100	1,061,952	1,136,000	360,862	224,229
AFRICA	**4,358,592**	**8,019,000**	**16,034,586**	**57,739,077**	**61,732,961**	**46,720,000**	**48,766,524**	**55,059,501**
	2.2%	2.7%	3.3%	7.6%	7.5%	4.9%	4.6%	3.6%
Belize								
Canada	1,541,334	4,246,000	17,890,788	42,278,279	50,355,609	36,383,000	29,152,000	28,343,000
Costa Rica								
Cuba	682,095	17,000	1,968					
Dominican Republic			14,763					
El Salvador								
Guatemala			4,921			5,000		
Haiti								
Honduras								
Jamaica								
Mexico	112,749	460,000	1,109,193	4,550,941	7,768,291	13,000,000	8,660,000	14,468,000
Nicaragua								
Panama								
USA	74,199,815	118,375,000	70,202,002	79,485,960	72,017,851	56,596,000	46,192,000	55,000,000
NORTH AND CENTRAL AMERICA	**76,535,993**	**123,098,000**	**89,223,635**	**126,315,181**	**130,141,750**	**105,984,000**	**84,004,000**	**97,811,000**
	38.0%	41.9%	18.3%	16.6%	15.7%	11.1%	8.0%	6.3%
Argentina		54,000	134,835	273,608	385,806	259,000		

Country	1929	1951	1961	1971	1981	1991	2001	2005
Bolivia				5,905	5,905	102,000		
Brazil	30,000	2,407,000	9,900,068	41,336,400	94,793,223	150,500,000	201,400,000	280,861,534
Chile	1,812,343	3,252,000	6,770,312	10,873,442	7,500,588	8,692,000	8,834,152	7,862,100
Colombia			654,493	428,127	405,490	607,000	636,837	498,623
Ecuador								
French Guiana								
Guyana								
Peru			8,463,136	8,553,682	5,878,627	3,593,000	4,563,551	5,619,500
Suriname								
Uruguay				2,953				
Venezuela		1,270,000	14,108,507	19,684,000	15,044,481	21,196,000	16,902,437	20,000,000
SOUTH AMERICA	**1,842,343**	**7,000,000**	**40,031,351**	**81,158,116**	**124,014,121**	**184,949,000**	**232,336,977**	**314,841,757**
	0.9%	2.4%	8.2%	10.6%	15.0%	19.4%	22.1%	20.4%
Bhutan	2,672,400							5,679
Cambodia								
China		3,000,000	33,856,480	53,146,800	63,973,000	176,070,000	217,014,700	420,492,700
Hong Kong		164,000	115,151	157,472				
India	2,467,533	4,152,000	18,165,379	33,187,224	40,057,924	57,638,000	86,226,000	154,436,000
Indonesia				262,781	84,641	173,000	469,376	32,203
Iran			40,352	147,630	580,678	4,890,000	14,835,692	18,200,000
Israel								
Japan	177,557	1,168,000	2,781,349	1,375,912	428,127	31,000		
Kazakhstan							15,886,300	19,471,100
Korea, Dem. P.R. of	551,814		3,438,795	8,267,280	7,775,180	10,000,000	1,000,000	1,200,000
Korea, Republic of			489,147	488,163	575,757	222,000	22,693	212,971
Kyrgyzstan								
Laos								
Malaysia	810,831	860,000	6,627,603	905,464	515,721	376,000	376,476	949,605
Mongolia								
Myanmar			15,747					
Nepal								
Oman								

Country	1929	1951	1961	1971	1981	1991	2001	2005
Pakistan			3,937				25,085	104,278
Philippines		903,000	1,134,783	2,257,755	5,905			
Saudi Arabia								
Taiwan			12,795					
Tajikistan								
Thailand		6,000	54,131	38,384	60,036	240,000	50	230,946
Uzbekistan								
Vietnam								
ASIA	**6,680,135**	**10,274,000**	**66,735,649**	**100,234,865**	**114,056,970**	**249,640,000**	**335,856,372**	**615,335,482**
	3.3%	3.5%	13.7%	13.1%	13.8%	26.1%	32.0%	39.9%
Australia	713,798	2,475,000	5,257,596	60,153,320	81,959,255	117,134,000	181,435,000	261,796,000
Fiji			9,842					
New Caledonia			268,687					
New Zealand	12,929			558,041	3,151,408	2,265,000	1,636,400	2,207,244
Papua New Guinea								
Solomon Islands								
OCEANIA	**726,727**	**2,500,000**	**5,536,125**	**60,711,361**	**85,110,663**	**119,399,000**	**183,071,400**	**264,003,244**
	0.4%	0.9%	1.1%	8.0%	10.3%	12.5%	17.4%	17.1%
WORLD TOTAL	**201,175,000**	**294,103,000**	**486,887,677**	**762,948,887**	**828,282,052**	**955,552,000**	**1,049,438,618**	**1,544,062,062**
Unit Value in [US$ 1998]	25.2	34.0	49.6	44.0	67.1	36.0	22.6	37.5

Table A2.31: Gold Mine Production [kilograms (metal content)]

Country	1931	1951	1961	1971	1981	1991	2001	2005
Albania								
Armenia							1,900	1,550
Austria								
Azerbaijan								
Belgium								
Bosnia & Herzegovina								
Bulgaria							1,700	2,400
Cyprus								
Czechoslovakia	34							
Denmark								
Finland		575	641	544	992	2,200	1,700	1,300
France	1,327	1,978	1,514	2,041	1,131	3,060	2,512	
Georgia						10	1,880	1,620
Germany	128	47	68	53	95			
Greece	15							
Greenland								1,828
Hungary					1,866	500		
Irish Republic								
Italy	67	376	19				522	
Luxembourg								
Macedonia								
Netherlands								
Norway								
Poland						30,000	349	713
Portugal		571	696	426	340	160		
Romania	3,001			1,866	2,022	3,000	1,600	500
Russia							152,641	163,148
USSR	52,906	295,483	367,022	208,394	262,047	260,000		
Serbia and Montenegro								330
Slovakia							157	109
Spain	15	397	256		3,060	7,402	4,277	2,260

Country	1931	1951	1961	1971	1981	1991	2001	2005
Sweden	2,799	2,192	2,590	1,696	2,177	6,247	4,986	6,564
Switzerland								
Turkey	28					970	1,100	
Ukraine								
United Kingdom								
Yugoslavia	680	665	2,090	3,850	3,582	6,000		
EUROPE	**61,000**	**304,815**	**388,794**	**218,870**	**277,312**	**319,549**	**175,324**	**182,322**
	8.8%	29.3%	26.5%	15.1%	21.6%	14.7%	6.9%	7.5%
Algeria								641
Angola		2	1	1				
Botswana		15	8			20	2	2,709
Burkina Faso		177	482			5,600	229	1,400
Burundi					3	25	415	3,905
Cameroon		169	17	3	10	10	540	600
Central African Republic		1,644	2		43	176		
Congo, Democratic Republic		10,958	7,373	92	1	12		
Egypt		499	31					
Eritrea		21	172				107	25
Ethiopia		1,024	1,291	762	371	3,038	3,862	3,121
Gabon			476	427	17	50	70	300
Ghana		21,731	26,519	21,695	10,606	26,311	70,049	66,530
Guinea				124		5,870	16,256	17,474
Ivory Coast						1,100	3,672	1,500
Kenya		615	383		3	20	1,545	616
Liberia		305	65	79	525	600		
Madagascar		61	11	13	3	200	294	
Mali				1	498	4,900	41,273	44,156
Mauritania								
Morocco		64	4				1,191	1,500
Mozambique		27	3	1		394		
Namibia						1,857	2,852	2,649
Niger				4			30	3,500

Country	1931	1951	1961	1971	1981	1991	2001	2005
Nigeria		49	21	1				
Rwanda			28		37	1,000		
Senegal							550	600
Sierra Leone		101			107	26		
South Africa		358,202	713,563	976,297	656,942	601,110	394,757	294,803
Sudan	363,911	46	38		9	50	5,438	4,739
Swaziland		10	41					
Tanzania		2,029	3,188	5	12	4,200	30,088	45,405
Tunisia								
Uganda		7	14				6,090	
Zaire				5,340	2,004	8,800		
Zambia		27	130	307	328		120	170
Zimbabwe		15,145	17,732	15,600	11,539		18,050	13,453
AFRICA	**371,002**	**412,928**	**771,678**	**1,020,752**	**683,061**	**665,369**	**597,480**	**509,796**
	53.4%	39.6%	52.6%	70.6%	53.2%	30.7%	23.6%	21.0%
Belize						5		
Canada	83,831	136,630	139,148	69,765	52,033	176,552	160,200	119,225
Costa Rica			93	156	622	550	100	424
Cuba		26					1,000	500
Dominican Republic		13			12,684	3,160		
El Salvador		843		109	121			
Guatemala						31	4,500	700
Haiti				93				
Honduras		971	52	84	49	180	3,553	2,535
Jamaica							214	
Mexico	19,378	12,255	8,357	4,694	6,319	10,142	23,543	26,782
Nicaragua		7,812	7,037	3,768	1,928	1,154	3,840	3,628
Panama		90				194		200
USA	68,855	58,933	48,733	46,503	42,897	294,062	335,000	261,098
NORTH AND CENTRAL AMERICA	**174,170**	**217,572**	**203,421**	**125,172**	**116,653**	**486,030**	**531,950**	**415,092**
	25.1%	20.9%	13.9%	8.7%	9.1%	22.4%	21.0%	17.1%
Argentina		249	71		459	1,510	30,630	25,377

