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the development of a knowledge gap

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The mining sectors in Chile and Norway from approximately 1870 to 1940: the development of a knowledge gap A comparative empirical analysis of knowledge institutions and organisations

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Abstract

This project explores how knowledge accumulation occurred and how it was transformed by learning into technological innovation in Chile and Norway. Chile and Norway are closely similar in industrial structure and geophysical conditions, yet have had different development trajectories. The questions of why and how Chile and Norway have developed so differently are explored through a comparative empirical analysis of similar types of knowledge organisations that were directly involved in developing knowledge for mining in the two countries. These were notably formal and practical education, industrial societies and exhibitions, laboratories and research centres. Together with mining companies, these organisations interacted with each other with the aim of learning and accumulating knowledge, developing technological capabilities and continuously adopting more efficient technology. Using primary sources in the form of written documents, the focus of the analysis is 1870 to 1940, the period leading up to the economic gap between the two economies.

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The mining sectors in Chile and Norway from approximately 1870 to 1940: the development of a knowledge gap

A comparative empirical analysis of knowledge institutions and organisations

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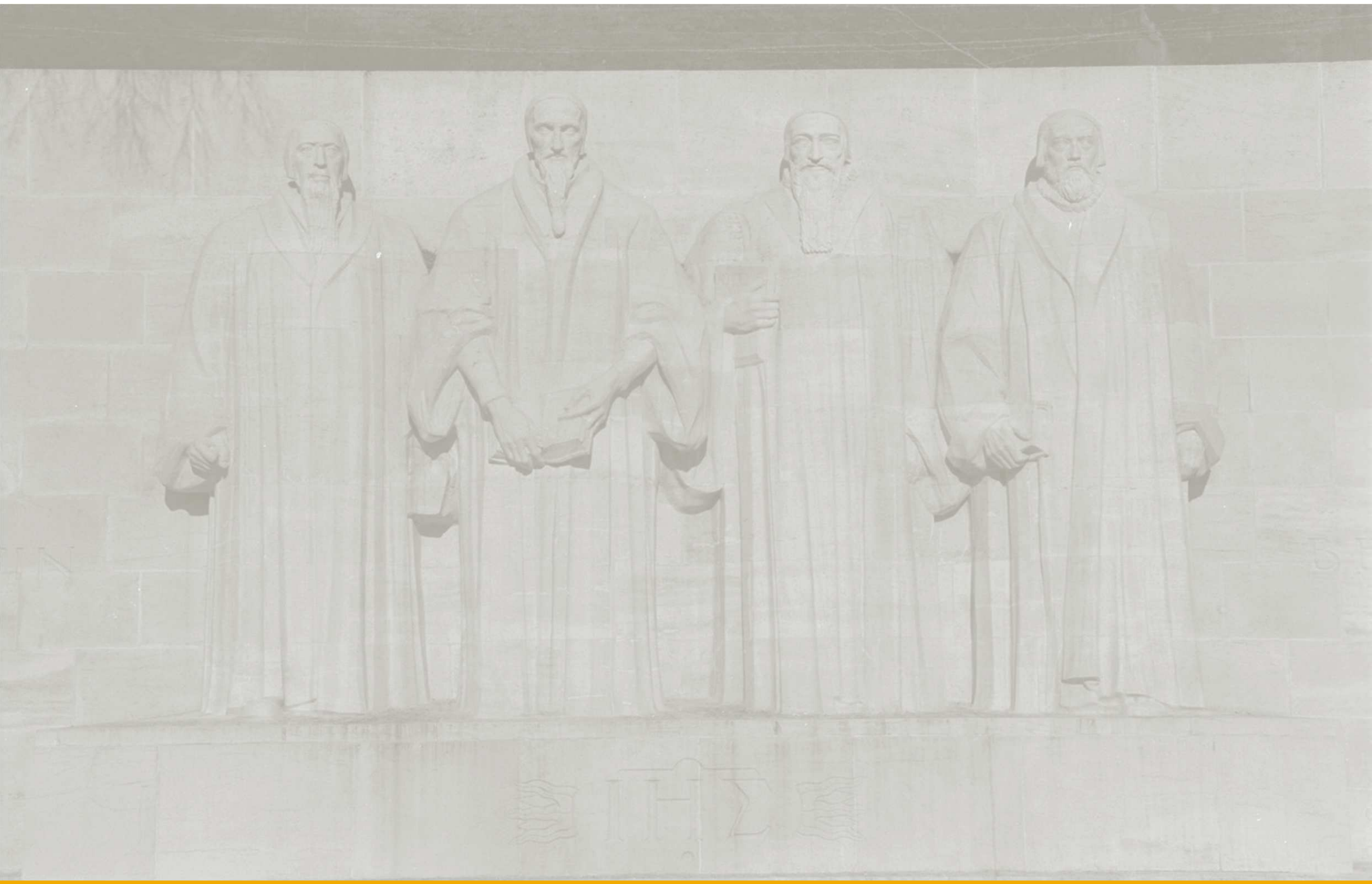

FACULTÉ DES SCIENCES ÉCONOMIQUES ET SOCIALES

UNIVERSITÉ DE GENÈVE

Content

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1 Introduction

This thesis is a study of comparative economic development, looking at two economies that have had different development trajectories, yet are closely similar in structure and geophysical conditions. Norway and Chile are long, narrow and mountainous countries with long coastlines and extensive natural resource bases. Norway has developed strongly around resource-based industries, and has created a high-income diversified economy, while Chile, with closely similar resources, has experienced nothing like that success. The thesis explores these developmental differences by looking in detail at a central resource activity in both economies, namely mining. It argues that a key factor in explaining the differences lies in the actions of states in creating and supporting institutions that develop and distribute technological knowledge.

What is the foundation of modern economic growth, and why is there such inter-country variation within it? Why are some countries rich and others poor? A strong argument in economic history is that knowledge is the underlying basis of economic growth and that a substantial increase in "useful knowledge" is the basis for the economic development that has occurred since the late eighteenth century.[1] This kind of approach focuses attention on how knowledge accumulation occurs, and how it is transformed by learning into technological innovation. Learning and innovation, however, depend on institutional and organisational support, and differences in institutions and organisational structures are now used to explain why some countries have experienced considerably more economic growth than others.[2] In this thesis, I deepen this approach by exploring its relevance in the cases of small, resource-based economies that were far from the mainstream of industrialisation in Europe and the United States.

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[1] J. Mokyr, *The Enlightened Economy* (New Haven, 2009); J. Mokyr, "Knowledge, Enlightenment, and the Industrial Revolution: Reflections on *Gifts of Athena",* History of Science, vol. 45, part 2 (2006); P. O'Brien, *Stages in the Evolution of a Western regime for the discovery, development and diffusion of useful and relaiable knowledge*, URKEW *Discussion Paper* No 7, London School of Economics (2011)

[2] D. Acemoglu and J. A. Robinson, *Why Nations Fail* (London, 2012); J. Mokyr, *The Enlightened Economy* (New Haven, 2009)

Many economic historians have explored these questions by analysing large economies, in particular the British Industrial Revolution and the industrialisation processes that followed in Germany, the United States and Japan. Alexander Gerschenkron argued that Britain industrialised first because it was early in developing certain institutional and technological conditions, which he regarded as necessary "prerequisites" for industrialisation to take place. These included entrepreneurship, an industry-oriented financial system, and an effective labour market. When other European countries industrialised they could do so because they had succeded in developing efficient "substitutes" for any prerequsities that they missed. According to Gerschenkron, "certain major obstacles to industrialization must be removed", such as feudal obstructions to movement of people and goods, and "certain things propitious to it must be created before industrialization can begin."[3] These "propitious things" are the prerequsities referred to above. Scholars have continued to develop models of industrialisation and to focus on preconditions or "prerequisites" for economic growth. Institutions have occupied a central position in such efforts. They are often evaluated in terms of whether they constrain or act as incentives to economic transactions. According to Douglass C. North, there are lower transaction costs when institutions are efficient, and costs are higher when institutions are inefficient.[4] Daron Acemoglu and James Robinson develop a general model for the relation between institutions and growth and make broad historical comparisons of institutions. They find that what matters is political institutions, which in turn determine economic institutions. Countries are categorised according to whether they have developed "inclusive" institutions, which enforce property rights and encourage investments, or "extractive" institutions, which fail to protect property rights.[5]

Although these approaches are a big advance, they still need development. There are several continuing problems. The first is related to growth models that are based on only a few countries. A

[3] A. Gerschenkron, *Economic backwardness* (Cambridge, 1962), p. 31
[4] D. C. North, "Institutions" in *The Journal of Economic Perspectives*, Vol. 5, No. 1., (1991), p. 97
[5] D. Acemoglu and J. A. Robinson, *Why Nations Fail* (London, 2012), p. 43

very substantial proportion of the economic historiography of industrialisation rests on discussions of Britain, Western Europe, the United States and Japan, which are compred to China and India. Kenneth Pomeranz initiated the most recent debate on this with a comparison of Northwest Europe and East Asia.[6] A second problem is that economic models will usually ignore specificities of individual countries. Although all modelling generalises, there is often a serious absence of specific details in accounts of industrialisation. Third, such models tend to ignore the fact that countries have in fact followed very different paths to growth.[7] The problem here is that the industrial and economic characteristics of the larger nations have differed considerably from those of smaller countries, such as Benelux or the Scandinavian countries, although these countries also have experienced strong economic growth. Furthermore, even when analysing the larger economies, Gershcenkron's model has been criticised. Patrick O'Brien argues of Gerschenkron's model that "…more often than not, its heuristic value seems to reside in supplying explanations and predictions that simply fail to fit the country or case under investigation."[8] Similarly, Acemoglu and Robinson develop a model based on relatively few historical cases, in which the complexity of different countries' developments are barely revealed.

Many of the models deriving from Gerschenkron and North emphasise preconditions for economic growth. There is a relative lack of attempts to explore how technological change actually happened, or how technological capabilities developed, within particular institutional and organisational systems. With regard to European industrialisation, O'Brien writes that "…discussion very quickly runs into that hoary old debate on the relative importance of necessary and sufficient conditions."[9] It

[6] K. Pomeranz, *The Great Divergence* (Princeon, 2001)
[7] A. Milward and S.B. Saul's work is a rare exception to this. See *The Economic Development of Continental Europe, 1780-1870* (London, 1973) and *The Development of the Economies of Continental Europe* (London, 1977)
[8] P. O'Brien, "Do we have a typology of European industrialisation?", *Journal of European Economic History*, vol. 15, issue 2 (1986), pp. 324-325
[9] P. O'Brien "Do we have a typology of European industrialisation?", *Journal of European Economic History*, vol. 15, issue 2 (1986), p. 324

is often argued that certain "good" institutions should be in place to generate growth: democratic institutions, secure property rights, high quality education and research institutions, free trade policy, and so on. Other characteristics, such as rent-seeking, non-democratic institutions, etc. are, by contrast, negative for economic growth. However, describing the prerequisites for innovation do not tell us how learning and innovation processes actually take place or anything about the actors involved. Kristine Bruland points out that the historical literature on economic growth "… has not focussed in adequate detail on whether or how [industrialisation] actually occurred."[10] According to her, "(t)he principal weakness of this literature lies in its treatment of the technological level itself."[11] Even the innovation system approaches, which focus on the institutional framework in which innovation is generated, are criticised for making too simple models, based on research and development (R & D). They do not grasp or account for the entire complex, random and disorganised processes of learning and innovation. Charles Edquist claims that:

> "…we know far too little about the determinants of innovation, although this is a weakness of innovation studies in general…[…]… [the systems] approach partly neglects other types of learning process than those leading to innovations in a direct and immediate way."[12]

We still have little information about how institutions, innovation and economic growth are connected. Which institutions actually determine innovation? And which institutions or organsations are directly involved in knowledge development and innovation?

Several economic historians have recently addressed the question of how innovations actually occur from a historical perspective. Instead of analysing preconditions and incentives for innovation and making economic growth models which generalise reality, economic historians, such as Joel Mokyr,

[10] K. Bruland, *British technology and European industrialization* (Cambridge, 1989), p. 10
[11] K. Bruland, *British technology and European industrialization* (Cambridge, 1989), p. 15
[12] C. Edquist, "The Systems of Innovation Approach and Innovation Policy: An account of the state of the art" (Aalborg, 2001) p. 3

Kristine Bruland and Patrick O'Brien, identify and analyse the actual institutions and organisations through which knowledge was developed and learning and innovation processes took place. Fundamental to their approach, is the claim that knowledge creation, and the building of knowledge societies, required specific institutions and organisations. These included scientific and technical societies, education systems, industrial exhibitions, industrial espionage operations, study trips for learning, research institutions and business firms, all of which interacted with each other and actively transferred, used, modified and diffused knowledge.[13]

This thesis explores specific cases of innovation and growth by analysing knowledge development in two similar sectors of two small economies with similar geophysical structures, but different constitutional and political arrangements. The aim is to explore how knowledge was in fact created, transferred, adopted and diffused in the mining sectors in Chile and Norway. This includes comparing knowledge institutions and organisations involved in the development of the mining sectors in the two countries. The period from 1870 to 1940 has been chosen largely because mining went through important technological changes during these years. It allows us to ask how the mining sectors coped in a situation of technological turbulence. New energy sources were brought into use, and both the organisation of companies and the techniques for finding, removing and processing ores changed radically. Taking a comparative empirical approach, the following questions will be explored: what mining techologies were used in the two countries, and how advanced or backward were they? Which, if any, institutions were involved in learning and innovation processes in the two mining sectors? Can we see significant similarities or differences between the two sectors in this respect?

[13] See for instance J. Mokyr, *Gifts of Athena*, (Princeton and Oxford, 2005); J. Mokyr, *The Enlightened Economy* (New Haven, 2009); K. Bruland, "Kunnskapsinstitusjoner og skandinavisk industrialisering" in *Demokratisk konservatisme,* Engelstad, F and Sejersted, F (eds.) (Oslo, 2006); K. Bruland, "Skills, learning and the International Diffusion of Technology: a Perspective on Scandinavian Industrialization", in *Technological Revolutions in Europe,* M. Berg and K. Bruland (eds.) (Cheltenham, 1998); K. Bruland and K. Smith, "Knowledge Flows and Catching-Up Industrialization in the Nordic Countries The Roles of Patent Systems", in *Intellectual property rights, development and catch-up an International comparative study,* H. Odagiri et al. (Oxford, 2010), pp. 63-94; P. O'Brien, *Stages in the Evolution of a Western regime for the discovery, development and diffusion of useful and relaiable knowledge*, URKEW *Discussion Paper* No 7, London School of Economics (2011)

Can these differences be related in any way to overall development trajectories of Norway and Chile?

Chile and Norway are two countries on the peripheries of their respective continents. They do not fit easily with standard models of industrialisation. The two countries have been defined as "resource-based economies" in the literature. In fact, they possess many similar natural resources, such as waterfalls, forests, fish, minerals and metallic ores, and they have developed many of the same natural resource industries, such as agriculture, extraction of minerals, timber and timber-related industries and, in recent decades, salmon farming industries. From their earliest development, natural resource industries have accounted for the largest share of GDP and exports in both countries. However, Norway has developed to become one of the richest countries in the world with small social differences, while the Chilean economy has, until recent decades, experienced slow growth, poverty, debt and trade deficits. Why did these two countries, with similar geophysical structures and industrial patterns, develop so differently?

Many answers have been proposed to this type of question. The poor economic performance of the natural resource abundant countries of African and Latin America led to the idea that natural resources directly cause slow growth and retard development. These countries have largely experienced slow growth, stagnation and underdevelopment. One argument for this is that resources "crowd out" manufacturing. Imports are therefore focused on manufactures, which means that countries which base their economies mostly on natural resource industries, find themselves in a vicious circle or a "resource curse" in which they are always in external deficit because of declining terms of trade between resources and manufactures. Other, more political, arguments stress inadequate state organisations and rent-seeking elites that divert investment away from growth.

A key empirical problem with the "resource curse" argument is that some of the richest countries in the world, such as Norway, Sweden, Canada, New Zealand and Australia, have developed highly successful and fast-growing economies on the basis of natural resources. Natural resource industries, such as agriculture, fish, metal and minerals have constituted very large parts of these countries' economies, yet have not obstructed long-run development. Therefore, natural resource sectors do not seem to be in themselves obstacles to growth.

Why, then, have only some resource-based economies experienced strong economic growth? Which factors have determined growth in the successful countries? New analyses suggest that there have been large differences when it comes to the utilisation of the natural resource potential across countries. Some countries have built competitive, knowledge intensive and innovative natural resource industries with linkages to the wider economy, such as to upstream and downstream manufacturing industries, while others have stagnated and declined. First and foremost, there is the issue of how much of the mineral resources is utilised. Paul David and Gavin Wright argue that between 1850 and 1950, the mining sector in the United States was able to benefit from its mineral resources to a far greater extent than any other country, even though other countries initially had more mineral reserves than the United States. Brazil, Chile, Russia and Australia, for example, had a much smaller resource production than their mineral deposits would suggest. Chile had large unutilised mineral deposits and copper production was far below its proportionate share of the world's copper resources.[14] In this respect, it is argued, the defining difference between these countries has been variations in the knowledge foundations of the resource industries, and in the *way* natural resources have been produced. This suggests that in successful resource-based economies, institutions have actually encouraged and stimulated the utilisation of natural resources and the building of natural resource industries.[15] Beyond this, there are questions about

[14] P. David, G. and Wright, "Increasing Returns and the Genesis of American Resource Abundance", *Oxford Journals*, vol. 6, issue 2 (1997), pp. 210-218

[15] See D. De Ferranti et al. *From Natural Resources to the Knowledge Economy* (Washington D. C., 2002); H. Hirsch-Kreinsen et al., "Low-Tech Industries and the Knowledge Economy: State of the Art and Research Challenges", *PILOT Policy and Innovation in Low-Tech, STEP – Centre for Innovation Research* (Oslo, 2003); S. Ville and O. Wicken, "The Dynamics of Resource-Based Economic Development: Evidence from Australia and Norway" (Wollongong, 2012)

diversification, and about how resource industries can lead via linkages to the creation of a more complex economic structure. I explore such questions by looking to the past, and by examining empirically how knowledge institutions and organisations at different levels created, transferred, diffused, modified and used knowledge for mining in Chile and Norway.

The thesis is divided into three main parts; "theoretical and methodological framework", "diverging paths of Chile and Norway" and "a comparative empirical analysis of knowledge institutions and organisations for mining – late nineteenth century to 1940". The three main parts are subdivided into fifteen chapters. The first part presents the research questions, use of concepts, methodology and a discussion about literature concerning natural resources, institutions and economic growth. The purpose of this part is to explain the value and implementation of my study. The second part provides a historiographical outline of the economic growth and social structures of Chile and Norway and discusses some of the theories explaining why Latin American and Scandinavian countries have had such different development paths, with a specific focus on Chile and Norway. The aim here is to set a point of departure for the analysis. The third part provides a comparative empirical analysis of the knowledge institutions in Chile and Norway, which aimed to develop knowledge for mining. The first chapter sets a framework for the knowledge that was used to carry out technologically advanced mining in Chile and Norway. The second chapter gives an overview of the two mining sectors between the mid-nineteenth century and 1940. The factors I consider are (1) utilisation of the natural resource potential in the two countries, (2) technological level of the companies in the two sectors, (3) linkages between the two mining sectors and capital goods industries and (4) the role of multinational companies in the two economies. The aim of this chapter is to discuss discrepancies between the two mining sectors and the sectors' importance for the economic growth in the two countries. Differences in development lead to questions, which are explored further in the subsequent chapters. Extensive empirical evidence on knowledge institutions is presented and discussed in chapter ten, eleven, twelve and thirteen, and finally chapter fourteen discusses the role of the state. Finally, the conclusion sums up the findings and place them in the theoretical and historiographical context.

Theoretical and methodological framework

2 Research questions and hypotheses

New studies find that natural resource sectors can be knowledge intensive and innovative, much like other industries. Learning and education are factors, which would be crucial for the development of such industries. An argument in the literature is that differences in development between resource-based economies can largely be explained by variances in institutional and organisational settings in terms of knowledge development.

This thesis seeks to analyse Norway and Chile, two countries with many of the same natural resources, notably waterfalls, metals, minerals, fish and forests. In spite of similar historical and geophysical basis, the two countries have experienced different economic developments. Norway have developed to become one of the richest countries in the world, while Chile, until recent decades, has had a much slower growth. The focus of this analysis is knowledge development and innovation in one particular sector, which developed in both countries, namely mining, from the late nineteenth century to 1940. How did learning and innovation processes occur? Did the institutional settings in the two countries encourage knowledge development and enable technologically advanced mining sectors? The specific institutions and organisations that are analysed and compared here, are formal mining education, geological research institutions and travels, visits and work by engineers, technicians and other professionals. This thesis proposes the following questions:

- Was the divergence between Chile and Norway linked to discrepancies in the two mining sectors?
- Did knowledge institutions and organisations create, transfer, adopt and diffuse knowledge for the two mining sectors?
- Were knowledge institutions and organisations used in innovation processes?

- Did the knowledge, which the knowledge institutions and organisations provided, reach into the mining sectors and contribute to continuous transferring and adoption of new technology?

These questions are explored by searching for evidence of:

- Formations of institutions and organisations
- Aims, objectives and outcomes of knowledge institutions and organisations
- Direct or indirect links and connections between institutions and actors to enable innovation

This thesis proposes the following hypotheses:

- The divergence of the two economies were linked to different developments in the two mining sectors
- Knowledge institutions and organisations in Norway continuously transferred and used knowledge, which contributed to an innovative mining sector
- Knowledge institutions and organisations in Chile developed knowledge, but did not support continuous innovation in the mining sector

3 Concepts and definitions

Technology

The economic historian Joel Mokyr defines technology as "the manipulation of nature for human material gain."[16] More specifically, technology can be understood as all the knowledge and processes required in relation to production for economic uses.[17] The economic historian Kristine Bruland and the economist David C. Mowery are more concrete in their definition. They divide technology in three main categories: knowledge, techniques and organisation: (1) the knowledge entails the understanding and skills which are necessary for production and involves scientific knowledge and natural laws as well as engineering, know-how and operative skills; (2) technology further involves techniques, i.e. the machines, tools and equipment in productions and the instructions and processes required to employ, repair and maintain these; (3) The organisation involves the administration, management and coordination systems through which productions occur. These different aspects of technology are integrated in production processes.[18] This description of technology is used in this thesis.

Innovation

All changes in technology are innovations. Richard Nelson defines innovation as: "…the process by which new products and techniques are introduced into the economic system."[19] Innovation is often divided into product and process innovation. A process innovation involves the introduction of a new hardware or changes in the way equipment, machinery and devices are used. Such changes involve modifications in operating processes. Product innovation involves the introduction of a completely new product. A successful innovation, defined by the economist Richard Nelson, is a change which results in the capability of doing something that is not previously done, or at least not so well, or so

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[16] J. Mokyr, *Gifts of Athena*, (Princeton and Oxford, 2005), p. 3

[17] J. S. Metcalfe, "Technology Systems and Technology Policy in an Evolutionary Framework", *Cambridge Journal of Economics*, vol. No 1 (1995), p. 279

[18] K. Bruland and D. C. Mowery, "Technology and the spread of capitalism", in *Cambridge History of Capitalism, vol. II*, L. O'Neil and J. G. Williamson (Cambridge, 2014), p. 84

[19] R. R. Nelson, "Innovation", in *International Encyclopedia of social sciences* 7 (1968), pp. 339-345

economically.[20] Innovation includes large as well as small changes. Bruland and Mowery stress that:

> "(i)nnovation may be incremental, making relatively small-scale improvements to an existing technology, or radical, which includes the replacement of an entire technology with a new one, or the creation of entirely new technological and economic possibilities."[21]

The engineer Stephen J. Kline and the economist Nathan Rosenberg explain this in further detail:

> "A large part of the technological innovation that is carried out in industrial societies takes the form of very small changes, such as minor modifications in the design of a machine that will enable it to serve certain highly specific end-uses better, or that make it easier and therefore cheaper to manufacture; or improving the performance characteristics of a machine by introducing a harder metal, or a new alloy with a higher melting point; or by slight engineering changes that economize on some raw-material requirement, or simply substitute a cheaper material for a more expensive one where possible; or by a design change that reduces friction or vibration and therefore increases the useful life of a machine; or by a mere rearrangement of the sequence of operations, or location of operations, in a plant…"[22]

I take as a starting point that both small and large changes in technology are important for economic growth; all types of innovations are relevant.

Learning and knowledge

Technological change involves learning. Actors have to acquire the skill, or capability, to do something

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[20] R. R. Nelson, "Innovation", in *International Encyclopedia of social sciences* 7 (1968), pp. 339-345

[21] K. Bruland and D. C. Mowery, "Technology and the spread of capitalism", in *Cambridge History of Capitalism, vol. II*, L. O'Neil and J. G. Williamson (Cambridge, 2014), p. 84

[22] D. Kline and N. Rosenberg, "An Overview of Innovation", in R. Landau and N. Rosenberg (eds.) *The Positive Sum Strategy: Harnessing Technology for Economic Growth* (Washington, 1986), p. 282

new in order to innovate. The process of learning in turn means acquisition of knowledge.[23] Knowledge is subdivided into different categories. Knowledge used for productive purposes often includes both codified and tacit knowledge. Codified knowledge is knowledge, which have been articulated, written down and stored. On the other hand, there is certain knowledge, which is more difficult to pass on to others. The scientist Michael Polanyi explains tacit knowledge as the knowledge, which can hardly be described or explained. He states that: "we can know more than we can tell".[24] In an economic setting Mokyr refers to tacit knowledge as "… implicit skills such as dexterity, hand-eye coordination, and sense of "what worked"".[25] Polanyi gives an example of tacitness. For instance, when a tool is used "(w)e are attending to the meaning of its aspect on our hands in terms of its effect on the things to which we are applying it."[26] In this sense, different types of knowledge are acquired in different contexts. Since tacit knowledge cannot be expressed, it often passes on from person to person. It is acquired through observing or practice in a specific context, through "learning by observing" and "learning by doing". For instance, words are viewed as a more effective tool when learning elementary algebra than when learning carpentry.[27] Nobel Laureate in economics Gary Becker explains that the adequate way of learning depends on the nature of the knowledge:

> "Some type of knowledge can be mastered better if simultaneously related to a practical problem; others require prolonged specialization. That is, there are complementary elements between learning and work and between learning and time. Most training in the construction industry is apparently still best given on the job, while the training of physicists requires a long period of specialized effort. The development of certain skills requires both specialization and experience and can be had partly from firms and partly from schools..."[28]

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[23] K. J. Arrow, "The economic implications of learning by doing", *The Review of Economic Studies*, Vol. 29, No. 3 (1962), p. 155
[24] M. Polanyi, *The Tacit Dimension* (Gloucester, 1983), p. 4
[25] J. Mokyr, *Gifts of Athena*, (Princeton and Oxford, 2005), p. 73
[26] M. Polanyi, M. *The Tacit Dimension* (Gloucester, 1983), p. 13
[27] R. R. Nelson and S. G. Winter, *An Evolutionary Theory of Economic Change* (Cambridge, 1982), p. 78
[28] G. S. Becker, *Human Capital* (New York, 1975), p. 37

Following this line of argument, there are some skills that cannot be learned in a classroom, but in a practical setting.

Absorptive capacity

Absorptive capacity is vital to successfully transfer and adopt new knowledge. Professors Wesley M. Cohen and Daniel A. Levinthal define absorptive capacity as the “ability to recognize the value of new information, assimilate it, and apply it to commercial ends.”[29] Learning processes have in common that they are cumulative and depend on previous knowledge. Prior knowledge permits the assimilation, absorption, and use of new knowledge, which makes absorptive capacity something that evolves through time:

> “Accumulating absorptive capacity in one period will permit its more efficient accumulation in the next. By having already developed some absorptive capacity in a particular area, a firm may more readily accumulate what additional knowledge it needs in the subsequent periods in order to exploit any critical external knowledge that may become available. [Furthermore,] … the possession of related expertise will permit the firm to better understand and therefore evaluate the import of intermediate technological advances that provide signals as to the eventual merit of a new technological development…[…] These two features of absorptive capacity- cumulativeness and its effect on expectation formation- imply that its development is domain-specific and is path- or history-dependent.”[30]

The gap between the knowledge bases should not be too wide. Cohen and Levintal explains this further. They argue that knowledge is more likely to be absorbed when the knowledge domain that

[29] M. Cohen and D. Levinthal, “Absorptive capacity: A new perspective on learning and innovation”, *Administrative Science Quarterly*, vol. 35, Issue 1 (1990), pp. 128-152
[30] M. Cohen and D. Levinthal, "Absorptive capacity: A new perspective on learning and innovation", *Administrative Science Quarterly*, vol. 35, Issue 1 (1990), p. 136

the firm wishes to exploit is closely related to its current knowledge base:

> "Some portion of that prior knowledge should be very closely related to the new knowledge to facilitate assimilation, and some fraction of that knowledge must be fairly diverse, although still related, to permit effective, creative utilization of the new knowledge.[31]

Specific prior related knowledge includes "…basic skills or even a shared language but may also include knowledge of the most recent scientific or technological developments in a given field."[32] For a company, in particular, to absorb knowledge successfully:

> "… the firm required an existing internal staff of technologists and scientists who are competent in their fields and are familiar with the firm's idiosyncratic needs, organizational procedures, routines, complementary capabilities, and extramural relationships."[33]

On the other hand, if the new knowledge is very different or unrelated to the current knowledge base, it is less likely, or requires more effort, to be absorbed.