Country	1931	1951	1961	1971	1981	1991	2001	2005
Bolivia	539	100	2,494	670	2,064	3,501	12,374	8,906
Brazil	3,592	6,221	5,599	4,895	37,324	89,369	42,884	41,154
Chile	665	5,401	1,757	2,004	12,456	28,879	42,673	40,447
Colombia	6,042	13,397	12,474	5,874	16,460	34,844	21,813	35,783
Ecuador	1,854	392	473	343	73	12,200	3,005	5,416
French Guiana	1,354	375	247	72	124		4,062	1,955
Guyana	216	419	53	44	599	1,844	14,179	8,325
Peru	2,292	4,503	4,274	2,022	5,476	9,934	138,022	207,822
Suriname	143	202	125	20	12	30		10,619
Uruguay							2,083	1,800
Venezuela	1,316	89	935	577	570	4,215	9,076	10,000
SOUTH AMERICA	**18,013**	**31,352**	**28,502**	**16,520**	**75,619**	**186,326**	**320,801**	**397,604**
	2.6%	3.0%	1.9%	1.1%	5.9%	8.6%	12.7%	16.4%
Bhutan								
Cambodia			130	124				
China	3,009	3,110	1,866	1,555	52,876	120,000	181,870	224,050
Hong Kong								
India	10,279	7,044	4,868	3,688	2,484	1,973	2,810	3,050
Indonesia	3,113			330	1,687	16,879	166,090	142,894
Iran						500	770	800
Israel								
Japan	13,500	5,520	9,161	7,939	3,087	8,299	8,162	8,319
Kazakhstan							15,226	9,788
Korea, Dem. P.R. of	6,489		4,977	4,977	4,977	5,000		
Korea, Republic of		237	2,616	896	1,342	20,809	10	1,853
Kyrgyzstan							24,670	16,500
Laos								6,232
Malaysia	1,024	558	517	176	2,354	2,777	3,965	4,249
Mongolia						800	13,675	24,122
Myanmar		4	6				100	100
Nepal								
Oman							603	

Country	1931	1951	1961	1971	1981	1991	2001	2005
Pakistan								
Philippines	5,660	12,242	13,187	19,814	23,435	25,916	33,841	37,490
Saudi Arabia		2,274				4,780	2,500	7,456
Taiwan	2,875	949	544	606	1,763			
Tajikistan							2,700	1,927
Thailand	9						313	4,393
Uzbekistan							85,400	84,210
Vietnam							3,000	3,000
ASIA	**45,958**	**40,124**	**38,102**	**40,106**	**94,005**	**207,733**	**545,705**	**580,433**
	6.6%	3.9%	2.6%	2.8%	7.3%	9.6%	21.5%	23.9%
Australia		27,854	33,476	20,905	18,374	234,218	280,080	263,000
Fiji		2,912	2,595	2,772	952	2,713	4,907	2,793
New Caledonia								
New Zealand		2,336	880	293	189	6,758	9,850	10,583
Papua New Guinea		2,934	1,301	749	16,806	60,780	67,043	68,483
Solomon Islands				14	33	30		
OCEANIA	**24,383**	**36,037**	**38,252**	**24,733**	**36,353**	**304,499**	**361,880**	**344,859**
	3.5%	3.5%	2.6%	1.7%	2.8%	14.0%	14.3%	14.2%
WORLD TOTAL	**694,526**	**1,041,968**	**1,468,086**	**1,446,153**	**1,283,003**	**2,169,506**	**2,533,140**	**2,430,106**
Unit Value in [US$ 1998]	7,740.0	7,010.0	6,160.0	5,340.0	26,500.0	14,000.0	8,060	12,065

Table A2.32: Nickel Mine Production [tonnes (metal content)]

Country	1929	1951	1961	1971	1981	1991	2001	2005
Albania			3,638		6,834	7,500		
Armenia								
Austria								
Azerbaijan								
Belgium								
Bosnia & Herzegovina								
Bulgaria								
Cyprus								
Czechoslovakia								
Denmark								
Finland		85	2,620	4,413	8,340	9,900	3,700	3,400
France								
Georgia								
Germany			121		3,307			
Greece	313			12,847	18,960	19,300	20,742	20,400
Greenland								
Hungary								
Irish Republic								
Italy								
Luxembourg								
Macedonia								
Netherlands								
Norway	532			438	606	2,200	2,800	342
Poland			1,602	2,425	2,535			
Portugal								
Romania								
Russia							272,800	300,000
USSR		33,000	91,491	143,299	191,800	280,000		
Serbia and Montenegro								
Slovakia								
Spain								5,380

Country	1929	1951	1961	1971	1981	1991	2001	2005
Sweden								
Switzerland								
Turkey								700
Ukraine							1,500	2,000
United Kingdom								
Yugoslavia					4,850	2,400		
EUROPE	**845**	**33,085**	**99,472**	**163,421**	**237,233**	**321,300**	**301,542**	**332,222**
	1.23%	19.81%	22.36%	21.12%	26.81%	32.61%	23.5%	22.9%
Algeria								
Angola								
Botswana					20,062	23,500	22,454	28,212
Burkina Faso								
Burundi								
Cameroon								
Central African Republic								
Congo, Democratic Republic								
Egypt								
Eritrea								
Ethiopia								
Gabon								
Ghana								
Guinea								
Ivory Coast								
Kenya								
Liberia								
Madagascar								
Mali								
Mauritania								
Morocco			313	121	154			
Mozambique								
Namibia								
Niger								

Country	1929	1951	1961	1971	1981	1991	2001	2005
Nigeria								
Rwanda								
Senegal								
Sierra Leone								
South Africa		1,138	3,197	15,501	32,077	27,700	36,443	42,497
Sudan								
Swaziland								
Tanzania								
Tunisia								
Uganda								
Zaire								
Zambia								
Zimbabwe			71	14,109	15,818	12,371	8,009	7,799
AFRICA	**-**	**1,138**	**3,580**	**29,731**	**68,111**	**63,571**	**66,906**	**78,508**
	0.00%	0.68%	0.80%	3.84%	7.70%	6.45%	5.2%	5.4%
Belize								
Canada	60,828	125,108	256,826	324,453	194,712	192,259	194,058	198,369
Cost Rica								
Cuba			17,990	42,990	46,836	33,349	72,600	72,000
Dominican Republic				243	22,708	29,062	33,419	46,000
El Salvador								
Guatemala								
Haiti								
Honduras								
Jamaica								
Mexico				61				
Nicaragua								
Panama								
USA	375	686	12,319	18,834	13,337	5,523		
NORTH AND CENTRAL AMERICA	**61,203**	**125,794**	**287,135**	**386,580**	**277,593**	**260,193**	**300,077**	**316,369**
	89.36%	75.33%	64.56%	49.95%	31.38%	26.41%	23.4%	21.8%
Argentina								

Country	1929	1951	1961	1971	1981	1991	2001	2005
Bolivia								
Brazil			121	3,858	8,276	20,456	45,456	74,198
Chile								
Colombia						20,590	53,000	89,000
Ecuador								
French Guiana								
Guyana								
Peru								
Suriname								
Uruguay								
Venezuela							10,600	18,500
SOUTH AMERICA	**-**	**-**	**121**	**3,858**	**8,276**	**41,046**	**109,056**	**181,698**
	0.00%	0.00%	0.03%	0.50%	0.94%	4.17%	8.5%	12.5%
Bhutan								
Cambodia								
China					13,228	30,400	51,000	72,000
Hong Kong								
India	1,025							
Indonesia			766	24,030	59,357	71,681	102,100	147,700
Iran								
Israel								
Japan								
Kazakhstan								
Korea, Dem. P.R. of								
Korea, Republic of								
Kyrgyzstan								
Laos								
Malaysia								
Mongolia								
Myanmar			123	29	24	20		
Nepal								
Oman								

Country	1929	1951	1961	1971	1981	1991	2001	2005
Pakistan								
Philippines					35,537	13,658	27,176	22,560
Saudi Arabia								
Taiwan								
Tajikistan								
Thailand								
Uzbekistan								
Vietnam								
ASIA	**1,025**	**-**	**890**	**24,059**	**108,146**	**115,759**	**180,276**	**242,260**
	1.50%	0.00%	0.20%	3.11%	12.22%	11.75%	14.1%	16.7%
Australia	105			43,194	90,493	69,000	205,000	186,000
Fiji								
New Caledonia	5,309	6,700	53,572	123,056	94,885	114,492	117,734	111,939
New Zealand								
Papua New Guinea								
Solomon Islands								
OCEANIA	**5,413**	**6,700**	**53,572**	**166,250**	**185,378**	**183,492**	**322,734**	**297,939**
	7.9%	4.0%	12.04%	21.48%	20.95%	18.62%	25.20%	20.6%
WORLD TOTAL	**68,487**	**167,000**	**444,769**	**773,899**	**884,737**	**985,361**	**1,280,591**	**1,448,996**
Unit Value in [US$ 1998]	7,350	7,440	9,400	11,800	10,700	9,760	5,470	12,416