Knowledge institutions and organisations

Innovations occur in an institutional setting. The economist Avner Greif defines an institution as "…a system of rules, beliefs, norms and organizations that together generate a regularity of (social) behaviour."[34] Other scholars use a slightly more tight definition. The Nobel Laureate in economics Douglass C. North makes a distinction between institutions and organisations. Institutions are

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[31] M. Cohen and D. Levinthal, "Absorptive capacity: A new perspective on learning and innovation", *Administrative Science Quarterly*, vol. 35, Issue 1 (1990), p. 136
[32] M. Cohen and D. Levinthal, "Absorptive capacity: A new perspective on learning and innovation", *Administrative Science Quarterly*, vol. 35, Issue 1 (1990), p. 128
[33] M. Cohen and D. Levinthal, "Absorptive capacity: A new perspective on learning and innovation", *Administrative Science Quarterly*, vol. 35, Issue 1 (1990), p. 135
[34] A. Greif, *Institutions and the Path to the Modern Economy: Lessons from Medieval Trade* (Cambridge, 2006), p. 30

understood as “rule of the game” and are frameworks of formal written laws and informal unwritten codes of conduct, which regulate procedures, interactions and economic behaviour of individuals, firms and other organisations.[35] Organisations, on the other hand, are groups of individuals bound by a common purpose to achieve objectives. They are players or actors.[36] These wide definitions of institutions and organisations are useful, since they cover all activities related to innovation processes. The framework of rules and norms, in which actors operate, is the core of economic activity. It is how entrepreneurs, company leaders, workers, traders, politicians, and others, operate, which determine the economic result.

“Knowledge institutions” are here understood as institutions, which regulate, obtain, adopt, use, modify, transfer and diffuse knowledge. Knowledge institutions include for instance economic regulations and arrangements for the spread of knowledge, government policies for travel and immigration as well as educational systems. Organisations include for instance scientific and technical societies, education institutions, scientific and engineering journals and magazines, industrial exhibitions, as well as the business firm.[37] I explore primarily the proceedings of and interactions between the following types of organisations:

- Formal mining education
- Scholarships and study travels
- Research institutions
- Companies (foreign and domestic)
- Industrial exhibitions

[35] D. C. North, “Institutions” in *The Journal of Economic Perspectives*, Vol. 5, No. 1., (1991), p. 97
[36] D. C. North, ”New institutional economics and development” (Washington, 1993), p. 6
[37] J. Mokyr, *Gifts of Athena*, (Princeton and Oxford, 2005); J. Mokyr, *The Enlightened Economy* (New Haven, 2009), K. Bruland, ”Kunnskapsinstitusjoner og skandinavisk industrialisering” in *Demokratisk konservatisme,* Engelstad, F and Sejersted, F (eds.) (Oslo, 2006); K. Bruland, “Skills, learning and the International Diffusion of Technology: a Perspective on Scandinavian Industrialization”, in M. Berg and K. Bruland (eds.), *Technological Revolutions in Europe* (Cheltenham, 1998)

- Foreign experts

Mining and mining sector

Mining is based on utilisation of natural resources, in contrast to manufacturing and high-tech industries, which are based on production of finished consumer or manufactured production goods. Halfdan Carsten's definition of "mining" includes productions of metal ores, non-metallic minerals, stones, or rocks, and energy minerals.[38] Accordingly, it encompasses the extraction of any material, which is not grown through agricultural processes or created artificially in a laboratory or factory. More specifically, mining involves the removal of metals and minerals from the earth along with the processing of metals and minerals. In order to obtain the desired product, normally as pure as possible, a number of procedures are required. First, the ore deposit needs to be found. Geological surveys are carried out to investigate conditions beneath a given ground. Subsequently, the ore is dug out and removed from the earth. After the ore is removed and transported from the mine the mineral is processed so that the useful mineral can be separated from the worthless rock mass. Big pieces of material are first crushed into smaller chunks or powder through crushing and milling. As much gangue as possible is removed before smelting. Minerals are then separated from each other through a variety of methods depending of the physical and chemical characteristics of the mineral composition. Finally, pure metals are produced using a range of smelting and refining methods (see table below):[39]

Mining

<table>
<tr><th>Production branches</th><th colspan="5">Operational activities</th></tr>
<tr><td>metal ores</td><td rowspan="4">Geological and ore surveys</td><td rowspan="4">Removal of ore</td><td colspan="3">Processing of ore</td></tr>
<tr><td>non-metallic minerals</td><td rowspan="3">Crushing and milling</td><td rowspan="3">Concentration and separation techniques to remove gauge</td><td rowspan="3">Smelting and refining</td></tr>
<tr><td>stones or rocks</td></tr>
<tr><td>energy minerals</td></tr>
</table>

[38] H. Carstens, …*Bygger i Berge* (Trondheim, 2000), p. 10

[39] H. Carstens, …*Bygger i Berge* (Trondheim, 2000), pp. 24-25

Based on H. Carstens, *…Bygger i Berge: en beretning om norsk bergverksdrift* (Trondheim, 2000).

The term “industry” often describes a specific group of companies, while “sector” refers to a larger section of the economy. In this thesis, each metal and mineral production is understood as an industry and all mineral and metal industries in a country are defined more broadly as a mining sector. The entire mining sector is taken as a starting point for analysis, because the knowledge institutions that I examine aimed to develop knowledge for all mineral and metal productions.

4 Methodology

4.1 Comparative research

Historical research often aims to carry out "the description of a situation or state of affairs which is unique".[40] In contrast to natural and social sciences, historians seek to understand particular and concrete events, which cannot be generalised. Finding comparable cases is therefore difficult and makes comparative historical analyses problematic. Nevertheless, such studies can provide useful insights about societies and allows the researcher to find structures and processes that otherwise would be difficult to detect. The historian Jurgen Kocka finds that "comparing in history means to discuss two or more historical phenomena systematically with respect to their similarities and differences in order to reach certain intellectual aims."[41] Much in the same line of argument, the historian Ingar Kaldal argues that by analysing similarities and differences in historical developments it is possible to "… circle in on" the factors that might explain differences in development. This requires first the separation of variables, which "…can be said to be about the same or equivalent."[42] The sociologist Charles Ragin explains that:

> "(o)ften comparativists seek to formulate historical explanations of specific historical outcomes or historically defined categories of empirical phenomena. Instances of such phenomena are intrinsically interesting to comparatvists as cases, in part because they embody certain values, but also because they are finite and enumerable. It is their particularity – the fact that they are instances of significant events or phenomena – that attracts the attention of the investigator. Sometimes, there is only one or two or a small handful of such instances.[43]

He further explains that:

[40] Quote taken from C. B. Joynt and N. Rescher, "The problem of uniqueness in history", *History and Theory*, vol. 1, no. 2 (1961), p. 150
[41] J. Kocka, "Comparison and Beyond", *History and Theory*, vol. 42, No. 1 (Feb. 2003), p. 39
[42] I. Kaldal, *Historisk forskning, forståing og forteljing* (Oslo, 2003), p. 134
[43] C. C. Ragin, *The comparative method: moving beyond qualitative and quantitative strategies* (Berkeley, 1987), p. 34

> "…one of the concerns of comparative research is to establish familiarity with each case included in a study. Like qualitative researchers, comparative researchers consider how different parts of each case – those aspects that are relevant to the investigation – fit together; they try to make sense of each case. Thus, knowledge of each cases is considered an important goal of comparative research, independent of any other goal."[44]

Within global history, this approach is often used. Economic historians compare countries, regions and industries, which have developed differently from what appeared to have been a similar starting point.[45] The economic historian Kenneth Pomeranz, for example, compares Britain and China in *The Great Divergence* based on the argument that both countries were similar in many respects until 1750, but that Britain thereafter took a step forward due to its fortunate access to coal and colonies.[46]

Within comparative methods, "the method of difference" is a way of finding the ultimate factor, which causes the different outcomes. In this case a phenomenon y only occurs in one of the cases and the objects of study are similar in all relevant respects except that one condition x appears in one of the cases. This suggests that when x is not present, y also lacks.[47] In *From Natural Resources to the Knowledge Economy* and *Diverging paths: Comparing a Century of Scandinavian and Latin American Economic Development* the scholars compare Scandinavia and Latin American countries from a historical perspective. They also use method of difference to find out why the Scandinavian countries have experienced more economic growth than the Latin American countries, although in a superficial way. The starting point is that a phenomenon y; strong economic growth, only happened in Scandinavia. This thesis uses the method of difference, but is not restricted to this method. Knowledge development in the two mining sectors is analysed and compared, but it is not assumed

[44] C. C. Ragin, *Constructing Social Research* (Thousand Oaks, 1994), p. 105
[45] J. Kocka, "Comparison and Beyond", *History and Theory*, vol. 42, No. 1 (Feb. 2003), p. 40
[46] K. Pomeranz, *The Great Divergence* (Princeton, 2001)
[47] K. Kjelstadli, "Nytten av å sammenligne", *Tidsskrift for samfunnsforskning*, vol. 29 (1988), p. 438

that only one cause is linked to the different outcomes of Norway and Chile. There are certainly a number of factors explaining the different paths between Chile and Norway. Second, emphasising only one economic sector prevents conclusions about the economy as a whole. Instead, it is expected to identify some of the differences, which might contribute to explain the economic divergence of the two economies.

4.2 Empirical research of knowledge institutions and organisations

The focus of investigation is knowledge institutions and organisations, which are pointed out in the literature as crucial for the creation, transfer, adoption and diffusion of knowledge. Specific knowledge institutions and organisations, which aimed to develop knowledge for the mining sectors in Chile and Norway, are analysed. Focusing on one sector, instead of the whole countries, allows for an in-depth detailed comparative study.

In both Chile and Norway, a number of similar types of institutions and organisations were established with the aim of developing knowledge for mining during the nineteenth and twentieth centuries. Both Chile and Norway had intermediate and higher mining engineering programs from the mid-nineteenth century with the purpose of providing professional mining technicians and engineers for the mining industries. Geological maps and ore analyses aimed to identify mineral deposits in the country; examine their contents and grade and estimate potential economic profits. Industrial societies actively promoted the development of companies and mining production and published mining journals with updates on new technology. Engineers, technicians and other workers from both countries participated in and organised industrial exhibitions, established scholarships for study travels and work abroad with the aim of transferring valuable practical knowledge:

Selected knowledge institutions and organisations
aimed to develop knowledge for mining

Institution/organisation	Aims	Year of establishment	
		Chile	Norway
Companies	Private or public business organisations, which made metals and minerals and sold them for profit.	Continuously	Continuously
Foreign companies	Foreign business organisations, normally large entities, with better opportunities for large investments than domestic companies.	From early nineteenth century	From early nineteenth century
Mining education on tertiary level	Institutions with the aim of providing high quality instruction for mining, with emphasis on scientific and theoretical courses.	1853	1757
Mining education on intermediate level	Institutions with the aim of providing high quality instruction for mining, with emphasis on practical courses.	1857	1866
Technical society for mining	Interest groups with the aim of supporting initiatives, which sought to promote development in mining.	1883	1900
Technical magazine for mining	Written magazines with the aim of publishing and diffusing information and knowledge of news about the industry.	1883	1913
Scholarships for study travels and working experience abroad	Private and public funds with the aim of acquiring practical learning about the industry, notably foreign technology.	From mid-nineteenth century	From late eighteenth century
Industrial exhibitions (participation)	Expositions with the aim of presenting new technology in mining.	From mid-nineteenth century	From mid-nineteenth century
Geological Surveys	Institutions in charge of and with the aim of implementing geological mapping, surveys and research of the metal and mineral ores in the country.	1914 (temporary)	1858

However, the establishment and presence of such institutions did not guarantee development. The mere detection of these institutions does not tell us anything about their functions, outcomes and links to innovation. We still do not know whether they influenced learning and innovation processes. Therefore, to understand more about these institutions, I will carry out a detailed comparative analysis of their work, proceedings and interactions.

4.3 Use of sources

The analysis is based on primary sources. Written documents, lists, books, magazines, student yearbooks, company reports and correspondence, newspapers and statistics from the past are described, analysed and compared. Documentation is collected from archives in Chile, Norway and the United States.

First part of the analysis: use of complex knowledge in mining

The first part of the analysis seeks to present a picture of the knowledge that was used to carry out technologically advanced mining in Chile and Norway. How can such a framework be made? Operational activities, working tasks and responsibilities in mining are described and linked to different knowledge concepts. Knowledge terms commonly used by economists and economic historians are useful to detect and identify various kinds of knowledge used in mining operations. Tacit and codified knowledge and scientific knowledge domains, such as geology, mechanics, mineralogy, chemistry etc. are used to detect and classify the different aspects of knowledge. A useful way of categorising the different aspects of technology transfer processes is the economist Bengt-Åke Lundvall's "know-what", "know-why", "know-who" and "know-how". Know-what is the factual information about the technology; know-why being the scientific and technological principles for the solution of problems; know-who being the knowledge about who the relevant people are for the solution of problems; know-how being the ability, practical skills and capabilities to do something.[48] It is evident that in order to successfully adopt a new technique it is crucial to 1) acquire information about the kind of technology that exists, 2) know who has relevant information about technology, 3) know how it works in operation and, if modifications are needed, 4) know why it works the way it does to understand how it can be changed.

The following questions are used as guidelines:

- How can mining operational activities; in terms of geological surveys, removal of ore and processing of ores, classified and linked to specific scientific domains, such as geology, chemistry, mineralogy etc.? Did technological development mean the use of new knowledge domains over time?

[48] B. Å. Lundvall, "From the Economics of Knowledge to the Learning Economy" (OECD, 2000)

- Which working functions and what type of work were mining engineers and technicians meant for?
- How was codified and tacit knowledge used in mining?
- How were know-what, know-how, know-who and know-why transferred from abroad and used in innovation processes? Which institutions were involved?

Student yearbooks, engineering descriptions, mining company reports, correspondence, articles in the Chilean and Norwegian Mining Journals, technical magazines, encyclopaedias and secondary literature about mining companies are revised and analysed. The emphasis is given on the mining sectors in Chile and Norway, but descriptions from other countries are also used as illustrations.

Second part of the analysis: the development of the two mining sectors

In this chapter, an outline of the developments of the two mining sectors from the late nineteenth century to 1940 is provided. All mining industries are taken as a starting point for analysis, because the knowledge institutions that I examine aimed to develop knowledge in principle for all metal and mineral productions. The purpose is to clarify differences in development between the two sectors. The analysis is based on the entire mining sectors, because the knowledge institutions and organisations that were developed aimed to create, transfer, adopt and diffuse knowledge for all mineral and metal industries. Analysing all mineral and metal productions as a whole calls for a generalisation and makes it difficult to nuance diversities between industries. However, the whole sector needs to be covered to obtain as complete a picture as possible of the range of knowledges these institutions provided.

A number of factors are stressed, notably mineral productions, technological change and companies, foreign companies and linkages to the capital goods sector. Guiding questions in this section are:

- Were metals and minerals utilised in Chile and Norway?

- Did the mining sectors meet new challenges in terms of finding, removing and processing ores?
- Did the mining sectors keep up-to-date with new and and up-to-date technology?
- Were linkages created between mining companies and the domestic capital goods sectors?

In the case of Chile, official mining statistics of imports, production and mines, descriptions and reports of the mining industry and companies, literature about mining companies and company reports, notably of Arturo Prat Mining Company, Las Vacas Mining Company and Taltal Mining and Processing Company, are used. In the case of Norway official mining statistics of production, engineering reports, literature of mining companies and company records, notably of Trondhjem Mechanical Workshop and the Bede Metal and Chemical Co. Ltd. are used.

Third part of the analysis: a comparison of formal mining instructions

In this chapter, the aim is to examine the relevance of formal instruction at mining schools and universities in Chile and Norway for the mining sectors. Instead of assuming a positive correlation between education and industrial growth, this part of the analysis examines the mining instructions in detail. First, the intermediate and higher mining instructions are related to technological changes in the mining sectors, and then similarities and differences between the two countries are discussed.

Some research has been done on Norwegian and Chilean mining education. The historiography of the mining education of the two countries provides us with histories of how institutions were created and to some degree the content of the instructions. The functions and aims of the institutions are explained, namely to educate skilled mining engineers and leaders for the mining industries. *Fra Bergseminar til teknisk høyskole* by Grethe Authén Blom, *Bergingeniørutdanning i Norge gjennom 250 år* by the historians Anne Kristine Børresen and Jan Thomas Kobberrød (red.) and *Bergskolen 100 år* address the creation and development of formal educational institutions in Norway. The instruction and study reforms are analysed to some degree. In *Bergingeniørutdanning i Norge gjennom 250 år* some of the traditional subjects related to mining are described, notably geology and metallurgy. However, emphasis is given on how the institutions were organised, their objectives and the work of some of the professors. Debates about the instruction in terms of whether it was to focus on “theory and science” or be more “practically-oriented” are also described. In the case of Chile *Historia de la Ingeniería en Chile* by the historian Sergio Villalobos, *Historia de la Universidad de Chile* by the authors Ronaldo Mellafe R., Antonia Rebolledo and Mario Cárdenas and *Escuela de Minas de La Serena* by the mining engineer Claudio Canut de Bon Urrutia examine engineering education in a more general way. Also in these analyses the creation of the institutions and the role of specific professors are stressed. Sergio Villalobos relates the education to technological development to some degree, but does not analyse this in detail. What lacks in the literature of both Chile and Norway are detailed analyses of the mining instructions, in terms of study plans and learning forms, and their role in industrial development.

Guiding questions are: did the instruction support the technological development in the industries? Was the knowledge that was taught at the educational institutions useful and relevant? Specific questions here are:

- Which courses were included and how was the study programs organised?
- Which teaching forms were used?
- Were there any changes in the programs?

These questions are addressed and sought answered to (1) understand the cognitive and practical content of the instructions in relation to the technology used in the two mining sectors and (2) compare the instructions of the two countries to search for qualitative differences, or differences in character, between the instructions in the two countries. A comparison of the concrete content of the instruction, in terms of program structure, scientific and practical subjects and teaching forms, provide an important insight into the knowledge that was provided at the educational institutions in both countries.

Annual reports by the University of Chile include mining engineering study plans and programs with information about courses, subjects, professors and exams. Reports by professors, notably the Polish mining engineer Ignacio Domeyko, provide additional information about courses. Pamphlets, bulletins, regulations, admission brochures etc. published by the Schools or the Ministry of Education give further information about courses and teaching methods at the Mining Schools.

Study plans, programs and descriptions of subjects from the Royal Frederick University and the Norwegian Institute of Technology (NIT) are used in the case of Norway. The annual reports from the University provide information about courses, lectures and related issues. They mainly reveal knowledge about which courses and subjects that were provided each semester and the professors in charge, but include to some degree the content of the courses and teaching forms. Evaluation forms and descriptions of exams are included for some of the years. Study plans and programs published by the NIT provide detailed information about the curriculum and include detailed descriptions of all the courses. Information about exams is taken from a separate document about the mining engineering exam. *Bergskolen 100 år* and articles in the Mining Journal include information about the study plans and courses at Kongsberg Silver Works Elementary Mining School.

Fourth part of the analysis: a comparison of the supply and demand of mining engineers, technicians and other professionals

The aim of this chapter is to analyse the role of the mining engineers, technicians and other professionals and the degree to which they reached across the two mining sectors. Literature on Chile and Norway account for the career paths of some engineers and professors and their contribution to new technologies. However, a systematic analysis of what mining engineers and technicians did after they finished studies, their work, travels, practical experience and positions in mining lacks for both countries. Therefore, learning processes, experiences, interactions, positions and working tasks for mining engineers and technicians are examined here as far as possible. The purpose of an in-depth comparative of this sort is to detect variances between the role of the mining engineers and technicians in the two countries. Lists of students, student yearbooks, journal and newspaper articles, company reports etc. provide a detailed overview of work and positions of educated trained workers in the two mining sectors.

The literature offers a general description of the supply of engineers in both countries. For Norway, the historian Gudmund Stang has done this most extensively in "Ble det for mange ingeniører?" and "The Dispersion of Scandinavian Engineers 1870-1930 and the Concept of an Atlantic System." The debate in Norway in the beginning of the twentieth century, and especially after the creation of the NIT, was about whether the industries were able to absorb the large number of technicians and engineers who graduated from the education institutions. Literature about Chile, on the other hand, concludes that there were far too few technicians and engineers, both in the mining sector and in other industries. The role of the mining engineer in the building of the mining sector was emphasised by Pedro Alvarez Suárez. He graduated as mining engineer in 1915 and presented "the importance of the Chilean mining engineer for the national industry and the mission he has to play in it" in 1916 at a Mining and Metallurgical Congress. One of the key arguments was that mining engineers could play an essential role in achieving economic independence.[49] In relation to the crisis in the saltpetre industry, the economist Patricio Meller concludes that:

> "…large-scale exporting required very distinct skills. Although the production technology required for nitrate exploitation was known and available to Chilean entrepreneurs, the scale of production and export was simply so large that the specific human capital that was needed – banking and marketing

[49] S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 198; *Boletín de la Sociedad Nacional de Minería* (Santiago, 1926), pp. 639-640

> expertise, organisational and diplomatic external contacts etc. – was not available in the country. Foreign investments, was, thus fundamental to generate a booming nitrate export business."[50]

The Chilean politician and lawyer Santiago Macchiavello Varas argued in 1920 that an important reason for the denationalisation of the copper industry was not only the lack of entrepreneurship among local industrialists, but the:

> "…lack of competent technicians who could give prestige to mining negotiations and give people confidence to our capitalists, who often have been disappointed in their expectations due to the lack of previous scientific studies…[…]…, disappointments which have resulted in real horror for the mining industry." [51]

In the same line of argument, the general comparative studies of Scandinavia and Latin America argue that education, and technical education in particular, contributes to explain the divergence. In addition to a lack of capital, Meller emphasises the lack of technical knowledge for copper mining in Chile:

> "Although there were both Chilean copper producers and domestic investment resources generated by nitrate exports, the exploitation of copper required sizable investments and the use of modern, large-scale technology that was unknown to Chilean producers. Moreover, investment in large-scale copper mining is a slowly maturing activity, requiring many years for the return on invested capital…[…] Therefore, there were no domestic entrepreneurs who were able to initiate large copper mining exploitation."[52]

[50] P. Meller, "Chilean Economic Development 1880-1990", in *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development,* M. Blomström and P. Meller (eds.) (Washington, 1991), pp. 40-41

[51] S. Macchiavello Varas, *El problema de la industria del cobre en Chile y sus proyecciones económicas y sociales* (Santiago, 2010), p. 122

[52] P. Meller, "Chilean Economic Development 1880-1990", in *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development,* M. Blomström and P. Meller (eds.) (Washington, 1991), p. 42

Blomström and Meller find that:

> "…during the mid-1950s one could have learned more about Chilean copper in foreign libraries than in Chilean ones, despite the importance of copper in the Chilean economy. Neither was there training of Chilean engineers and technicians specializing in copper."[53]

The literature explains that technical knowledge was scarce, but it does not inform us of what this lack of knowledge entailed. How this lack affected Chile has not been examined in detail. What did the lack of technicians and engineers in Chile mean for the industry?

First, evaluations by company leaders, professors, students etc. of the supply of mining engineers, technicians and other professionals for the mining sectors are discussed. Articles by professors, engineers, company leaders, students etc. in newspapers, the Mining Journal and Technical Magazine are used to give an outline of how the supply and demand were discussed by mining engineers, technicians and other professionals and specialists in the sector. Moreover, all the yearbooks from Norwegian secondary school from 1855 to 1940 are used to analyse the career of all professional workers in mining. These yearbooks include formal education, domestic and foreign, travels, work and positions and the career paths of all mining engineer and technician graduates are traced and accounted for. After secondary school exam, many continued to study at the University or technical school either in Norway or abroad, while others started to work immediately. From these yearbooks, it has been possible to obtain a near complete picture of the background of all workers with formal education, i.e. secondary, technical, economic or scientific education, in the mining sector from 1866 to 1940. In addition to these books, the Norwegian Institute of Technology (NIT), the technical schools of Christiania, Bergen, Trondheim and Horten and students abroad published their own

[53] M. Blomström and P. Meller (eds.), *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development* (Washington, 1991), p. 8

yearbooks of graduated and visiting students. In the case of the mining technicians, *Bergskolen 100 år* is used extensively.

In the case of Chile, student yearbooks have not been published to the same degree. However, the number of mining engineers is known and it has been possible to acquire extensive information about mining engineers and technicians from mining journals, company reports and other publications. Of the mining engineers, information about around one third of the graduates between 1856 and 1940 is known. Furthermore, *Album Escuela de Minas de Copiapó* contains a nearly complete picture of the graduates from the Mining School of Copiapó. Although the sources are scarcer on this subject than in the Norwegian case, there is extensive information about some of the engineers. Moreover, foreign professionals were widespread in Chile. Company reports, articles in the Mining Bulletin, literature on mining companies, and so on, provide an overall image of workers and their work, tasks and positions in the Chilean mining industry. For the roles and functions of professionals in the industry company reports, notably by Taltal Mining Company, Las Vacas Mining Company, Braden Copper Company, and others, are used.

Subsequently, the actual number of mining engineer and technician graduates are compared to the number of workers in the sector for both countries. The number of mining engineer graduates per year are known for both countries. This makes it possible to calculate the number of workers per mining engineer based on the supposition that the average career in mining was forty years. The same calculation is carried out for the number of workers per professionals (including all workers with education, not only the ones with an education in mining) in Norway. Such numbers of all professionals are not available for Chile. On the other hand, the Mining Bulletin published by the National Mining Society became a forum for debate and articles about the mining education were frequently published. The members of this Society were normally owners and leaders of mines and mining companies. Professors, civil engineers, mining engineers, industrialists and others often wrote long descriptions about the industry and discussions of the supply and demand. A review of these articles gives a reasonably good impression of what professors, engineers, industrialists and company leaders thought of the extent to which mining engineers and technicians reached into mining companies. Correspondence between managers and engineers at the North American Andes Copper Company is used to evaluate the use of engineers and technicians at foreign companies. Therefore, in spite of the a scarcer source material on Chile in terms of supply and demand, this alternative source material for Chile makes it possible to compare both mining engineers and technicians and other professional workers for the two countries.

Fifth part of the analysis: a comparison of institutions and organisations for knowledge transfers

It has been argued in the literature that innovation was to a large degree based on the transfer and application of technology from other countries. Therefore, a focus is given on institutions, which sought to transfer knowledge from other countries. Magazines, scholarships and other funds for study travels, exhibitions and foreign working experience are examined. The number of scholarships, travels, cases of work abroad etc. are accounted for and compared. Questions, which are addressed here, are:

- Were these institutions used to transfer knowledge?
- If so, which type of knowledge was transferred?
- To what extent was knowledge transferred?

The aim here is to 1) explore the extent to which engineers and technicians transferred knowledge from abroad to the mining sectors in Chile and Norway and 2) compare the two countries.

Travel reports, student yearbooks, descriptions from industrial exhibitions, mining journals and other documentation are used for both countries.

Sixth part of the analysis: a comparison of geological mapping and ore surveys

The aim of this chapter is to examine and compare institutions, which aimed to carry out geological mappings and ore surveys for the mining sectors. The following questions are used as guidelines:

- Were geological maps made of the two countries?
- Were ore analyses made and ore deposits found?

In the case of Norway, Anne Kristine Børresen and Astrid Wale have done extensive work on Norwegian Geological Survey and its functions and work. The part about Norway is largely based on their work. In the case of Chile, the Mining Journal, engineering reports and other publications are used.

5 Institutions, natural resources, innovation and economic growth

The aim of this chapter is to set a framework for an empirical comparative analysis of knowledge institutions and organisations involved in mining innovation in Chile and Norway. The chapter is divided into five subsections. In the first section, I discuss theories concerning natural resources and economic growth and point out the large differences in growth that is observed across resource-based economies. In the second section, I refer to the argument that knowledge is the underlying foundation of economic growth and that learning and innovation depend on institutional support. Subsequently, I go through some of the literature about institutions and economic growth and find that few studies in fact analyse the links and connections between institutions, innovation and economic growth. I argue that to understand how technological knowledge develop, and how innovation occur, further in-depth and detailed empirical analyses are required of knowledge institutions and organisations, which were directly involved in learning processes and the development of technological capabilities. I propose an empirical approach of learning and innovation, in which specific knowledge institutions and organisations, and interactions between them, are analysed in detail. In the fourth section, I discuss some of the research, which address similar questions as I do. In the fifth section, I summarise the main arguments.

5.1 Do natural resources lead to slow growth?

Economies in which natural resource sectors account for at least ten per cent of GDP, a share of export of at least twenty to forty per cent, or where such sectors represent “key stone” sectors, have been defined in the literature as “resource-based economies”.[54] Natural resource industries rest essentially on productions of raw materials, such as agriculture, forestry and extraction of metals and minerals. Resource-based economies differ from countries, which base their economies on manufacturing or high-tech industries. Nobel Laureate in economics Douglass C. North gives the following explanation of an “industrialised” society: “A…[…]… useful concept of

[54] S. Ville and O. Wicken, “The Dynamics of Resource-Based Economic Development: Evidence from Australia and Norway” (Wollongong, 2012), p. 14

industrialization…[…]… is a region whose export base consists primarily of finished consumers' goods and/or finished manufactured producers' goods."[55] The economist Keith Smith describes resource-based economies in more detail. They:

> "… are often characterised by industrial structures with a strong emphasis on agriculture, a small manufacturing sector with a large proportion of output concentrated in low and medium-technology sectors, and a large service sector incorporating a large social and community services element (meaning especially health and education). Natural resources may provide a significant proportion of output, but more commonly a large proportion of exports. Both the gross and business… [...]… R&D tend to be low. There is usually a technology balance of payments deficit, suggesting significant technology import. Likewise a significant share of gross fixed capital is met by imports. Significant natural resources may include agricultural land, timber and forests, fish, hard rock minerals, and oil and gas. These countries often have significant area/population imbalances, and the physical make-up is such that there are communications problems and hence major physical infrastructure challenges."[56]

Some of the poorest countries in the world fit this description, notably the majority of African and Latin American countries. The poor economic performance of these countries led to theories, which argue that natural resources reduce growth. Import of industrial goods normally is more expensive, which means that countries, which base their economy on natural resource industries, find themselves in a vicious circle or a "resource curse" in which they are always in external deficit. These features prevent the economic progress that characterises industrialised countries and are understood to be important reasons why resource-based economies show poor economic performance.