Table A2.33: Zinc Mine Production [tonnes (metal content)]

Country	1943	1951	1961	1971	1981	1991	2001	2005
Albania								
Armenia							745	3,196
Austria		3,355	7,331	25,605	18,200	14,827		
Azerbaijan								
Belgium								
Bosnia & Herzegovina								
Bulgaria			89,794	97,002	65,000	29,100	10,600	12,700
Cyprus								
Czechoslovakia				10,406	6,800	11,600		
Denmark								
Finland	6,570	3,000	56,617	61,831	53,500	55,500	20,100	40,500
France	2,340	13,283	19,052	18,396	37,400	27,109		
Georgia							1,000	
Germany	238,552	75,294	114,517	172,496	110,700	53,987		
Greece		6,300	21,321	17,266	27,000		31,737	4,000
Greenland			9,700		79,700	30,000		
Hungary				5,842	2,000			
Irish Republic		2,355	203	106,372	120,300	187,500	298,100	445,400
Italy	36,492	100,733	163,090	128,638	43,900	36,349		
Luxembourg								
Macedonia							23,078	
Netherlands								
Norway	4,644	5,469	11,337	13,021	29,800	18,886		
Poland		86,200	169,597	235,231	146,500	171,800	152,700	135,600
Portugal				2,486				
Romania				48,391	55,000	26,871	29,786	13,784
Russia							164,000	186,000
USSR	90,000	148,000	485,012	790,349	790,000	475,000		
Serbia and Montenegro							5,988	2,000
Slovakia								
Spain	37,050	74,000	106,904	106,368	182,000	261,300	165,568	

Country	1943	1951	1961	1971	1981	1991	2001	2005
Sweden	28,256	38,318	96,515	120,345	180,900	161,170	156,334	215,691
Switzerland								
Turkey		500	10,061	29,437	30,700	32,546	36,000	48,000
Ukraine								
United Kingdom	4,140	194			10,900	1,078		
Yugoslavia		39,420	72,762	119,920	88,600	75,000		
EUROPE	**448,044**	**596,421**	**1,449,444**	**2,109,403**	**2,078,900**	**1,669,623**	**1,095,736**	**1,106,871**
	22.2%	25.9%	34.5%	31.4%	35.5%	23.0%	12.0%	11.0%
Algeria	2,680	9,466	51,200	19,194	20,000	2,610	5,700	2,206
Angola		330						
Botswana								
Burkina Faso								
Burundi								
Cameroon								
Central African Republic								
Congo, Democratic Republic	18,981	88,705	122,619	769	3,000		700	
Egypt		1,950						
Eritrea								
Ethiopia								
Gabon								
Ghana								
Guinea								
Ivory Coast								
Kenya								
Liberia								
Madagascar								
Mali								
Mauritania								
Morocco	450	19,455	49,549	14,991	7,900	24,331	89,631	128,000
Mozambique								
Namibia		14,800	16,430	53,094	29,600	33,150	37,622	246,000
Niger								

Country	1943	1951	1961	1971	1981	1991	2001	2005
Nigeria					100			
Rwanda								
Senegal								
Sierra Leone								
South Africa				192	87,200	64,425	61,221	32,112
Sudan								
Swaziland								
Tanzania								
Tunisia	133	3,548	5,066	14,330	7,500	5,000	40,098	15,713
Uganda								
Zaire				132,717	63,300	42,400		
Zambia	13,620	22,953	49,714	69,339	40,600	19,825		
Zimbabwe								
AFRICA	**35,864**	**161,207**	**294,578**	**304,627**	**259,200**	**191,741**	**234,972**	**424,031**
	1.8%	7.0%	7.0%	4.5%	4.4%	2.6%	2.6%	4.2%
Belize								
Canada	331,243	309,450	488,428	1,540,184	1,096,000	1,156,582	1,064,744	666,654
Costa Rica								
Cuba								
Dominican Republic								
El Salvador								
Guatemala		6,500	9,641	615	3,000			
Haiti								
Honduras		140	7,552	27,873	16,200	38,280	48,485	42,698
Jamaica								
Mexico	185,930	180,064	326,823	321,961	206,600	317,101	428,828	476,307
Nicaragua				4,928				
Panama								
USA	675,123	617,961	511,897	553,953	312,400	546,610	842,100	747,900
NORTH AND CENTRAL AMERICA	**1,192,296**	**1,114,115**	**1,344,341**	**2,449,515**	**1,634,200**	**2,058,573**	**2,384,157**	**1,933,559**
	59.1%	48.4%	32.0%	36.4%	27.9%	28.4%	26.1%	19.2%
Argentina	17,680	15,475	39,134	53,297	35,200	39,253	39,703	26,583

Country	1943	1951	1961	1971	1981	1991	2001	2005
Bolivia	15,900	30,535	6,479	54,772	47,000	129,778	141,983	157,019
Brazil				20,559	96,600	130,000	111,432	171,434
Chile			197	2,409	1,500	30,998	32,762	28,841
Colombia			1,543	136	200	266		
Ecuador				153	700	100		
French Guiana								
Guyana								
Peru	30,834	101,300	211,265	386,483	498,900	627,824	1,056,629	1,201,671
Suriname								
Uruguay								
Venezuela								
SOUTH AMERICA	**64,414**	**147,310**	**258,618**	**517,809**	**680,100**	**958,219**	**1,382,509**	**1,585,548**
	3.2%	6.4%	6.2%	7.7%	11.6%	13.2%	15.2%	15.7%
Bhutan								
Cambodia								
China			121,253	121,253	160,000	750,000	1,693,200	2,525,000
Hong Kong								
India		1,100	6,173	10,019	29,100	75,000	214,600	481,800
Indonesia								
Iran			16,424	70,547	35,000	70,000	105,000	118,000
Israel								
Japan	81,633	64,416	204,448	377,583	242,000	133,004	47,892	41,500
Kazakhstan							344,700	364,300
Korea, Dem. P.R. of	2,430		110,230	164,243	140,000	200,000	28,000	60,000
Korea, Republic of			547	34,218	56,500	22,039	5,100	77
Kyrgyzstan								
Laos							11,500	1,500
Malaysia								
Mongolia								3,000
Myanmar			8,929	4,864	3,600	1,750	500	1,600
Nepal								
Oman								

Country	1943	1951	1961	1971	1981	1991	2001	2005
Pakistan								
Philippines		150	4,026	4,708	5,300			
Saudi Arabia						2,475	3,000	1,000
Taiwan								
Tajikistan								
Thailand		520	1,093			87,000	8,866	20,381
Uzbekistan								
Vietnam	4,410				6,000	15,000	43,000	48,000
ASIA	**88,473**	**66,186**	**473,123**	**787,435**	**677,500**	**1,356,268**	**2,505,358**	**3,666,158**
	4.4%	2.9%	11.3%	11.7%	11.6%	18.7%	27.5%	36.4%
Australia	144,175	197,843	384,147	550,000	518,300	1,024,000	1,517,000	1,367,000
Fiji								
New Caledonia								
New Zealand				2,392				
Papua New Guinea								
Solomon Islands								
OCEANIA	**144,175**	**197,843**	**384,147**	**552,392**	**518,300**	**1,024,000**	**1,517,000**	**1,367,000**
	7.1%	8.6%	9.1%	8.2%	8.9%	14.1%	16.6%	13.6%
WORLD TOTAL	**2,018,000**	**2,300,000**	**4,204,250**	**6,721,181**	**5,848,200**	**7,258,424**	**9,119,732**	**10,083,167**
Unit Value in [US$ 1998]	1,720	2,480	1,390	1,430	1,760	1,390	892	1,244

Table A2.34: Silver Mine Production [kilograms (metal content)]

Country	1930	1951	1961	1971	1981	1991	2001	2005
Albania								
Armenia								4,000
Austria	317	170	1,810	6,843		29,000		
Azerbaijan								
Belgium								
Bosnia & Herzegovina								
Bulgaria					28,926	37,000	56,806	60,000
Cyprus								
Czechoslovakia	27,701	50,014	50,014	34,214	40,435	9,000		
Denmark								
Finland		4,892	14,188	19,377	37,791	30,000	11,000	13,000
France	20,279	21,956	35,101	165,066	53,032	29,000	929	700
Georgia								
Germany	170,615	166,608	207,754	211,504	80,123	4,000		
Greece	7,496	2,000	3,527	14,370	49,766	70,000	62,400	6,000
Greenland					22,395			
Hungary		1,499	2,000	187				
Irish Republic				44,540	21,772	11,000	8,700	10,500
Italy	17,782	25,170	30,268	38,444	54,991	176,000	1,000	100
Luxembourg								
Macedonia							22,216	
Netherlands								
Norway	10,507	5,100						
Poland	17,378	3,001	4,000	6,221	639,986	899,000	1,230,700	1,262,400
Portugal		2,036	1,501		1,213	43,000	23,100	23,700
Romania	4,417	20,000	20,000	31,104	26,438	80,000	18,000	18,000
Russia							400,000	1,100,000
USSR	9,331	746,485	777,588	1,213,037	1,446,314	2,200,000		
Serbia and Montenegro							5,745	2,400
Slovakia								
Spain	82,710	22,889	140,793	51,010	166,311	208,000	55,000	5,227