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[55] D. North, "Location Theory and Regional Economic Growth", *Journal of Political Economy* 63 (1955), p, 254
[56] K. Smith, "Innovation and growth in resource-based economies", in CEDA, *Competing from Australia* (Australia, 2007), p. 53

A theory, developed from the 1950s, which had major effects on economic policy in Latin America, was the "dependency theory", which claimed that resources flowed from peripheral underdeveloped countries to the core of industrialised and developed countries. The idea was that developed countries became rich at the expense of underdeveloped countries. In the 1950, the economist Raúl Prebisch argued that natural resource-based Latin American countries were dependent on technology from countries in the centre of industrialisation, notably European countries and the United States. There were nuances within this approach, but they had some common traits. The economist Matias Vernengo summarises the different traditions within the dependency theory approach and establishes that these theorists:

> "…would agree that at the core of the dependency relation between center and periphery lays [lies] the inability of the periphery to develop an autonomous and dynamic process of technological innovation. Technology – the Promethean force unleashed by the Industrial Revolution – is at the center of stage. The Center countries controlled the technology and the systems for generating technology."[57]

The economic activities, dominance and control of multinationals, were in this context seen as a hindrance to local industrial development. Prebisch saw the large foreign investments in natural resource industries as part of the negative dependence on foreign technology. He underlined that: "(i)t cannot be denied that the economic development of certain Latin-American countries and their rapid assimilation of modern technology, in so far as they can utilize it, depend to a very large extent upon foreign investment."[58] Part of the argument was that the new and up-to-date technology that was brought by multinationals to host countries did not contribute to economic growth. Matias Vernengo explains that "(f)oreign capital could not solve the problem, since it only led to limited

[57] M. Vernengo, "Technology, Finance, and Dependency: Latin American Radical Political Economy in Retrospect", *Review of Radical Political Economics,* Vol. 38, No. 4 (2006), pp. 552-553
[58] R. Prebisch, *The Economic Development of Latin America and its Principal Problems* (New York, 1950), p. 4

transmission of technology, but not the process of innovation itself."[59] Latin American countries imported gradually fewer and fewer manufactured goods in exchange for their exports of natural resource products. This, in turn, led to deficits in trade balances and subsequently economic underdevelopment.[60] In the same line of argument, the famous paper by the economists Jeffrey D. Sachs and Andrew M. Warner "Natural resource abundance and economic growth" compared data from a wide range of countries and found that economies with natural resources as a large share of exports in 1970, grew slowly during the following years 1970-1990.[61]

Which negative effects are caused by natural resources? A number of negative symptoms are categorised under the "resource curse". A vast amount of literature find that natural resources destroy institutions and create civil wars. Sudan, Nigeria, Angola and Congo are examples of countries with such problems.[62] Some analyses suggest that natural resources tend to implicate large incomes fast, but that they can also be fluctuating. The volatility, which these industries represent, often destabilise public regimes, weaken institutions and state capacity and encourage rent-seeking behaviour and corruption.[63] In Nigeria, for instance, oil extraction has changed politics and governance. Military dictatorships have plundered large amounts of the wealth from this production, which has contributed to miserable economic performance.[64] The political scientist Terry Lynn Karl examines oil-exporting countries during the 1970s and finds that governments in Venezuela, Iran, Nigeria, Algeria and Indonesia rely too heavily on income from natural resource sectors. Public

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[59] M. Vernengo, "Technology, Finance, and Dependency: Latin American Radical Political Economy in Retrospect", *Review of Radical Political Economics,* Vol. 38, No. 4 (2006), pp. 552-553

[60] R. Prebisch, *The Economic Development of Latin America and its Principal Problems* (New York, 1950)

[61] J. D. Sachs and A. M. Warner, "Natural resource abundance and economic growth", *NBER Working Paper* No. 5398, (1995)

[62] P. Collier and A. Hoeffler, "Greed and grievance in civil wars", *Oxford Economic Papers*, 56 (2004), pp. 663-695

[63] See for example T. L. Karl, *The Paradox of Plenty* (Berkeley, 1997); S. Andrade and J. Morales, "The Role of the Natural Resource Curse in Preventing Development in Politically Unstable Countries: Case Studies of Angola and Bolivia", Institute for Advanced Development Studies, Development Research *Working Paper Series* No. 11 (2007); F. van der Ploeg, "Natural Resources: Curse or Blessing?", CESifo Working Paper No. 3125 (2010)

[64] F. van der Ploeg, "Natural Resources: Curse or Blessing?", CESifo Working Paper No. 3125 (2010), p. 2

spending increased, but without maintaining a general tax regime and long term fiscal balance.[65] In some cases, large natural resource industries have led to so called "Dutch disease". This means that the increase of such sectors have caused a too strong currency for other export products, resulting a decline in manufacturing, or other, industries. The term is related to the decline of the manufacturing sector in the Netherlands after the discovery of natural gas in 1959.[66] Other analyses show the negative effects that natural resources have had on social structures and human capital formation. According to the economists Thorvaldur Gylfason and Gylfi Zoeda dependency on natural resources is often accompanied by greater social inequality.[67] Natural resources have also appeared to weaken the incentives to invest in human capital. This is based on the idea that natural resource sectors, based on medium and low technological activities, create very few qualified jobs, which leads to lower incentives to develop a good education system compared to countries with less natural resources. This, in turn, slows down the pace of economic development.[68] The authors Elena Suslova and Natalya Volchkova test human capital formation based on this theory and finds that industries, which requires "sophisticated human capital inputs", would be in disadvantage in natural resource rich countries relative to industries that only require "modest levels of human capital inputs."[69]

Thus, in many cases and in many countries natural resources are argued to have different negative impacts on institutions, social structures and economic development. Underlying these negative economic effects lies the notion that natural resources generate sectors with medium and low technological activities that are less knowledge intensive and innovative than manufacturing sectors. Although economists recognise that natural resources provide opportunities for economic growth, it

[65] T. L. Karl, *The Paradox of Plenty* (Berkeley, 1997)
[66] "The Dutch Disease" *The Economist*, (1977). pp. 82-83
[67] T. Gylfason and G. Zoeda, "Inequality and Economic Growth: Do Natural Resources Matter?", CESifo Working Paper Series No. 712 (2002)
[68] T. Gylfason, "Natural Resources, Education and Economic Development", *European Economic Review 45* (2001), pp. 847-859
[69] E. Suslova and N. Volchkova, "Human Capital, Industrial Growth and Resource Curse", *New Economic School: Working Paper* # WP2007/075 (2007), p. 3

is claimed that natural resource sectors have weak dynamic development patterns, lack linkages with the wider economy and are less knowledge intensive and productive than manufacturing or "high tech" industries.[70]

To generate long-term growth the recommendation has been, therefore, to move away from natural resource industries and develop institutions, which support the development of manufacturing sectors and finished goods. Latin American natural resource abundant countries with terms of trade deficits and heavy involvement of foreign investments opened up to the idea to focus instead on manufacturing industries. Arguably, part of the problem in these countries was that natural resource export sectors favoured the traditional oligarchy and the established economic policy systems prevented the growth of other sectors.[71] In Chile, for instance, the capacity to import was low, but productions suffered even further as the elite imported more luxury goods than manufactured goods for use in production. The historian Francisco Encina argued that:

> "If half of what we have wasted in the last 40 years or invested in luxury we had applied to buying Nitrate mining machinery or to setting up the copper industry, to irrigating our fields ... the position of Chile in America would today be different."[72]

The alternative to the export-led economy of the time, which apparently led to slow growth, and stagnation in some industries, was to adopt protectionism and substitute imports.[73] Prebisch found that "…any industry that can produce substitutes for imports is justifiable", "because (i)ndustrialization has become the most important means of expansion."[74] In line with this argument,

[70] For a review of literatre on this subject see B. Nelson and A. Behar, "Natural Resources, Growth and Spatially-Based Development: A View of the Literature" (Washington, 2008)
[71] J. A. Mahon, "Was Latin America too rich to prosper? Structural and political obstacles to export-led industrial growth", *Journal of Development Studies,* vol. 28**,** issue 2 (1992), p. 256
[72] Quote taken from A. Pinto Santa Cruz, *Chile, un caso de desarrollo frustrado* (Santiago,1959), p. 75
[73] R. Prebisch, *The Economic Development of Latin America and its Principal Problems* (New York, 1950), p. 6
[74] R. Prebisch, *The Economic Development of Latin America and its Principal Problems* (New York, 1950), p. 6

Latin American countries began an industrialisation process based on new manufacturing productions called "Import substitution industrialisation" (ISI) after the Great Depression in the 1930s.[75] The aim of these changes was to reduce the dependence on exports of natural resources, based on the belief that manufacturing activities created more economic growth than natural resource industries. In Chile, free trade dominated until 1928, with moderate tariff rates of twenty-five per cent on the majority of imports. In 1928, the emerging industrial groups were subjected to a new customs law, which allowed setting rates on any product to a maximum of thirty-five percent.[76] Restrictive policies to control the external sector were established, such as tariffs, import quotas, multiple exchange rates, price setting etc.[77] New productions developed, which had not previously been produced in Chile. New industries were for instance car production, factories of sanitary ware, light bulbs, metal furniture, china, cotton yarn, crockery, underwear, steel, milk pasteurizer, cement, paint etc.[78] These were large, modern mass production installations with a certain degree of automation, electric engines and oil as an important energy source.[79] The state attained a larger role in the economy and became employer, investor and source of credit for the private industrial sector.[80] The creation of a public National Development Corporation (CORFO) in 1939, a domestic program for industrial development through public investments, illustrates a more active state in economic issues.[81] However, these political institutions did not meet with their basic expectations. In retrospect, the policy turned out to be negative and damaging to long-term economic growth. The economist Patricio Meller explains that:

[75] D. De Ferranti et al. *From Natural Resources to the Knowledge Economy* (Washington D. C., 2002), p. 4
[76] P. Cabezón, "Antecedentes historicos de las importaciones y de la politica comercial en Chile", *Latin American Journal of Economics-formerly Cuadernos de Economía*, vol. 8, issue 25 (1971), p. 3
[77] G. Salazar and J. Pinto, *Historia contemporánea de Chile III*. Santiago: Editorial LOM (2002), p. 39
[78] S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 229; D. De Ferranti et al. *From Natural Resources to the Knowledge Economy* (Washington D. C., 2002), p. 68
[79] S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 230
[80] M. Carmagnani, *El desarollo industrial y subdesarrollo económico* (Santiago, 1998), pp. 28-29
[81] P. Meller, "Chilean Economic Development 1880-1990", in *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development,* M. Blomström and P. Meller (eds.), (Washington, 1991), p. 51

> "(t)he promotion of manufacturing industry was indiscriminate, i.e., there were no attempts to focus the incentives on those industries that might have had potential comparative advantages. Any domestic production that replaced imports was believed to eventually increase national welfare."[82]

The general criticism is that political institutions were not able to encourage competitive manufacturing industries through import substitution.[83] In the case of Chile "…the overall GDP performance was considered to be unsatisfactory, and the increases in domestic productivity were very low".[84] The economy was still dependent on natural resources, with copper being the most important industry.[85] Thus, moving away from natural resource industries have not shown to be a good alternative.

Some of the richest countries in the world are resource-based economies. In a study about natural resources and development, Cali Nuur and Stephan Laestadius conclude that: "…natural resources were of core importance in the industrialisation of Sweden."[86] Like Latin American and African economies, Norway, Sweden, Canada, New Zealand and Australia have developed their economies on natural resources industries. Historically, resource sectors, such as agriculture, fishing, timber, minerals and metals, have constituted very large parts of these countries' economies. The difference is that they have developed fast-growing economies, instead of slow growth, stagnation and underdevelopment. These countries have small social differences, are open, transparent democracies with a low degree of corruption and rent seeking. Keith Smith finds that:

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[82] P. Meller, "Chilean Economic Development 1880-1990", in *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development,* M. Blomström and P. Meller (eds.) (Washington, 1991), p. 50

[83] See for example P. Meller, "Chilean Economic Development 1880-1990", in *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development,* M. Blomström and P. Meller (eds.) (Washington, 1991); A. Pinto Santa Cruz, *Chile, un caso de desarrollo frustrado* (Santiago,1959); D. De Ferranti et al. *From Natural Resources to the Knowledge Economy* (Washington D. C., 2002)

[84] P. Meller, "Chilean Economic Development 1880-1990", in *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development,* M. Blomström and P. Meller (eds.) (Washington, 1991), p. 51

[85] A. Pinto Santa Cruz, *Chile, un caso de desarrollo frustrado* (Santiago,1959), p. 172

[86] C. Nuur and S. Laestadius, "Anomalies in the resource curse paradigm: the case of Sweden" (Stockholm, 2009), p. 47

> "(t)hese small, open economies have rested their development paths on resource-based sectors, and out of them have developed low- and medium-technology industries that have driven growth within these countries. This has been the case not only historically, but in many instances remains the case today."[87]

The economists Magnus Blomström and Patricio Meller compare Latin America and Scandinavia and explain that, despite similar conditions, these two groups of countries have developed very differently:

> "Although the physical characteristics of several Latin American countries have been similar to those in Scandinavia – in both regions, countries have been small in area and population and rich in natural resources – Latin America has developed very differently. While the northern countries were able to use their natural resources to generate the momentum for sustained growth, the countries of Latin America have tried different formulas without much success."[88]

It is clear that there are marked differences in economic growth among countries, which are defined as resource-based economies. Some of these countries have developed extensively, progressed and transformed into being among the richest countries in the world, while others remain underdeveloped and relatively poor.

More specifically, and in line with the observation that some of the richest countries in the world are resource-based economies, alternative analyses suggest instead that natural resources do not necessarily inhibit growth. Comparative analyses by the economist Angus Maddison finds that

[87] K. Smith, "Innovation and growth in resource-based economies", in CEDA, *Competing from Australia* (Australia, 2007), p. 53
[88] M. Blomström and P. Meller (eds.), *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development* (Washington, 1991), p. vii

resource rich countries from 1913 to 1950, including Latin American economies, actually grew faster than industrialised countries.[89] Research on specific natural resource sectors find that agriculture and mining sectors often experience more productivity growth than manufacture industries.[90] Based on these findings the economist Jacob Viner argued that: "(t)here are no inherent advantages of manufacturing over agriculture"[91] The idea that natural resources are unfavourable to economic growth was questioned early. In 1955 Douglass North argued, as a counterargument to Prebisch's thesis, that: "the contention that regions must industrialize in order to continue to grow ...[…]… [is] based on some fundamental misconceptions".[92]

Therefore, a severe problem in much of the literature, which argues that natural resources inhibit growth, is that these their conclusions are too general. The differences in growth are not accounted for or explained. Based on these observations, Smith, among others, criticises the generalisation that has been made to claim slow growth among resource-based economies. He points out that:

> "…if the data on resource-based economies [is not] as secure as it might be, then it may be that the problems that the "resource curse" hypothesis is seeking to explain are not as general as they seem to be. This leaves us with an interesting question: what factors explain growth in successful resource-based economies?"[93]

Some scholars have recently started to address this question. Instead of assuming that natural resource industries result in poor economic performance, scholars focus on the factors, which actually determine growth in natural resource sectors and countries. Fundamental to the new ways of

[89] D. De Ferranti et al. *From Natural Resources to the Knowledge Economy* (Washington D. C., 2002), p. 6
[90] W. Martin, and D. Mitra, "Productivity Growth and convergence in Agriculture and Manufacturing", Economic Development and Cultural Change, vol. 49, issue 2 (2001), 403-22; G. Wright, G. and J. W. Czelusta, "Resource-Based Growth Past and Present", in D. Lederman and W. F. Maloney, *Natural Resources: Neither Curse nor Destiny*, chapter 7 (Washington D. C., 2007)
[91] J. Viner, "International Trade and Economic Development" (Glencoe, 1952), p. 72
[92] D. North, "Location Theory and Regional Economic Growth", *Journal of Political Economy* 63 (1955), p. 252
[93] K. Smith, "Innovation and growth in resource-based economies", in CEDA, *Competing from Australia* (Australia, 2007), p. 7

approaching natural resources and growth, is that natural resources are not geologically predetermined, but endogenous and socially constructed. Needs and usages of natural resources have determined their extraction and transformation. As demonstrated by Cali Nuur and Steffan Laestadius, development of natural resource industries and their application areas have changed over time:

> "Charcoal was important for steel production until mid nineteenth century but its role diminished rapidly after coal became the dominant source of energy for industrial processes. Later the large waterfalls became a Scandinavian energy resource compensating for lack of coal. And the phosphorous iron ores in Sweden increased dramatically in value with the Gilchrist-Thomas process. Radical technical change – which does not fall like manna from heaven but is the result of capabilities created for some reason somewhere - may thus cause tough incentives to industrial transformation as knowledge related to a specific, and maybe local, natural resource becomes obsolete."[94]

Historically, countries have differed with regard to utilisation of initial stocks of natural resources. In a historical analysis, the economists Paul David and Gavin Wright find that the mining sector in the United States was able to benefit from their mineral resources to a far greater extent than any other country between 1850 and 1950, even though other countries initially had more mineral reserves. Mineral rich countries, such as Brazil, Chile, Russia and Australia had a much smaller production than the mineral deposits would suggest. Chile, for instance, had large unexploited mineral deposits and the country's copper production was far below its proportionate share of the world's copper resources.[95] These observations indicate that natural resources, and the extraction of these, are not given. Differences in the way natural resources are produced, suggests varieties in knowledge foundations. Utilisation of resources and successful natural resource industries require knowledge,

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[94] C. Nuur and S. Laestadius, "Anomalies in the resource curse paradigm: the case of Sweden" (Stockholm, 2009), pp. 46-47

[95] P. David, G. and Wright, "Increasing Returns and the Genesis of American Resource Abundance", *Oxford Journals*, vol. 6, issue 2 (1997), pp. 210-218

effort. In rich resource-based economies, institutions have actually encouraged and stimulated the utilisation of natural resources and the development of such industries. The economist David Ferranti and colleagues suggest that:

> "… (t)he fact that Australia, Canada, and the Scandinavian countries succeeded by playing to their resource strengths, suggests that success has less to do with what a country produces in particular, and everything to do with the way in which it produces it."[96]

An important argument, which is repeated in studies which argues against the resource curse, is that differences in growth across resource-based economies are based on complex knowledge. The historian Olav Wicken stresses that different knowledge bases can encourage specialisations and develop competitive firms and industries, which in turn can lead to dissimilar trajectories between such economies.[97] Analyses of specific natural resource sectors support this theory. In a recent study Hartmut Hirsch-Kreisen, David Jacobsen, Steffan Laestadius and Keith Smith show that current fish production, a traditional natural resource industry, actually is based on a number of knowledge systems and is linked to several other industries:

> "Examples of embodied flows in fishing include use of new materials and design concepts in ships, satellite communications, global positioning systems, safety systems, sonar technologies (linked to winch, trawl and ship management systems), optical technologies for sorting fish, computer systems for real-time monitoring and weighing of catches, and so on. Within fish farming, these high-technology inputs include pond technologies (based on advanced materials and incorporating complex design knowledges), computer imaging and pattern recognition technologies for monitoring (including 3D measurement systems), nutrition technologies (often based on biotechnology and genetic research), sonars, robotics (in feeding systems), and so on."[98]

[96] D. De Ferranti et al. *From Natural Resources to the Knowledge Economy* (Washington D. C., 2002), p. 52
[97] O. Wicken, "The Norwegian Path Creating and Building Enabling Sectors" (Oslo, 2010), pp. 4-5
[98] H. Hirsch-Kreinsen et al., "Low-Tech Industries and the Knowledge Economy: State of the Art and Research Challenges", *PILOT Policy and Innovation in Low-Tech, STEP – Centre for Innovation Research* (Oslo, 2003), p. 22

Mining companies, and especially large-scale mining companies, depend on energy supply and input of machinery, equipment, engineering, infrastructure, technical services and finances. In such cases, important backward linkages were created. A recent study of the mining sector in Peru shows that universities and firms supplied inputs, such as power generation, technical services in geology, mining engineering, environmental engineering and metallurgy to mining firms.[99] Wicken explains this further. He and economic historian Simon Ville study and compare two successful resource-based economies, Norway and Australia, and argue that linkages between resource-based industries and other sectors, such as capital goods sectors, services and research institutions, have been vital in both countries. New industries based on natural resources have often emerged out of these linkages. They conclude that: "…dynamic interactive relationship between natural resource industries and enabling sectors is regarded as the core aspect of the successful economic development of Australia and Norway."[100] Paul David and Gavin Wright analyse the underlying institutional foundations for the successful mining sector in the United States and find that new knowledge and techniques enabled growth and connections to other parts of the economy, including non-resource-based sectors:

> "We find…[…]… that late nineteenth century American mineral expansion embodied many of the features that typify modern knowledge-based economies: positive feedbacks to investments in knowledge, spillover benefits from one mining specialty to another, complementarities between public- and private-sector discoveries, and increasing returns to scale—both to firms and to the country as a whole."[101]

[99] UNCTAD, "World Investment Report 2001 Promoting Linkages" (New York and Geneva, 2001), p. 138
[100] S. Ville and O. Wicken, "The Dynamics of Resource-Based Economic Development: Evidence from Australia and Norway" (Wollongong, 2012), p. 37
[101] P. David, G. and Wright, "Increasing Returns and the Genesis of American Resource Abundance", *Oxford Journals*, vol. 6, issue 2 (1997), pp. 204-205

In addition to linkages to other sectors and institutions, David and Wright argue that the mining sector depended on detailed scientific research, knowledge in geology, mineralogy and chemistry and engineering work.[102] The underlying reason for the successful mining sector in the United States was the use of highly qualified scientists and engineers: "Scientifically trained personnel were instrumental in maintaining the flow of new mineral discoveries in America, through the application of increasingly sophisticated forms of geological knowledge and search procedures."[103] Additionally, one can only imagine that machinery, equipment and power stations required a number of workers with different educational and scientific specifications, which strengthen the argument that technologically advanced and competitive natural resource industries can be innovative and based on complex and dynamic learning processes, much like manufacturing or "high tech" industries.

The previous argument goes against the idea that the utilisation of natural resources necessarily are based on low technological activities. Perhaps the most severe problem with the literature arguing for the "resource curse" is the assumption that natural resource industries are based on simple knowledge and working operations, which only require unskilled workers. Suslova and Volchkova, for instance, find that:

> "resource intense sectors absorb national savings while creating only a few eminently qualified jobs which leads to lower incentive of the society to educate their citizens compared to the societies with lower abundance in natural resources.[104]

[102] P. David, G. and Wright, "Increasing Returns and the Genesis of American Resource Abundance", *Oxford Journals*, vol. 6, issue 2 (1997)
[103] P. David, G. and Wright, "Increasing Returns and the Genesis of American Resource Abundance", *Oxford Journals*, vol. 6, issue 2 (1997), p. 234
[104] E. Suslova and N. Volchkova, "Human Capital, Industrial Growth and Resource Curse", *New Economic School: Working Paper* # WP2007/075 (2007), p. 3

Accordingly, they argue, "(n)atural resource abundance which is an exogenous characteristic of the country serves as an impediment for manufacturing sectors that depend on sophisticated human capital."[105] Similarly, Thorvaldur Gylfason argues that:

> "…nations that are confident that their natural resources are their most important asset may inadvertently…[…]… neglect the development of their human resources, by devoting inadequate attention and expenditure to education. Their natural wealth may blind them to the need for educating their children."[106]

These assumptions lack of empirical evidence. Historical studies and analyses of recent decades indicate that natural resource industries have had similar characteristics as manufacture or high-tech industries, in the sense that they depend on a number of knowledge specialisations, inputs from other sectors and skilled workers. In the case of mining, a typical natural resource industry, would not the mapping of ore deposits and analyses of minerals and metals require workers with in-depth knowledge in geology, mineral and chemistry? The planning and making of mines, would they not entail some of the most complex constructions that exist? After all, they are normally underground and involve solid tunnels, adits and ventilation systems, which demand precise mathematical calculations and scientific principles to prevent from collapsing. In some of the rich natural resource-based economies, such as the Nordic countries, Australia and Canada, it is generally recognised that the education system is well developed. Using Norway as a model for other resource-rich countries, Thorvaldson Gylfason underlines the high level of human capital in this country.[107] Wicken explains this further. He stresses that resource-based industries and economies instead should be examined:

[105] E. Suslova and N. Volchkova, "Human Capital, Industrial Growth and Resource Curse", *New Economic School: Working Paper* # WP2007/075 (2007), p. 4

[106] T. Gylfason, "Natural Resources, Education and Economic Development", *European Economic Review 45* (2001), p. 850

[107] T. Gylfason, Policy conference: competitiveness & diversification: strategic challenges in a petroleum-rich economy, "Resources and Economic Growth:Is Africa (Ghana) Different?" (Accra, 2011)

> "… as dynamic processes which can evolve in different directions depending on social and political contexts as well as by decisions undertaken by organizations and individuals. Economies specializing in natural resources may therefore follow different historical paths of economic and social evolution. This perspective is in line with a tradition in economics and economic history which regards technology and institutions as the main elements of long term economic development, and where we find a diversity of development patterns with path dependence characteristics."[108]

Some natural resource-based economies have managed to benefit from their natural resources, develop competitive natural resource sectors and had strong economic growth, while others have stagnated and declined. Instead of assuming that natural resources lead to slow growth, the notion is that industries are dependent on society and the institutional environment to make the most of natural resources. With these theories of natural resources and economic growth in mind, literature about institutions, and the institutional setting, which influence innovation will be revised in the next section.

5.2 Knowledge, innovation, institutional support and economic growth

A strong argument in economic history is that knowledge is the underlying foundation of economic growth. In 1965, Nobel Laureate in economics Simon Kuznets found that useful knowledge is the source of modern economic growth.[109] Douglass C. North argued later that "…modern economic growth had as its source the growth in the stock of knowledge…"[110] Kristine Bruland and economist Keith Smith confirm that:

> "… however much growth may require capital accumulation and changes in the quantity and quality of labour, its ultimate source is technological capability. Capital and labour can only be deployed around

[108] O. Wicken, "The Norwegian Path Creating and Building Enabling Sectors" (Oslo, 2010), p. 2
[109] S. Kuznets, *Economic Growth and structure* (New York, 1965), p. 84
[110] D. C. North, "Economic Performance Through Time: The Limits to Knowledge", EconWPA, Economic History, 9612004 (1996), p. 9

> specific technologies, and the capability to use them. Such capability in turn is a function of learning, of knowledge accumulation."[111]

Joel Mokyr explains that the enormous increase in the knowledge base that has occurred the past two centuries is the foundation of modern economic growth and the material world, as we know it today.[112] He finds that throughout history, the lack of knowledge has been the principal reason why societies have been limited in their ability to increase material wealth.[113] In his work about why the Industrial Revolution happened first in Britain, and not somewhere else, Mokyr shows that the West acquired the necessary "useful knowledge" to undergo a sustained economic progress. The Industrial Revolution represented the emergence of continuous technological advance, which had not existed before. Inventions and technological changes had happened before industrialisation, but the new at this point in history was that innovation processes continued and acceleration of technological changes did not stop or fade out.[114] In the same line of argument Kline and Rosenberg point out that: "(t)he relevant questions are not whether innovation is necessary to increases in efficiency or for survival, but rather: what kind of innovations? At what speed?"[115]

Learning and innovation depend on institutional support. The capacity and decision to innovate are intimately linked to the context within which they operate. Bengt-Aake Lundvall confirms that: "…learning is predominately an interactive and, therefore, a socially embedded process which cannot be understood without taking into consideration its institutional and cultural context..."[116] Scholars understand institutions in different ways. Perhaps the most influential economist in this respect is

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[111] K. Bruland and K. Smith, "Knowledge Flows and Catching-Up Industrialization in the Nordic Countries The Roles of Patent Systems", in H. Odagiri et al. *Intellectual property rights, development and catch-up an International comparative study* (Oxford, 2010), pp 63-94

[112] J. Mokyr, *Gifts of Athena* (Princeton and Oxford, 2005), p. 291

[113] J. Mokyr, *Gifts of Athena* (Princeton and Oxford, 2005), p. 17

[114] J. Mokyr, *The Enlightened Economy* (New Haven, 2009), p. 4

[115] D. Kline and N. Rosenberg, "An Overview of Innovation", in R. Landau and N. Rosenberg (eds.) *The Positive Sum Strategy: Harnessing Technology for Economic Growth* (Washington, 1986), p. 279

[116] B.-Å. Lundvall, *National Systems of Innovation* (London, 1992), p. 1

North. He understands institutions as "the rules of the game", including formal laws, regulations, informal norms, and values, which regulate economic behaviour.[117] Organisations, on the other hand, are defined as players, actors or groups of individuals bound by a common purpose to achieve objectives. Institutions and organisations affect, influence and interact with each other.[118] Charles Edquist explains the relations between institutions and organisations the following way:

> "The relations between organisations and institutions are important for innovations and for the operation of systems of innovation. Organisations are strongly influenced and shaped by institutions; organisations can be said to be 'embedded' in an institutional environment or set of rules, which include the legal system, norms, standards, etc. But institutions are also 'embedded' in organisations. Examples are firm specific practices with regard to bookkeeping or concerning the relations between managers and employees; a lot of institutions develop inside firms. Hence, there is a complicated two-way relationship of mutual embeddedness between institutions and organisations, and this relationship influences innovation processes and thereby also both the performance and change of systems of innovation."[119]

A system of innovation is "…all important economic, social, political, organizational, and other factors that influence the development, diffusion, and use of innovations."[120] Using this line of argument, scholars search for differences in institutions and organisations when explaining variances in growth among countries. Simon Kuznets argued in 1965 that: "...the capacity of the society to devise and accept the institutional changes that may be necessary for these changes in technology and substance of economic production [is indispensable]..."[121] North argues that an institutional framework, which promotes, or at least not hinder technological change and learning is a

[117] D. C. North, "Institutions" in *The Journal of Economic Perspectives*, Vol. 5, No. 1., (1991), p. 97
[118] D. C. North, "New institutional economics and development" (Washington, 1993), p. 6
[119] C. Edquist, "The Systems of Innovation Approach and Innovation Policy: An account of the state of the art" (Aalborg, 2001), p. 6
[120] C. Edquist, "The Systems of Innovation Approach and Innovation Policy: An account of the state of the art" (Aalborg, 2001), p. 2
[121] S. Kuznets, *Economic Growth and structure* (New York, 1965), pp. 111-112

requirement for innovation.[122] The argument, explained by Kristine Bruland, is that:

> "we might expect to find significant inter-country differences in how learning occurs, in terms of institutions and organisations, and this is likely to have important implications for histories of economic growth."[123]

In the next section, I give an outline and discuss some of the literature, which explore institutions and their effects on economic growth.