Country	1930	1951	1961	1971	1981	1991	2001	2005
Sweden	2,333	35,642	87,875	121,148	165,999	239,000	306,029	309,933
Switzerland								
Turkey	6,843				6,221	64,000	188,000	219,000
Ukraine								
United Kingdom	1,275	833	148					
Yugoslavia	3,120	94,306	107,434	104,321	138,006	84,000		
EUROPE	**382,104**	**1,202,601**	**1,484,001**	**2,061,386**	**2,979,717**	**4,212,000**	**2,389,625**	**3,034,960**
	4.8%	19.5%	20.1%	22.5%	26.5%	26.9%	12.6%	14.9%
Algeria	5,194	299	9,331	6,221	3,421	3,000	1,700	800
Angola								
Botswana	12	2						
Burkina Faso								
Burundi								
Cameroon								
Central African Republic								
Congo, Democratic Republic	404	118,046	107,552				500	53,600
Egypt								
Eritrea								
Ethiopia							3,545	886
Gabon								
Ghana		1,634	219		529	1,000	1,900	3,300
Guinea								
Ivory Coast								
Kenya			1,267					
Liberia								
Madagascar								
Mali								
Mauritania								
Morocco		48,801	28,239	91,507	65,939	296,000	280,700	240,000
Mozambique	1	3						
Namibia		32,039	57,026	53,747	107,494	91,000	20,396	34,102
Niger								

Country	1930	1951	1961	1971	1981	1991	2001	2005
Nigeria		6						
Rwanda								
Senegal								
Sierra Leone								
South Africa	32,659	36,161	71,174	105,068	235,391	171,000	109,600	89,023
Sudan							1,600	2,900
Swaziland		1	3					
Tanzania	44	1,110	1,995				6,861	12,891
Tunisia		1,901	2,170	3,297	2,613	1,000	3,650	4,000
Uganda		0	2					
Zaire				45,722	80,247	80,000		
Zambia	2,282	3,132	22,972	6,034	22,208	14,000		
Zimbabwe		2,486	3,322	2,830	26,656	19,000	3,344	3,400
AFRICA	**324,105**	**245,622**	**305,272**	**314,426**	**544,498**	**676,000**	**433,796**	**444,902**
	4.0%	4.0%	4.1%	3.4%	4.8%	4.3%	2.3%	2.2%
Belize								
Canada	822,250	719,295	976,090	1,431,508	1,128,996	1,339,000	1,320,030	1,121,500
Costa Rica		18			62			
Cuba		5,360						
Dominican Republic					64,135	22,000		
El Salvador		10,952		6,687	4,261			
Guatemala		9,638	16,046		249			
Haiti				529				
Honduras		98,979	110,253	113,279	56,702	39,000	46,760	53,617
Jamaica								
Mexico	3,278,650	1,362,264	1,255,002	1,140,162	1,645,874	2,295,000	2,759,985	2,894,161
Nicaragua		4,409	12,978	8,118	4,666	1,000	2,532	2,936
Panama		180						
USA		1,241,256	1,085,513	1,292,787	1,265,385	1,855,000	1,740,000	1,225,800
NORTH AND CENTRAL AMERICA	**5,796,888**	**3,452,350**	**3,455,882**	**3,993,070**	**4,170,329**	**5,551,000**	**5,869,307**	**5,298,014**
	72.3%	55.9%	46.9%	43.5%	37.1%	35.4%	30.9%	26.0%
Argentina	467	39,000	44,499	98,878	78,319	70,000	152,802	148,119

Country	1930	1951	1961	1971	1981	1991	2001	2005
Bolivia	220,558	222,000	121,341	166,995	198,876	376,000	409,720	420,270
Brazil	622	632	7,214	19,409	23,794	154,000	10,000	6,672
Chile	22,780	30,590	67,083	84,882	361,112	678,000	1,348,667	1,399,539
Colombia	1,866	4,036	3,979	2,115	4,448	8,000	7,242	7,142
Ecuador	3,300	1,045	3,147	2,177	995			
French Guiana								
Guyana	233							
Peru	482,117	465,282	1,062,549	1,194,313	1,459,999	1,770,000	2,673,834	3,193,146
Suriname								
Uruguay								
Venezuela	131							
SOUTH AMERICA	**732,074**	**762,585**	**1,309,814**	**1,568,768**	**2,127,543**	**3,056,000**	**4,602,265**	**5,174,888**
	9.1%	12.3%	17.8%	17.1%	18.9%	19.5%	24.2%	25.4%
Bhutan								
Cambodia								
China	1,555	9,953	24,883	24,883	77,759	150,000	2,013,250	2,500,000
Hong Kong								
India	778	454	5,941	3,764	17,262	32,000	57,675	27,950
Indonesia	65,137		10,080	8,865	25,816	80,000	348,455	326,993
Iran						40,000	20,000	25,000
Israel								
Japan	175,069	143,385	247,590	351,252	280,243	171,000	82,452	54,100
Kazakhstan							943,027	812,095
Korea, Dem. P.R. of	2,140		19,906	21,772	49,766	50,000	50,000	50,000
Korea, Republic of		168	14,318	60,341	95,208	265,000	58	41,489
Kyrgyzstan								
Laos								3,100
Malaysia					14,681	13,000	3	402
Mongolia							21,000	21,000
Myanmar	219,187	8,731	54,223	21,306	13,997	5,000	700	1,000
Nepal								
Oman								

Country	1930	1951	1961	1971	1981	1991	2001	2005
Pakistan								
Philippines	3,431	8,541	25,281	60,341	62,954	38,000	29,590	19,150
Saudi Arabia		3,419				16,000	10,000	13,500
Taiwan	473	821	2,404	2,271	6,687			
Tajikistan								
Thailand								
Uzbekistan							60,000	60,000
Vietnam	100							
ASIA	**467,869**	**175,472**	**404,627**	**554,794**	**644,372**	**860,000**	**3,636,210**	**3,955,779**
	5.8%	2.8%	5.5%	6.0%	5.7%	5.5%	19.1%	19.4%
Australia		335,670	406,186	675,040	743,561	1,180,000	1,970,000	2,407,000
Fiji		774	1,173	622	249		2,109	1,418
New Caledonia								
New Zealand		4,146	25	2,053		11,000	27,118	43,003
Papua New Guinea		1,045	941	591	42,394	125,000	69,368	51,125
Solomon Islands								
OCEANIA	**316,167**	**341,635**	**408,325**	**678,306**	**786,204**	**1,316,000**	**2,068,595**	**2,502,546**
	3.9%	5.5%	5.5%	7.4%	7.0%	8.4%	10.9%	12.3%
WORLD TOTAL	**8,019,206**	**6,180,266**	**7,367,919**	**9,170,749**	**11,252,663**	**15,672,000**	**18,999,798**	**20,411,089**
Unit Value in [US$ 1998]	120	179	162	201	606	155	129	198

Table A2.35: Lead Mine Production [tonnes (metal content)]

Country	1929	1951	1961	1971	1981	1991	2001	2005
Albania								
Armenia								
Austria	6,569	4,522	6,670	9,374	4,300	1,200		
Azerbaijan								
Belgium	82,850							
Bosnia & Herzegovina								
Bulgaria		10,000	97,255	121,253	96,000	43,600	18,500	13,000
Cyprus								
Czechoslovakia	4,609		7,937	7,055	3,400	3,400		
Denmark								
Finland		216	3,791	5,758	1,900	1,300		
France	20,358	10,074	22,911	36,173	17,200	1,700		
Georgia								
Germany	97,909	52,977	68,511	62,066	21,600	5,900		
Greece	5,361	3,800	14,095	12,721	27,400	31,700	26,588	3,000
Greenland			11,138		27,400			
Hungary	109			2,105	1,000			
Irish Republic		1,207	308	62,688	28,800	39,900	44,500	72,200
Italy	22,650	40,200	57,994	38,396	21,600	14,200	2,700	800
Luxembourg								
Macedonia							9,672	
Netherlands								
Norway	300	414	2,782	3,721	3,600	3,500		
Poland	35,789	18,000	46,416	76,279	50,400	63,600	52,600	50,900
Portugal	94	1,621	31	1,680				
Romania	565	4,000	14,550	46,297	33,500	16,200	19,676	11,610
Russia							14,000	36,400
USSR	6,200	128,400	429,897	551,150	425,000	380,000		
Serbia and Montenegro							4,291	1,000
Slovakia								
Spain	142,753	40,442	96,851	85,238	80,200	46,000	35,573	

Country	1929	1951	1961	1971	1981	1991	2001	2005
Sweden		19,693	77,732	96,543	84,100	91,100	85,975	60,445
Switzerland								
Turkey	7,324	600	3,900	8,003	8,000	15,300	17,884	11,341
Ukraine								
United Kingdom	10,839	4,925	1,825	1,819	7,000	1,000	800	500
Yugoslavia	9,471	78,750	117,474	151,091	118,600	90,000		
EUROPE	**453,750**	**419,841**	**1,082,068**	**1,379,409**	**1,061,000**	**849,600**	**332,759**	**261,196**
	25.4%	21.9%	37.3%	33.4%	31.6%	25.6%	10.7%	7.8%
Algeria		2,838	11,394	5,732	5,100	900	560	
Angola								
Botswana								
Burkina Faso								
Burundi								
Cameroon								
Central African Republic								
Congo, Democratic Republic		2,504	1,064	35	7,700			
Egypt		144	43					
Eritrea								
Ethiopia								
Gabon								
Ghana								
Guinea								
Ivory Coast								
Kenya								
Liberia								
Madagascar								
Mali								
Mauritania								
Morocco		68,504	107,253	94,776	116,000	73,700	76,748	53,000
Mozambique								
Namibia	2,802	39,230	77,158	86,876	46,900	15,000	12,827	14,320
Niger								

Country	1929	1951	1961	1971	1981	1991	2001	2005
Nigeria		4	8	261	200	100		
Rwanda								
Senegal								
Sierra Leone								
South Africa		228,407	100		98,900	76,300	50,771	42,159
Sudan								
Swaziland								
Tanzania		1,561	427					
Tunisia	18,850	21,250	21,123	22,928	5,700	1,300	6,942	8,407
Uganda		9						
Zaire								
Zambia	1,661	14,194	18,738	33,620	17,200	9,100		
Zimbabwe								
AFRICA	**23,313**	**378,645**	**237,308**	**244,228**	**297,700**	**176,400**	**147,848**	**117,886**
	1.3%	19.8%	8.2%	5.9%	8.9%	5.3%	4.8%	3.5%
Belize								
Canada	138,095	143,544	201,233	477,481	332,000	276,500	153,932	79,252
Costa Rica								
Cuba								
Dominican Republic								
El Salvador		470						
Guatemala		3,300	10,426	607				
Haiti								
Honduras		454	7,454	21,831	12,600	8,700	6,750	10,488
Jamaica								
Mexico	239,952	225,463	220,324	190,588	157,400	167,700	118,247	134,388
Nicaragua				699				
Panama								
USA	636,997	352,135	288,716	637,736	445,500	476,900	466,400	436,500
NORTH AND CENTRAL AMERICA	**1,015,044**	**725,366**	**728,152**	**1,328,942**	**947,500**	**929,800**	**745,329**	**660,628**
	56.8%	37.8%	25.1%	32.2%	28.2%	28.1%	24.0%	19.8%
Argentina	9,020	20,000	34,509	48,467	32,700	23,700	12,334	9,663

Country	1929	1951	1961	1971	1981	1991	2001	2005
Bolivia		30,558	24,695	28,099	16,800	20,800	9,090	11,093
Brazil		3,500	16,865	33,823	28,400	7,300	10,725	16,063
Chile		7,801	2,482	1,070	200	1,100	1,193	878
Colombia			796	249	200	600		
Ecuador		30	134		200	200		
French Guiana								
Guyana								
Peru	19,448	82,350	165,734	201,476	192,700	199,800	289,546	319,345
Suriname								
Uruguay								
Venezuela								
SOUTH AMERICA	**28,468**	**144,239**	**245,215**	**313,184**	**271,200**	**253,500**	**322,888**	**357,042**
	1.6%	7.5%	8.5%	7.6%	8.1%	7.6%	10.4%	10.7%
Bhutan								
Cambodia								
China		1,500	109,128	121,253	160,000	352,000	676,000	1,023,000
Hong Kong		179						
India			4,936	1,890	15,300	25,100	32,600	62,300
Indonesia				243				
Iran		1,100	18,188	29,211	20,000	16,000	18,000	15,000
Israel								
Japan	3,374	12,876	56,234	85,768	46,900	18,300	5,516	3,400
Kazakhstan							37,500	45,370
Korea, Dem. P.R. of	333		60,627	97,002	100,000	80,000	17,000	20,000
Korea, Republic of			1,118	20,102	13,600	12,600	1,000	50
Kyrgyzstan								
Laos								
Malaysia								
Mongolia								
Myanmar	81,521	2,000	20,413	10,935	16,100	4,700	900	2,000
Nepal								
Oman								

Country	1929	1951	1961	1971	1981	1991	2001	2005
Pakistan				8				
Philippines		571	122	24	1,100			
Saudi Arabia						300		
Taiwan								
Tajikistan							2,000	407
Thailand	17	1,821	2,686	1,790	17,300	16,700	300	
Uzbekistan								
Vietnam							900	1,200
ASIA	**85,245**	**20,047**	**273,452**	**368,226**	**390,300**	**525,700**	**791,716**	**1,172,727**
	4.8%	1.0%	9.4%	8.9%	11.6%	15.9%	25.5%	35.1%
Australia	180,358	228,407	332,911	490,352	388,100	579,000	759,000	767,000
Fiji								
New Caledonia								
New Zealand				1,513				
Papua New Guinea								
Solomon Islands								
OCEANIA	**180,358**	**228,407**	**332,911**	**491,865**	**388,100**	**579,000**	**759,000**	**767,000**
	0.100974259	0.119176435	0.11483233	0.119215325	0.115650516	0.174713337	24.5%	23.0%
WORLD TOTAL	**1,786,178**	**1,916,545**	**2,899,106**	**4,125,854**	**3,355,800**	**3,314,000**	**3,099,540**	**3,336,479**
Unit Value in [US$ 1998]	1,440	2,410	1,310	1,230	1,440	884	886	1,131

Table A2.36: Bauxite Mine Production [tonnes (metal content)]

Country	1929	1951	1961	1971	1981	1991	2001	2005
Albania						20,000		
Armenia								
Austria		7,795	17,716					
Azerbaijan								
Belgium								
Bosnia & Herzegovina							90,000	480,000
Bulgaria								
Cyprus								
Czechoslovakia								
Denmark								
Finland								
France	666,348	1,124,400	2,155,398	3,084,483	1,842,000	9,000	153,000	17,000
Georgia								
Germany	7,256	5,327	3,937	2,953				
Greece	6,280	197,060	1,082,620	2,771,507	3,216,000	2,133,000	1,903,280	2,441,443
Greenland								
Hungary	389,152	734,000	1,322,765	2,024,499	2,914,000	2,037,000	1,000,044	535,337
Irish Republic								
Italy	192,774	174,014	312,976	187,982	19,000	9,000		
Luxembourg								
Macedonia								
Netherlands								
Norway								
Poland								
Portugal								
Romania	926	10,000	66,926	295,260	712,000	200,000		
Russia							4,805,000	6,409,300
USSR		850,000	3,936,800	3,936,800	4,600,000	5,000,000		
Serbia and Montenegro							630,000	600,000
Slovakia								
Spain	975	10,581	5,905	4,921	9,000	1,000		

Country	1929	1951	1961	1971	1981	1991	2001	2005
Sweden								
Switzerland								
Turkey				148,614	575,000	489,000	242,040	356,480
Ukraine								
United Kingdom	2,359							
Yugoslavia	103,366	453,357	1,193,835	1,897,538	3,249,000	1,912,000		
EUROPE	**1,369,436**	**3,566,534**	**10,098,876**	**14,354,557**	**17,136,000**	**11,810,000**	**8,823,364**	**10,839,560**
	63.7%	33.1%	35.5%	23.9%	20.0%	10.9%	6.3%	6.2%
Algeria								
Angola								
Botswana								
Burkina Faso								
Burundi								
Cameroon								
Central African Republic								
Congo, Democratic Republic								
Egypt								
Eritrea								
Ethiopia								
Gabon								
Ghana		131,404	192,903	317,897	181,000	353,000	692,620	606,700
Guinea			1,711,524	1,934,937	11,112,000	15,466,000	17,312,100	19,236,900
Ivory Coast								
Kenya								
Liberia								
Madagascar								
Mali								
Mauritania								
Morocco								
Mozambique		3,329	5,905	6,889		8,000	8,597	9,518
Namibia								
Niger								

Country	1929	1951	1961	1971	1981	1991	2001	2005
Nigeria								
Rwanda								
Senegal								
Sierra Leone				571,820	610,000	1,288,000		
South Africa								
Sudan								
Swaziland								
Tanzania								
Tunisia								
Uganda								
Zaire								
Zambia								
Zimbabwe			984		5,000			
AFRICA	**-**	**134,733**	**1,911,316**	**2,831,543**	**11,908,000**	**17,115,000**	**18,013,317**	**19,853,118**
	0.0%	1.2%	6.7%	4.7%	13.9%	15.9%	12.8%	11.3%
Belize								
Canada								
Costa Rica								
Cuba								
Dominican Republic			727,324	1,054,078	457,000	7,000		
El Salvador								
Guatemala								
Haiti			258,845	622,999	427,000			
Honduras								
Jamaica			6,557,725	12,050,545	11,682,000	11,552,000	12,369,647	14,118,319
Mexico								
Nicaragua								
Panama								
USA	371,648	1,878,347	1,208,598	1,956,590	1,510,000		200,000	200,000
NORTH AND CENTRAL AMERICA	**371,648**	**1,878,347**	**8,752,491**	**15,684,211**	**14,076,000**	**11,559,000**	**12,569,647**	**14,318,319**
	17.3%	17.4%	30.8%	26.1%	16.5%	10.7%	9.0%	8.1%
Argentina								