5.3 Broad theories of institutions and incentives to economic growth

Institutions are often understood in relation to whether they constrain or act as an incentive to economic transactions. In this line of thought, scholars tend to characterise institutions according to their "quality" and classify them as either "good" and "bad" or "efficient" and "inefficient". It is common among scholars to follow North's argument, that there are lower transaction costs when institutions are efficient and the costs are higher when institutions are inefficient, or a hindrance to economic growth.[124] Depending on the setting, institutions enable possibilities or set limits to human behaviour. The economist Avner Greif affirms that some institutions:

> "…provide the foundations of markets by efficiently assigning, protecting, and altering property rights; securing contracts; and motivating specialization and exchange. Good institutions also encourage production by fostering saving, investment in human and physical capital, and development and adoption of useful knowledge. They maintain a sustainable rate of population growth and foster

[122] D. C. North, "Institutions" in *The Journal of Economic Perspectives*, Vol. 5, No. 1., (1991), p. 97

[123] K. Bruland, "Skills, learning and the International Diffusion of Technology: a Perspective on Scandinavian Industrialization", in M. Berg and K. Bruland (eds.), *Technological Revolutions in Europe* (Cheltenham, 1998), p. 161

[124] D. C. North, "Institutions" in *The Journal of Economic Perspectives*, Vol. 5, No. 1., (1991), p. 97

> welfare-enhancing peace; the joint mobilization of resources; and beneficial policies, such as the provision of public goods."[125]

Which types of institutions actually determine growth? Which institutions influence learning and innovation? In general terms, it is argued that democracy, freedom, openness, transparency and honesty reduce corruption and rent-seeking; education and training build human capital and a more productive work force; secure property rights motivate savings and investments, an organised system for imports and exports facilitates trade and economic stability reduce inflation and volatility. In cases in which institutions do not favour development of industries, slow growth or stagnation follow. The table below gives a simple overview of positive and negative economic impacts according to some types of institutions:

Simple overview of impacts of some institutions

Encouraging institutions		**Damaging institutions**	
Institution	***Impacts***	***Institution (or lack of)***	***Impacts***
Secure property rights	Encourage savings and investments	Insecure property rights	Discourage savings and investments
Secure intellectual property rights	Encourage innovation	Insecure intellectual property rights	Discourage innovation
State democracy	Reduces corruption and rent-seeking	Autocracy/absolutism	Increases corruption and rent-seeking
Education system	Provides skilled workers	Lack of education system	Reduces provision of skilled workers
Credit system	Encourages investments	Lack of credit system	Discourages investments
Organised trade system	Promotes trade	Trade barriers	Discourages trade

The state clearly influences economic activities in different ways. Public institutions regulates taxes, property rights, the monetary system and imports and exports through tariffs; finances education and research, infrastructure and other national projects; and often redistribute wealth, controls the utilisation of natural resources through regulations and provision of concessions. However, there is no consensus with regard to how public institutions should relate to the economy. Should the state

[125] A. Greif, *Institutions and the Path to the Modern Economy: Lessons from Medieval Trade* (Cambridge, 2006), p. 4

regulate markets and protect domestic industries through tariffs on imports, or should it not interfere in the economy and assure free trade? Economists have long tradition of discussing "right" market incentives and institutional constraints and disagree on whether free trade or protectionism is better to achieve material prosperity and growth.[126] Throughout the nineteenth century, scholars such as David Ricardo, Richard Cobden and John Bright argued in favour of free trade. Later the politician Alexander Hamilton and the economist Friedrich List claimed that free trade was unfavourable trade policy for a new nation that had not developed internationally competitive industries. Both defended taxes on imported finished goods as part of the fostering of national industries.[127]

Although there are heavy disagreements related to which role the state should play in the economy, the literature suggests that democracies allows for a more efficient utilisation of natural resources and encourage innovation to a larger degree than authoritarian regimes. The argument is that in democratic societies, a broader part of the population has access to property rights, wealth and education and actors are free to organise, operate and trade. Within the resource curse debate, the main argument is that political institutions in successful resource-based countries facilitate incentives to make profits, while less successful ones do not. For instance, in her thesis, Malebogo Bakwena finds that democratic regimes generate more growth from natural resources than non-democratic regimes.[128] The economists Rabah Arezki and Markus Bruckner examine the effect of commodity price booms in different countries from 1997 to 2007, and find that high incomes from natural

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[126] F. Sejersted, *Demokratisk kapitalisme* (Oslo, 1993), p. 46
[127] F. Hodne and O. H. Grytten, *Norsk økonomi i det nittende århundre* (Bergen, 2000), p. 13
[128] M. Bakwena, "Do Better Institutions Alleviate the Resource Curse? Evidence from a Dynamic Panel Approach", PhD Thesis, The University of Queensland Publication (April 2010). See also M. Bakwena, P. Bodman , T. Le and T. Ki, "Avoiding the Resource Curse: The Role of Institutions" University of Queensland, Australia, No 32, (2009) *MRG Discussion Paper Series* from School of Economics, University of Queensland, Australia; A. Cabrales and E. Hauk. "The quality of political institutions and the curse of natural resources", *The Economic Journal*, 121 (February 2009).

resources in democracies increased GDP per capita, while GDP per capita decreased in autocracies.[129] The economists Halvor Mehlum, Karl Moene and Ragnar Torvik look at rule of law, bureaucratic quality, corruption in government, risk of expropriation, and risk of government repudiation of contracts, and distinguish between "grabber friendly" and "producer friendly" institutions. They make broad categories of countries and find that grabber friendly institutions reduce income, while producer friendly institutions increase income.[130] They argue that: "(t)he better the quality of institutions, the less profitable it is to be engaged in grabbing – better institutions means that profits of grabbing at every level of production becomes lower."[131] Much in the same way, Sambit Bhatacharyya and Roland Hodler study corruption and resource wealth, and predict that the rents from natural resources lead to an increase in corruption if the quality of institutions is poor, while this is not the case otherwise.[132]

Political institutions are also used in general models of institutions. Acemoglu and Robinson find that what matters is political institutions, which determine economic institutions.[133] They present broad historical comparisons in which countries are deliberately classified into two main categories. Their model is based on what the authors define as "extractive" and "inclusive" political and economic institutions. Inclusive political institutions are institutions, which "…distribute political power widely in a pluralistic manner and are able to achieve some amount of political centralization so as to establish law and order, the foundation of secure property rights and an inclusive market economy."[134] Inclusive economic institutions are institutions, which "…enforce property rights, create a level playing field, and encourage investments in new technologies and skills…"[135] In such societies,

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[129] R. Arezki, R. and M. Bruckner, "Resource Windfalls and Emerging Market Sovereign Bond Spreads: The Role of Political Institutions", University of Adelaide, School of Economics, *Research Paper* No. 2011-08 (January 2011).
[130] H. Mehlum, K. Moene and R. Torvik, "Cursed by resources or insitutions?" (Oslo, 2005), p. 1
[131] H. Mehlum, K. Moene and R. Torvik, "Cursed by resources or insitutions?" (Oslo, 2005), p. 9
[132] Bhattacharyya, Sambit and Roland Hodler. "Natural Resources, Democracy and Corruption". *OxCarre Research Paper*, No. 2009-20 (2009).
[133] D. Acemoglu and J. A. Robinson, *Why Nations Fail* (London, 2012), p. 43
[134] D. Acemoglu and J. A. Robinson, *Why Nations Fail* (London, 2012), p. 430
[135] D. Acemoglu and J. A. Robinson, *Why Nations Fail* (London, 2012), pp. 429-430

a broad spectrum of the population is included in democratic governing processes and exploitation of people is absent, or reduced. On the other hand, extractive political institutions "…concentrate power in the hands of a few who will then have incentives to maintain and develop extractive economic institutions for their benefit…". Extractive economic institutions are "…structured to extract resources from the many by the few and…[…]… fail to protect property rights to provide incentives for economic activity."[136] In these societies only a small elite have been in control and encouraged exploitation of the rest of the population. Drawing on historical comparisons, they find that throughout history inclusive political systems have provided incentives for people to acquire skills, save capital, invest, work hard and innovate, whereas extractive institutions, in the long run, have not.[137] The problem with Acemoglu and Robsinson's argument is that it is too general and ignore specificities of individual countries. General categorisations of countries do not reveal peculiarities and idiosyncrasies of each society or the complexity of different countries' developments. This weakness appears as Acemoglu and Robinson argue that extractive and inclusive institutions are linked to vicious and virtuous circles and have generally persisted over time. In the case of Latin American countries, they argue that the legacy of extractive institutions developed under the Spanish rule, which sought to extract natural resources from the colonies to empower the coloniser and maintain social inequality, have persisted after Independence up until today.[138] Douglass North explains the path dependence of institutions the following way:

> "[H]istory…[…]… is largely a story of institutional evolution in which the historical performance of economies can only be understood as a part of a sequential story. Institutions provide the incentive structure of an economy; as that structure evolves, it shapes the direction of economic change towards growth, stagnation, or decline."[139]

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[136] D. Acemoglu and J. A. Robinson, *Why Nations Fail* (London, 2012), p. 430
[137] D. Acemoglu and J. A. Robinson, *Why Nations Fail* (London, 2012)
[138] D. Acemoglu et al. "Colonial origin of comparative development" in *The American Economic Review*, vol. 91, No. 5 (2001), pp. 1369-1401
[139] D. C. North, "Institutions" in *The Journal of Economic Perspectives*, vol. 5, No. 1 (1991), p. 97

However, the economic historian Peer Vries refers to new evidence, which suggests that the general theory of colonial legacy should be modified.[140] Studies, which analyse wages and prices more closely over time, find that inequality in Latin American countries was not so different from European countries until *after* independence. Rafael Dobado-Gonzáles, for instance, finds that:

> "…living standards of the Spanish Americans compare favourably with those of other regions of the world, including Europe. As in many parts of the West, a trend towards deterioration of real wages is observed in Spanish America at the end of the period. Our findings suggest that the Great Divergence in living standards between Spanish America and the developed Western countries might have taken place mainly after the Independence.[141]

Institutions may certainly be path dependent and persist over time, but the questions that arise are: how do institutions emerge and develop? What determine institutional change? Do actors choose to change, or are they somehow determined by external factors? To answer these questions, I believe that more in-depth analyses of each country's institutional development would be useful.

Property rights are given a large role in the literature about institutions and economic growth. Secure property rights are regarded as a determinant of economic growth, because organisations will save, invest and innovate only in cases in which the rights to their property are protected. An efficient legal system and laws on how individuals can control, benefit from and transfer land property, are understood as a very important incentive for economic growth. Without secure property rights, the motives to save, invest and innovate will be reduced.[142] Acemoglu and Robinson use property rights

[140] P. Vries, "Does wealth entirely depend on inclusive institutions and pluralist politics?" *Working Papers in Technology Governance and Economic Dynamics* no. 43 (2012), p. 195
[141] R. Dobado-Gonzalez, "Neither so low nor so short: wages and heights in Bourbon Spanish America from an international comparative perspective", *EHES Working papers in Economic History*, No. 14 (2012)
[142] For the importance of secure property rights in a historical perspective see D. North et al., *Violence and social orders* (Cambridge, 2009) and A. Greif, *Institutions and the Path to the Modern Economy: Lessons from*

systems to explain why countries have succeeded or failed. According to them, the Glorious Revolution of 1688 in Britain led to secure and efficient property rights, which had not existed before, and caused the industrial processes known as the Industrial Revolution:

> "The Industrial Revolution…[…]… was unleashed by the institutional changes that flowed from the Glorious Revolution…[…] It was about a fundamental reorganization of economic institutions in favour of innovators and entrepreneurs, based on the emergence of more secure and efficient property rights."[143]

Douglass North and colleagues also underline the importance of the Glorious Revolution for a more secure ownership of land in Britain. Their argument is that the institutional setting no longer supported a systematic hinder to progress.[144] This change in history forms the basis of their theoretical framework, in which they generally divide societies into limited access societies and open access societies. They sustain that the economy grow more in the latter, because violence is controlled through inclusion of the broader part of the population:

> "Limited access orders, covering most developing countries today, solve the problem of violence by granting political elites privileged control over parts of the economy, each getting some share of the rents. Since outbreaks of violence reduce the rents, elite factions have incentives to refrain from violence most of the time. Stability of the rents and thus of the social order requires limiting access and competition. In contrast, open access orders, which dominate the modern developed world, control the problem of violence through open access and competition."[145]

Medieval Trade (Cambridge, 2006). For property rights in natural resource industries see W. W. Culver and C. J. Reinhart "Capital dreams: Chile's Response to Nineteenth-Century World Copper Competition", *Comparative Studies in Society and History*, vol. 31, No. 4 (October 1989) and P. David, G. and Wright, "Increasing Returns and the Genesis of American Resource Abundance", *Oxford Journals*, vol. 6, issue 2 (1997). For intellectual property rights in historical perspective, see B. L. Basberg, "Patenting and Early Industrialization in Norway, 1860-1914. Was there a Linkage?", *Scandinavian Economic History Review*, vol 54, Issue 1 (2006)

[143] D. Acemoglu and J. A. Robinson, *Why Nations Fail* (London, 2012), p. 197

[144] D. North et al., *Violence and social orders* (Cambridge, 2009), p. 78

[145] D. North et al., "Limited Access Orders: Rethinking the Problems of Development and Violence" (2011)

Other scholars find that the idea that secure property rights came with the Glorious Revolution is not all that simple.[146] The economic historian Deidre McCloskey, for example, finds that "(n)umerous societies – in fact all of them, or else they are not societies but wars of all against all – have produced rules of property."[147] The historian Julian Hoppit even suggests that property rights became more insecure after the Glorious Revolution:

> "After 1688, Britain's economic precocity rested less on the enhanced 'security' of property in any general sense of the word, much more on respect for parliament's authority and its willingness to allow property to be alienated, most usually by particular interests claiming to act for the public or wider good. At times this required the reversal of commitments made only a generation earlier, raising doubts about central government's credibility. Taken together, these uncertainties over property rights were sufficient for some to question whether property had a sound theoretical basis at all."[148]

Therefore, when it comes to explaining the Industrial Revolution in Britain, some scholars focus instead on other factors, such as high wages and cheap energy and access to coal and primary products.[149]

Then again, even if it was the case that property rights actually became more secure, their link to innovation is not all that clear. Secure property rights may "…provide incentives for economic activity", but they do not explain innovation and economic growth alone. Kristine Bruland highlights this point. She points out that it is often believed that if a set of conditions are in place, innovation

[146] P. Vries, "Does wealth entirely depend on inclusive institutions and pluralist politics?" *Working Papers in Technology Governance and Economic Dynamics* no. 43 (2012)

[147] D. McCloskey, *Bourgeois Dignity: Why Economics Can't Explain the Modern World*, p. 316

[148] J. Hoppit, "Compulsion, Compensation and Property Rights in Britain, 1688–1833", *Past and Present*, 210 (1) (2011) p. 93

[149] See for instance R. Allen, *The British Industrial Revolution in Global Perspective* (Cambridge, 2009) and K. Pomeranz, *The Great Divergence* (Princeton, 2001)

and growth will automatically follow.[150] Accounting for incentives to innovate, however, does not explain how innovation actually occurs and the actors who were involved.