Country	1929	1951	1961	1971	1981	1991	2001	2005
Bolivia								
Brazil		19,033	108,262	521,626	5,770,000	10,414,000	13,388,100	22,034,600
Chile								
Colombia								
Ecuador								
French Guiana								
Guyana	188,123	2,034,888	2,336,491	3,797,044	1,681,000	2,204,000	2,011,301	1,675,842
Peru								
Suriname	209,998	2,671,330	3,298,054	6,507,530	4,100,000	3,198,000	4,393,640	4,756,998
Uruguay								
Venezuela						1,992,000	4,584,893	5,900,000
SOUTH AMERICA	**398,121**	**4,725,251**	**5,742,807**	**10,826,200**	**11,551,000**	**17,808,000**	**24,377,934**	**34,367,440**
	18.5%	43.8%	20.2%	18.0%	13.5%	16.5%	17.4%	19.5%
Bhutan								
Cambodia								
China			393,680	531,468	1,500,000	2,600,000	8,650,000	18,000,000
Hong Kong								
India	9,189	68,123	460,606	1,469,411	1,923,000	4,735,000	8,688,752	12,335,198
Indonesia		393,700	406,475		1,203,000	1,406,000	1,237,006	1,081,739
Iran				1,198,756			283,877	500,000
Israel								
Japan								
Kazakhstan							3,685,100	4,815,400
Korea, Dem. P.R. of								
Korea, Republic of								
Kyrgyzstan								
Laos								
Malaysia			652,525	946,800	701,000	376,000	64,161	4,735
Mongolia								
Myanmar								
Nepal								
Oman								

Country	1929	1951	1961	1971	1981	1991	2001	2005
Pakistan					2,000	4,000	3,728	6,504
Philippines								
Saudi Arabia								
Taiwan		10,000						
Tajikistan								
Thailand								
Uzbekistan								
Vietnam							20,000	20,000
ASIA	**9,189**	**471,823**	**1,913,285**	**4,146,435**	**5,329,000**	**9,121,000**	**22,632,624**	**36,763,576**
	0.4%	4.4%	6.7%	6.9%	6.2%	8.5%	16.1%	20.9%
Australia	555	5,166	15,747	12,333,994	25,541,000	40,503,000	53,799,000	59,959,000
Fiji								
New Caledonia								
New Zealand								
Papua New Guinea								
Solomon Islands								
OCEANIA	**555**	**5,166**	**15,747**	**12,333,994**	**25,541,000**	**40,503,000**	**53,799,000**	**59,959,000**
	0.0%	0.0%	0.1%	20.5%	29.9%	37.5%	38.4%	34.0%
WORLD TOTAL	**2,148,949**	**10,781,854**	**28,434,522**	**60,176,941**	**85,541,000**	**107,916,000**	**140,215,886**	**176,101,013**
Unit Value in [US$ 1998]	43.3	38.9	51.8	49.3	50.7	36.3	21.4	21.9

Appendix 3: Guidelines for interviews

Appendix 3.1: Guide for interviewing KIMS supplier firms

The tables below were used as a guide for those aspects of the survey interviews with KIMS suppliers that were concerned with the firms' capabilities, learning, innovation and networks of interaction with other firms and organisations. These issues formed the core elements of what is described in the thesis as 'Process 2' – the firm-level learning and innovation cycle.

The tables were not designed as specific interview questions, but as summaries of the information sought from the interviewees, and as guides for initial rapid summarisation or classification of respondents; comments during sometimes varying approaches to questions and discussion – e.g. about levels of capability (Table A3.23).

Firm Code: Position interviewee: (Interview date)	Foundation/start up date (year): Country:

THE IDENTITY OF THE FIRM AND INFORMATION OF THESE QUESTIONNAIRES WILL BE KEPT CONFIDENTIAL !

General Overview:

Table A3.1: Origin of KIMS Firms

KIMS firm's origins	**Similarity to KIMS firms origin** Assess the similarity of the origin of the firm with the options presented in the first column. Use the following marks: **5**: Very similar - **3**: There is some similarity - **1**: Completely different
1. Graduates professionals (geologist, engineers, metallurgist, or others university graduates) that have gotten important experience and knowledge by working in mining companies decided to set-up their own firm.	
2. Experts, who were former members of other KIMS supplier firm, decided to set-up their own firm.	
3. Experts that have gotten important experience and knowledge by working in other supplier firm different to a KIMS supplier (e.g. equipment and input suppliers) decided to set-up their own firm.	
4. Experts working in research centres/programs or universities that found out they have knowledge and a services valuable to mining companies, set-up their own firm	
5. Experts that found a product/service or got a representation of a product/service valuable to mining companies, set-up their own firm (based on the representation) and later on develop their own services.	
6. Group of experts set-up a firm to get a share of the significant demand growth trigger by mining companies upgrading and expansion programs	
7. Important government programs supported knowledge accumulation, which lead to setting-up a firm	
8. Manufacturers of a goods, equipments or inputs that developed KIMS services later on	
9. Started-up in other industrial sector and enter into the mining sector because the knowledge and technology used were applicable to mining and there was a important demand in the mining sector	

Table A3.2: Evolution of Technological Indicators

Firm's Code	**Patent Applications (Yes /No)**				**Patents Granted (Yes/No)**				**R&D Effort (% Sales)**				**Yearly Publications in Tech. Journals** (0:No;1:<10;2: >10)			
	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005

Table A3.3: Evolution of Staff

Firm's Code	**Total Number of Employees**				**Num. Graduates** (Geologist, Engineers, Metallurgist, Others)				**Total Technician**				**Total Postgraduates (PhD and MSc)**			
	1975	1985	1995	2005	1975	1985	1995	2005	1975	1985	1995	2005	1975	1985	1995	2005

Table A3.4: Evolution of Technological Capability Level

Firm's Code	Technological Capability Level See Table A3.23 as a guide to assess capability level according to the following rank: 1: Simple User; 2: Advanced User; 3: Adaptor; 4: Intermediate Innovator; 5: Advanced Innovator							
	1970	1975	1980	1985	1990	1995	2000	2005

Table A3.5: Evolution of Sales and Exports

Firm's Code	Sales (Thousands US$, 2004) and Export Level (% Sales)															
	1970		1975		1980		1985		1990		1995		2000		2005	
	Sales	Export %	Sales	Export %	Sales	Export %	Sales	Export %	Sales	Export %	Sales	Export %	Sales	Export %	Sales	Export %

List 5: Features regarding economic performance (profit level, market position, market share, others issues important to be highlighted):

Table A3.6: Evolution of Sales by Regions

Firm's Code	Sales in local market (Yes/No)					Export to Latin America (Yes/No)					Export to North America (Yes/No)					Export to Africa (Yes/No)					Export to Australasia (Yes/No)					Export to Europe (Yes/No)				
	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005

Table A3.7: Evolution of KIMS Firm's Offices Geographical Location

Firm's Code	Local Offices (Yes/No)					Offices Latin America (Yes/No)					Offices North America (Yes/No)					Offices Africa (Yes/No)					Offices Australasia (Yes/No)					Offices Europe (Yes/No)				
	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005

Table A3.8: KIMS Suppliers' Key Events - Type of changes related to key events

Firm's Code	Improving the use of the technology already available (Yes/No)					Using new technology (e.g. equipment, software, etc.) (Yes/No)					Using new organisational arrangement and/or changing managerial capabilities (Yes/No)					Changing the range of services offered (Yes/No)					Performing important engineering and design activities (Yes/No)					Performing development or researching activities (Yes/No)				
	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005

Key events should be related to significant steps forward in term of firm's technological and organisational capability. Key events are those projects or activities that represented a significant challenges and efforts that lead to a change in terms of what was the firm was able to do, such as: (i) Projects or activities that represent or are associated to an important step forward in terms of what the firm was able to do; (ii) Projects or activities that have represented an important challenge that led to important changes in firm's technological or organisational capabilities level; (iii) Events that clearly mark a "before and after" in term of what the firm was able to do

Examples of key events and sources of challenges:

a) *Technology updating*: Project or activity that required the use of a technology never used before by the firms (e.g. the first time in using modelling and simulation software to valuate an ore deposit for mine designing).

b) *Performing task of higher complexity*: Project or activity that represented a new level of complexity never faced before by the firm (e.g. first time that an engineering firm is responsible for the development of a whole investment project, including design, construction, procurements and starting up)

c) *Technology capability level augmenting*: Project or activity that comprises changes in the level of firm's technological capability (e.g. the first time a drilling service provider who had been a user of technology so far, modified the equipment instead of just using it).

d) *Higher organisational capabilities requirements*: Project or activity that comprised coordinating multiples actors, various organisational tiers, and new contracts schemes (e.g. a contract that requires a joint venture with other firms and subcontracting several function).

e) *A challenge that requires research, development and engineering*: First time the firm launches research, development or engineering programs to deal with new challenges (e.g. a project related to a mine that has a complex geology never seen before that requires important research and engineering efforts).

f) *New standards introduced by mining companies*: A project or contracts that meant higher production quality and security standards required by a mining company (e.g. new requirements defined by standards of an international mining company).
g) *New markets standards and regulations*: A project facing more demanding standards derived from regulation or market standards (e.g. higher environmental and labour standards or first export experience to a country with tighter regulations).

Table A3.9: Key Events Relationship with Mining Investment Projects or Ongoing Operations

Firm's Code	The key event were related to mining investment project (Yes/No)					The key event were related to ongoing operation (Yes/No)				
	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005

Table A3.10: Interaction or Participation of Other Organisations during Key Events

Firm's Code	Was there any **mining company** supporting, participating in or encouraging the key event **(Yes/No)**					Was there any **other KIMS supplier** supporting, participating in or encouraging the key event **(Yes/No)**					Was there any **other supplier** (no KIMS) supporting, participating in or encouraging the key event **(Yes/No)**					Was there any **research centre** supporting, participating in or encouraging the key event **(Yes/No)**					Was there any **university** supporting, participating in or encouraging the key event **(Yes/No)**				
	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005

List 10: Features regarding key events (activities and motivations):

Table A3.11: Specialisation and Merge & Acquisition

Firm's Code	**Specialisation**															**Merge & Acquisition took place over the period (Yes/No)**				
	Num. KIMS Categories Offered (Average over the period)					**The firm offered other Product/ Service No KIMS (Yes/No)**					**The firm supplied other Industrial Sector No Mining (Yes/No)**									
	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005

Category Code	**Description**		*Approx. Share Revenue (2005)*
100	Geological and exploration services.	☐	
200	Mining engineering or mine planning and design (open pit or underground)	☐	
300	Processing and metallurgical (hydro, pyro or bio) engineering and design	☐	
400	Tailing dam and waste rock system design and engineering	☐	
500	Ore and mineral transport system engineering (piping and conveying)	☐	
600	Mine closure design and engineering	☐	
700	Environmental system design (gases, liquid, solid, restoration and monitoring)	☐	
800	Investment project management (due diligence, pre and feasibility studies, …)	☐	
900	Drilling equipment design and services	☐	
1000	Blasting engineering and design	☐	
1100	Mining truck part/replacement design and fleet maintenance	☐	
1200	Other (Please specify: …………………………………………………………)	☐	

Table A3.12: Evolution of the Geographical Distribution of Knowledge and Innovation Activities (Research and Developments, Advance engineering, etc.)

Firm's Code	**Level of K& I effort carried out in different regions (0: No Effort; 1: Minor Effort; 2: Mayor Effort)**																													
	K&I was carried out locally (0/1/2)					**K&I was carried out in Latin America (0/1/2)**					**K&I was carried out in North America (0/1/2)**					**K&I was carried out in Africa (0/1/2)**					**K&I was carried out in Australasia (0/1/2)**					**K&I was carried out in Europe (0/1/2)**				
	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005

Table A3.13: Requirement to entry in recent decades

Firm's Code	Different Requirements to Entry Level (1: Low - 2: Medium - 3: High)											
	The firm required to manage **Scientific Knowledge**		The firm required to manage **Engineering Capabilities**		The firm required **Experience, Know-how and Prestige**		**Cheap Labour** is required		**Capital** is required (e.g. infrastructure, machinery, equipment, etc.)		**Financial requirement**	
	70s-80s	**90s-00s**	**70s-80s**	**90s-00s**	**70s-80s**	**90s-00s**	**70s-80s**	**90s-00s**	**70s-80s**	**90s-00s**	**70s-80s**	**90s-00s**

List 14: Description of the Career Path of Senior Experts of KIMS firm's Staff

Table A3.14: Evolution of Training Activities

Period	**Firm's Code**	**Internal Activities** (Activity explanatory name and budget if possible)	**External Activities** (Activity explanatory name and budget if possible)
1981 – Back			
1982 – 1987			
1988 – 1993			
1994 – 1999			
2000 – 2005			

Description of the role of investment projects and ongoing operations in the learning process

Table A3.15: Evolution of Different Learning Means and their Importance

Firm's Code	**Importance of Different Learning Means** (5: Very Important - 3: Important - 0: No Important)																			
	Hiring Experts					**Seeking and Using BAT & Practises and Benchmarking**					**Seminars & congresses and Literature reviewing**					**Other activities such as courses**				
	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005	1981 back	1982 1987	1988 1993	1994 1999	2000 2005

Table A3.16: Evolution of R & D and Engineering Programmes

Period	**Firm's Code**	**Internal Activities** (Activity explanatory name including budget and external participant if possible)
1981 – Back		
1982 – 1987		
1988 – 1993		
1994 – 1999		
2000 – 2005		

List 16: Description of activities that have contributed the most to learning process

Table A3.17: Evolution of KIMS Suppliers' Interaction Web

Categories of Interaction	Evolution of KIMS Supplier Interactions with other Organisation at the Home Country (Key: 0: Did not happen – 1: Rarely – 2: Common – 3: Very Common)																							
	Mining Companies (Producer)				Mining Companies (Junior)				Other KIMS Supplier or Consultant				Other Supplier No KIMS (Equipment, inputs, etc)				Research Centre				Universities			
	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005
1.Marketing Relationship																								
2.Suppliers drew on other organisation capability																								
3.Other organisation drew on suppliers capability																								
4.Both drew on each other's capabilities																								
5.Innovation links																								

Categories of Interaction	Evolution of KIMS Supplier Interactions with other Organisation in Foreign Countries (Key: 0: Did not happen – 1: Rarely – 2: Common – 3: Very Common)																							
	Mining Companies (Producer)				Mining Companies (Junior)				Other KIMS Supplier or Consultant				Other Supplier No KIMS (Equipment, inputs, etc)				Research Centre				Universities			
	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005
1. Marketing Relationship																								
2.Suppliers drew on other organisation capability																								
3.Other organisation drew on suppliers capability																								
4.Both drew on each other's capabilities																								
5.Innovation links																								

Characterise the interactions organisation following interactions categories:
Category 1: Marketing – Production links

Purely marketing relationship involves the sale of services/products derived from the use of existing capabilities that does not involve significant elements designed to enhance or create those capabilities. Delivering the service is based on a routine and there is not any important knowledge flow between suppliers and user

Categories 2: Knowledge flows links

This relationship involves the enhancement and creation of new capabilities and significant elements of design. A firm drew on the other to build up new capabilities to produce a particular product, to use a particular process, to master specific managerial and organisational practices. This interaction may involve training and formalised experience acquisition, together with less formally organised learning through reverse engineering and incremental improvement. There are three types knowledge flows regarding to building higher technological capabilities level by interacting: (1) KIMS Suppliers drew on other organisation capability; (2) Other organisation drew on supplier capability; and (3) Suppliers and user drew on each others capability

Additionally, there is other type of knowledge flow link. If interacting firms already have innovative capabilities then interactions can be source of innovation. Firms collaborate in using their innovative capabilities to execute innovation projects, usually involving collaborative design/engineering, development and research for new product/services and processes.

List 17: List of features regarding interaction (issues to be highlighted):

Table A3.18: Experts' Mobility

Firm's Code	Where do experts hired by KIMS suppliers and that joint the firm's staff come from? (0: Did not happen – 1: Rarely – 2: Common – 3: Very Common)																			
	Mining Companies KIMS supplier hired experts from mining companies				**Other KIMS Supplier** KIMS supplier hired experts from other KIMS suppliers				**Other Supplier** KIMS supplier hired experts from other suppliers no KIMS				**Research Centre** KIMS supplier hired experts from Research Centres				**Universities** KIMS supplier hired experts from Universities			
	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005
Firm's Code	**Where do experts that leave KIMS suppliers firm's staff move to?** (0: Did not happen – 1: Rarely – 2: Common – 3: Very Common)																			
	Mining Companies Mining companies hired experts that leave the firm				**Other KIMS Supplier** Other KIMS suppliers hired experts that leave the firm				**Other Supplier** Other suppliers no KIMS hired experts that leave the firm				**Research Centre** Research Centres hired experts that leave the firm				**Universities** Universities hired experts that leave the firm			
	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005

Table A3.19: Evolution of the Frequency of Knowledge Based Peer Interaction

Firm's Code	**What is the frequency of knowledge based interaction (knowledge and experience sharing) between KIMS suppliers and other Organisations at the home country?** (0: Did not happen – 1: Rarely – 2: Frequent – 3: Very Frequent)																			
	Frequency of knowledge based interaction between KIMS suppliers experts and Mining Companies experts				**Frequency of knowledge based interaction between KIMS suppliers and Other KIMS Supplier experts**				**Frequency of knowledge based interaction between KIMS suppliers and Other Supplier experts**				**Frequency of knowledge based interaction between KIMS suppliers and Research Centre experts**				**Frequency of knowledge based interaction between KIMS suppliers and Universities experts**			
	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005
Firm's Code	**What is the frequency of knowledge based interaction (knowledge and experience sharing) between KIMS suppliers and other Organisations in foreign country?** (0: Did not happen – 1: Rarely – 2: Frequent – 3: Very Frequent)																			
	Frequency of knowledge based interaction between KIMS suppliers experts and Mining Companies experts				**Frequency of knowledge based interaction between KIMS suppliers and Other KIMS Supplier experts**				**Frequency of knowledge based interaction between KIMS suppliers and Other Supplier experts**				**Frequency of knowledge based interaction between KIMS suppliers and Research Centre experts**				**Frequency of knowledge based interaction between KIMS suppliers and Universities experts**			
	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005

List 19: Features regarding peer interaction

Table A3.20: Evolution of Supports Received

Firm's Code	**Sources of Supports** (Y: Yes, there was support - N: No support was received)																											
	Mining Companies				**Government programs of institutional settings**																				**Any other support**			
					Venture Capital System				**Financial system**				**R&D Programs**				**Export Support and Promotion Programs**				**Any other government program or setting**							
	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005

List 20: Features regarding supports:

Table A3.21: Evolution of Encouragement/Pressures to Innovate and Learn

Firm's Code	Sources of Encouragement/Pressure (Y: Yes, there was a encouragement/pressure - N: No encouragement/pressure was perceived)																											
	Mining Companies												Government programs of institutional setting												Any other encouragement/pressure			
	Technical Challenges (e.g. solve problem)				**New standards** (e.g. quality, security, etc.)				**Expansion and internationalisation**				**Regulations and standards** (e.g. environment standards)				**Tax regime/tax credits**				**Other such as information**							
	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005

List 21: Features regarding encouragement and pressure to learn and innovate:

Table A3.22: Evolution of the Barriers Faced

Firm's Code	Barrier to Enter (or to Grow) Faced by KIMS Suppliers (0: There is no Barrier – 1: Low level Barrier – 2: Medium Level Barrier - 3: High Level Barrier)																											
	Local Market												International Market												Critical Size			
	Difference of Capabilities Regarding Competitor				Regulations				Availability of skilled labour				Difference of Capabilities Regarding Competitor				Regulations				Availability of skilled labour							
	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005	1979 back	1980 1989	1990 1999	2000 2005

List 22: Features regarding barriers:

Table A3.23: Guide to Estimate the Level of Technological Capabilities

Features of product/service production process	Features of the product/services
Level 1 - Productive Capability: *Simple User* - Simple user and operator of technology that already exist. - Manage routinely production of goods/services.	
▪ Preparation of initial outline of simple investment projects. ▪ Routinely monitoring of investment projects and existing infrastructure. ▪ Synchronising civil construction with installation work. ▪ Routinely production process operation. ▪ Basic production planning and control and line balancing. ▪ Replication of simple and fixed specification of design. ▪ Routinely quality control to maintain existing standards.	▪ Simple ancillaries engineering services ▪ Construction of basic civil work ▪ Basic plant erection ▪ Disbursing finance ▪ Routinely engineering services in new or existing plants/mines ▪ Routine replacement and maintenance of equipment components. ▪ Participating in installation and routine tests of performance.
Level 2 - Productive Capability: *Advanced User* - Advanced user of technologies that already exist. - Process management/control including minor improvements.	
▪ Broad outline of investments project planning. ▪ Customising software solutions. ▪ Partial monitoring and control of expansion projects ▪ Efficiency improvements from experience. ▪ International quality control systems and standard (Certification) ▪ Minor adaptations, de-bottlenecking and capacity stretching. ▪ Minor clean-up of design to suit production or market ▪ Efficiency improvements from experience. ▪ International quality control systems and standard (Certification)	▪ Project management services. ▪ Simple project feasibility study ▪ Technically assisted feasibility studies for major expansions. ▪ Standard equipment procurement. Search, evaluation and selection of technology/supplier. ▪ Installation engineering (civil, electricity, mechanical, instruments, piping, and others) ▪ Technically assisted expansion ▪ Detailed engineering ▪ Basic and preventive maintenance of facilities and equipment ▪ Routine manufacturing and replacement of components under international standard/certification. ▪ Replication of unchanging items of equipments.
Level 3 - Innovative Capability: *Basic Innovator / Adaptor* - Incremental quality improvement and minor adaptations - Install the latest vintage equipment/technology - Change the existing stock through technological support and engineering services - Short-term development of product/process	

<table>
<tr><td>
▪ Minor adaptation of existing products/services design or specifications for local market.
▪ Set-up of process or production engineering units.
▪ Set-up of products/services development, design and engineering units
▪ Systematic studies of new process control systems and process improvements
▪ Incremental product design and development for local market.
▪ Product reverse engineering
▪ Copy of new types of equipments and tools.
▪ New organisational techniques (JIT, TQC, MRP, Lean Production)
▪ Statistical process control.
</td><td>
▪ Basic engineering of individual process plants/mines.
▪ Expanding plant/mine without technical assistance.
▪ Procurement engineering (specification, project analysis)
▪ Full monitoring, control and execution of search, evaluation, selection of technology/supplier.
▪ Full monitoring, control and execution of feasibility study and funding activity.
▪ Systematic provision of technical assistance in feasibility studies, basic, detailed and procurement engineering and plant start-up
▪ Repairing and trouble-shooting of equipment problems
▪ Large equipment upgrading and manufacturing
</td></tr>
<tr><td colspan="2">Level 4 - Innovative Capability: Intermediate Innovator
- Product/process design and engineering.
- Medium-term development of product/process and prototypes</td></tr>
<tr><td>
▪ Process and project software development
▪ Transferring specification to production/products direct from R&D.
▪ Own product/service design and development for local and regional market
▪ Development of sophisticated on-line production control and monitoring system
▪ Process reverses engineering.
▪ Major improvement to machinery and equipment
▪ New product development (Patents)
▪ Own equipment design and development for local and regional market
▪ Own process design and development for local and regional market
</td><td>
▪ Project management of large-scale investment projects or international investments.
▪ Basic engineering of whole process/mine (large scale projects)
▪ Selling or providing design services.
</td></tr>
<tr><td colspan="2">Level 5 - Innovative Capability: Advanced Innovator
- Long-term development and research
- Basic research</td></tr>
<tr><td>
▪ Own product/service design for global market.
▪ Research based innovation and rapid prototyping.
▪ International R&D into new products/process.
▪ Cutting edge equipment and product/service development and design (Patents)
▪ Process innovation based on R&D (Patents)
▪ Radical innovation in organisation.
</td><td>
▪ Project management on a global scale.
▪ World-class project management
▪ World-class engineering services
▪ Full turn key solutions
▪ Developing new production process system based on R&D
▪ Developing new product/services based on R&D
</td></tr>
</table>

Appendix 3.2: Guide for Mining Companies

1. Evolution of Technological Indicators
- Patents
- R&D
- Publications

2. Evolution of Staff

3. Evolution of Mineral Production
- Home country production
- Foreign countries production

4. Geographical Distribution of Mining Activity
- Mines Operating
- Process Plant
- Exploration
- Investment Projects

5. Evolution of the Degree of Vertical/Lateral Integration

6. Merging and Acquisition

7. Geographical Location of Knowledge and Innovation Activities

8. Evolution of Training Activities and Efforts
- Training activities at the home country
- Training activities in foreign countries

9. Evolution of R&D and Engineering Programs'
- National Activities
- International Activities

10. Evolution of Mining Companies' Interaction Web
- Interactions with other Organisation at the Home Country
- Interactions with other Organisation in Foreign Countries

11. Experts' Mobility
- Source of experts (to be hired)
- Destination of experts that leave the company

Appendix 3.3: Guide - Context variables to be collected

The following list of issues is a guide that indicates the information required to characterise context factors that shaped the technological learning and innovation process of KIMS sector

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Issues associated to Mining Activity

Issue 1. Mineral production over the 20th century of a selected group of metals in the world, Australia, Chile and in selected group of mining economies (tonnes, US$)

Issue 2. Number of mines operating in the world, Australia, Chile and in a selected group of mining economies over recent decades, 1970s onwards (Number of mines by mineral)

Issue 3. Number of metallurgical process plants in the world, Australia, Chile and in a selected group of mining economies over recent decades (Number of Plants)

Issue 4. Number of mining investment projects in the world, Australia, Chile and in a selected group of mining economies over recent decades (budget, number investment projects including exploration, mine and plants)

Issue 5. Ore deposit grade in recent decades in Australia, Chile and in a selected group of mining economies (Grade)

Issue 6. 'Geological and mining complexity' and other operational challenges such as logistic, mineral deposit size, infrastructure availability, energy and water availability, environment and safety standards in Australia and Chile (List of features).

Issues associated to Industry Structure's Change

Issue 7. Concentration of mineral production for a sample of minerals (share of mineral world production of the biggest mining companies)

Issue 8. Number of mining companies by category in Australia and Chile over recent decades (Number of big diversified corporation, number of medium size mining companies, number of juniors)

Issue 9. Number of mining companies by size and nationality in Australia and Chile over recent decades (Number of multinational/national big corporation, number of International/national medium size mining companies, number of International/national juniors)

Issues associated to Technological Rejuvenation

Issue 10. Innovation intensity in the mining industry in recent decades in the world, Australia, Chile and in a selected group of mining economies (Descriptions and figures of innovation intensity) (Variable: *KP4/C2/a*)

Issue 11. Mining industry productivity growth led by innovations in recent decades in Australia and Chile (Descriptions and figures of mining industry productivity growth) (Variable: *KP4/C2/b*)

Other issues regarding Learning and Innovation

Issue 12. University enrolment in mining related studies in Australia and Chile in recent decades (number of graduates and postgraduates geologist, engineers, metallurgist)

Issue 13. Number of universities with mining related studies program (geology, engineering and metallurgy) in Australia and Chile in recent decades (List of universities)

Issue 14. Main R&D centres and programs over recent decades in Australia and Chile (list of main research centres and programs, foundation date, budget, closure sate if the case, participants)

Issue 15. KIMS market expansion local and internationally over recent decades (Description)

Issue 16. KIMS impact on productivity and cost reduction over recent decades (Description)

Issue 17. KIMS ability to problem solving, risk control and improve safety and environmental impact (Description)