Property rights are also found important to enable development in natural resource industries. According to David and Wright, clear property rights and tax exemptions on mining were crucial for the successful development of the mining sector in the United States.[151] The authors William Culver and Cornel Reinhard go further and compare the role of mining laws and land rights in the copper industries in the United States and Chile. They find that efficient mining laws in the United States led to the success of this country's copper industry, while inefficient mining laws explain the declining copper industry in Chile:

> "The reformed mining law [of 1874] strengthened surface agricultural land rights against those of entrepreneurs trying to discover, claim, and operate mines. Despite the so-called reforms of 1874, Chilean mining continued to be organized under an eighteenth-century mining policy, while the competition in the United States operated under a modern capitalist code. Chile had a mining policy for state revenue; the United States had one of economic growth…[…] Whatever these policy differences meant to the society in general, they had critical implications for the copper regions involved in a struggle for survival."[152]

In Chile, the mining laws that were ratified in the late nineteenth century blocked industrial development for Chilean entrepreneurs:

> "Both conditions, large-scale production and low-grade ores, required consolidation of mining properties, but this was particularly difficult for Chilean producers as their code mandated the

[150] K. Bruland, *British technology and European industrialization* (Cambridge, 1989), p. 15
[151] P. David, G. and Wright, "Increasing Returns and the Genesis of American Resource Abundance", *Oxford Journals*, vol. 6, issue 2 (1997), pp. 210-218
[152] W. W. Culver and C. J. Reinhart "Capital dreams: Chile's Response to Nineteenth-Century World Copper Competition", *Comparative Studies in Society and History*, vol. 31, No. 4 (October 1989), p. 739

> individual working of each small claim. When consolidation was attempted, it required a team of lawyers to fend off claim challenges. Such insecurity was not conductive to obtaining the capital necessary for large-scale mine development complete with steam machinery and vast smelting capacity."[153]

The National Mining Society in Chile, SONAMI, tried to change these laws. The Society argued that the logic of the law presumed that miners would not mine unless forced to do so. At the same time it allowed anyone to claim an existing mine property, if work at that property was suspended, even for a short time.[154] Culver and Reinhart find that the different regulation systems in the United States and Chile came down to dissimilar approaches by the state governments. In the United States, they argue, the state became the firm ally of entrepreneurs, while in Chile it did not.[155] In Chile:

> "(u)nable to find a political consensus in a Congress dominated by agricultural interests, the copper industry remained stalemated between traditional miners, who conceived of their efforts as a speculative adventure, and modem mining engineers wanting to transform copper into a business. This split in the copper industry itself led to a political failure that echos down through Chilean history to the present."[156]

In the United States, on the other hand, the state favoured a prosperous copper industry:

> "As the 1880s ended New York-based copper corporations, working deposits in Montana and Arizona, along with their Boston competitors who were working the Michigan deposits, constituted a dominating influence on world copper markets. This dominance, grounded in supportive legislation at

[153] W. W. Culver and C. J. Reinhart "Capital dreams: Chile's Response to Nineteenth-Century World Copper Competition", *Comparative Studies in Society and History*, vol. 31, No. 4 (October 1989), p. 741
[154] W. W. Culver and C. J. Reinhart "Capital dreams: Chile's Response to Nineteenth-Century World Copper Competition", *Comparative Studies in Society and History*, vol. 31, No. 4 (October 1989), p. 741
[155] W. W. Culver and C. J. Reinhart "Capital dreams: Chile's Response to Nineteenth-Century World Copper Competition", *Comparative Studies in Society and History*, vol. 31, No. 4 (October 1989), p. 723
[156] W. W. Culver and C. J. Reinhart "Capital dreams: Chile's Response to Nineteenth-Century World Copper Competition", *Comparative Studies in Society and History*, vol. 31, No. 4 (October 1989), p. 724

> the regional and national levels, had its strength in promotion of access to the financing necessary to change copper mining from a family-run, small-scale, cottage speculation to a highly developed, large-scale, mechanized business…[…] Important for the growth of the copper industry in the United States were railroad expansion, joint-stock corporations, and limited liability; but the copper tariffs and a modem mining code based on private property stand out as absolutely critical. In short, copper in the United States was able to become an aggressive, efficient, and competitive industry because the state provided the necessary legal, physical, and economic infrastructure."[157]

The different mining laws probably meant that investors had more incentives to invest in mining in the United States than in Chile. The Chilean laws were more inconvenient and resulted in higher transaction costs than in the United States. Yet, it should be stressed that productions at some of the largest copper mines in Chile, and in the world, began under these inefficient laws. In the early twentieth century, large North American investments initiated large-scale and technologically advanced copper mining in the northern and central part of the country, which involved immense land properties. This goes against the argument that encouraging mining laws and property rights were a determinant for investments and innovation. The mining laws in Chile may have provided few incentives to invest, but these large investments indicate that it was still possible to begin large-scale mining projects in the country. Why, and how, did North American companies make investments in large properties and mines under these discouraging institutional conditions, while Chilean entrepreneurs did not? Were the laws really so inefficient? Incentives or motivations to innovate do not tell us why some specific actors and companies invest and innovate, while others do not, or fail to do so.

What about intellectual property rights, do they determine innovation? Intellectual property rights

[157] W. W. Culver and C. J. Reinhart "Capital dreams: Chile's Response to Nineteenth-Century World Copper Competition", *Comparative Studies in Society and History*, vol. 31, No. 4 (October 1989), p. 738

are argued to encourage innovation by granting inventors monopoly over their inventions.[158] The economic historian Bjørn Basberg examines the patent system in Norway between 1860 and 1914 and finds that an increase in patents coincided with industrialisation of the country. The patent system motivated and stimulated the industrialisation process, according to him.[159] The traditional argument is that technological change depend on incentives for makers to benefit from their inventions. Yet, scholars question whether such rights determine innovation. Joel Mokyr, for example, give the patent system less priority in his explanation for the Industrial Revolution. He finds that other institutions were equally, or more important, for the continuous technological change. It is true that Britain established a patent system in 1624 and the number of patents started rising in the mid-1750s, around the time the Industrial Revolution began.[160] Yet, during the eighteenth century, Mokyr argues, there was a growing belief that monopolies were bad and knowledge should be free. Sometimes, patents were even used strategically to block research in a specific direction, which in turn slowed down innovation. A number of inventors of the Industrial Revolution did not use the patent system at all.[161] Much in the same way, Bruland and Smith find that in the Nordic countries other institutions explain innovation to a larger degree than patent systems.[162] Recent studies also downgrade the importance of intellectual property rights. A study from 2012 actually suggests that weak intellectual property rights has stimulated to research and development (R & D) activities and encouraged knowledge spillovers. [163] The point to be made here is that patent systems may motivate inventors to make new machines and techniques, but they do not say anything about the process

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[158] R. Falvey and N. Foster, "The Role of Intellectual Property Rights in Technology Transfer and Economic Growth: Theory and Evidence" (Vienna, 2006), p. vii

[159] B. L. Basberg, "Patenting and Early Industrialization in Norway, 1860-1914. Was there a Linkage?", *Scandinavian Economic History Review*, vol 54, Issue 1 (2006), p. 14

[160] J. Mokyr, "Intellectual property rights, the Industrial Revolution, and the Beginnings of Modern Economic Growth", *American Economic Review,* vol. 99, issue 2 (2009), p. 349

[161] J. Mokyr, "Intellectual property rights, the Industrial Revolution, and the Beginnings of Modern Economic Growth", *American Economic Review,* vol. 99, issue 2 (2009), p. 351

[162] K. Bruland and K. Smith, "Knowledge Flows and Catching-Up Industrialization in the Nordic Countries The Roles of Patent Systems", in H. Odagiri et al. *Intellectual property rights, development and catch-up an International comparative study* (Oxford, 2010), pp 63-94

[163] A. Breitwieser and N. Foster, "Intellectual property rights, innovation and technology transfer: a survey", (Vienna, 2012), p. 2

behind them. The detection of incentives for innovation do not give us information about how technological capabilities developed.

Despite the little focus on innovation processes, innovation is generally regarded as the source of modern economic growth. Acemoglu and Robinson, for instance, affirm that the reason economic growth cannot be sustained under extractive institutions is because sustained economic growth requires changes, which the established ruling elite would oppose. They argue that "…sustained economic growth requires innovation, and innovation cannot be decoupled from creative destruction, which replaces the old with the new in the economic realm..."[164] Much in the same way, North argues that open access societies are developed because they support innovation through competition:

> "Open access societies…[…]… are competitive. Competition dominates the way in which both political and economic markets work. The economy works by innovative creation; there is competition in markets, and those players who create more efficient, productive methods stand to gain and replace those who are less efficient. Innovation and creativity are the heart of what makes markets work and what has made the modern world so dynamic and such an extraordinary place."[165]

He finds that central to economic growth is the ability to support complex, sophisticated organisations. He classifies developed societies according to their open access to organisations and support of organisational complexity. Developed societies are, according to him:

> "…filled with a rich variety of complicated and sophisticated organizations capable of producing goods and services, carrying out research and development, and coordinating individual behaviour on a scale

[164] D. Acemoglu and J. A. Robinson, *Why Nations Fail* (London, 2012), p. 430
[165] D. North, "Violence and social orders", The annual proceedings of the Wealth and Well-Being of Nations (2009), p. 22

never before seen in human history."[166]

If it is the case that complex organisations form successful economies, then the specific institutions, which directly influence and support the development of such organisations, should be explored in detail. The problem with these broad theories is that they provide little information about through which channels knowledge is developed and innovation is generated and do not detect the direct link between specific institutions and innovation processes. The underlying problem is that there is little information about which factors actually determine innovation and how it functions. We still have very little empirical information about knowledge accumulation and the processes behind technological change, which characterise successful industries and economies, and the underlying reasons for the less innovative and unsuccessful ones.

An approach, which in fact focus on innovation, and the institutions involved, is the National Innovation System approach. With this method, scholars conceptualise and analyse innovation within a given institutional and organisational framework.[167] Similarly, Regional Innovation System and Sectoral Innovation System are used to examine the network and interactions only within a smaller framework. An essential argument is that the institutional and organisational framework have varied considerably between countries. Economic policy, the role of the state and investments in R & D have differed considerably between countries. This, in turn, have resulted in different kinds of systems. For instance, Denmark and Sweden, two countries, which today are considered developed, have varied considerably with regard to these subjects.[168] The industrial production in the United States is much more specialised in high-tech products than in European countries.[169] According to Richard Nelson, R

[166] D. North, "A conceptual framework for interpreting recorded human history", George Mason University, *working paper* 75 (Cambridge, 2006), pp. 3-4
[167] C. Edquist, "The Systems of Innovation Approach and Innovation Policy: An account of the state of the art" (Aalborg, 2001), p. 2
[168] See R. R. Nelson, R. R. *National Innovation Systems A Comparative Analysis* (New York, 1993)
[169] C. Edquist, "The Systems of Innovation Approach and Innovation Policy: An account of the state of the art" (Aalborg, 2001), p. 5

& D facilities, staffed by university-trained scientists and engineers attached to business firms, universities, or government agencies, have today a central role in technological advance proceeds, especially in fields such as electrical equipment and systems, chemical products and processes, and aviation.[170] This has also been the case historically. Nelson explains that:

> "(c)hemistry became a laboratory discipline in which research could be carried out by trained professionals making use of well-understood methods and experimental procedures. In the 1860s Kekule managed to disentangle the molecular structure of benzene, a breakthrough of major significance for throusands of aromatics, including dyes and drugs, but ultimately, for all organic chemistry."[171]

Although this approach focuses on processes of innovation, it has been criticised for giving to too much emphasis on R & D in a national perspective. This makes the models too simple.[172] Formal scientific institutions and company research laboratories are not the only places where learning and innovation are formed and do not capture the complexity of innovation. Natural resource industries, for example, are perhaps based less on scientific research in terms of R & D and more on learning by doing.[173] The approach aims to analyse institutional and organisational frameworks within countries, but fails to capture the broader set of learning and knowledge institutions.

A type of institution, which is hardly included in National Innovation System models, is education and individual learning. Although there is a broad consensus that schooling is important to generate innovation, it is normally left out of the System of Innovation approach.[174] Still, there is a wide

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[170] R. R. Nelson, R. R. *National Innovation Systems A Comparative Analysis* (New York, 1993), pp. 5-6
[171] R. R. Nelson, R. R. *National Innovation Systems A Comparative Analysis* (New York, 1993), p. 6
[172] C. Edquist, "The Systems of Innovation Approach and Innovation Policy: An account of the state of the art" (Aalborg, 2001), p. 3
[173] H. Hirsch-Kreinsen et al., "Low-Tech Industries and the Knowledge Economy: State of the Art and Research Challenges", *PILOT Policy and Innovation in Low-Tech, STEP – Centre for Innovation Research* (Oslo, 2003), p. 9
[174] C. Edquist, "The Systems of Innovation Approach and Innovation Policy: An account of the state of the art" (Aalborg, 2001), p. 16

agreement that basic education encourages learning and an overall skilled work force. A number of studies suggest that education is crucial for industrial development and is used extensively in explanations for why some countries have developed and become rich and others have not. Gary Becker sees schooling, along with on-the-job training and so on, as an investment in human capital and understands education as a factor, which directly increases productivity. He makes a division between "specific" and "general" human capital. Specific human capital refers to skills that are useful only to a single firm, whereas general human capital can be useful across industries, such as literacy and numeracy, but also for example knowledge about mechanics or chemistry.[175] From a historical perspective, different kinds of training have been essential to industrial performance:

> "At least from the time of the Industrial Revolution, technologies (and their underlying knowledge bases) have become complex enough to require either high standards of literacy and numeracy or more specific training in relevant disciplines (such as basic sciences or technological disciplines such as electrical or chemical engineering) if they are to be operated successfully. From this perspective, education is seen as a key input to the advanced economy. More specifically, education is the investment process through which "human capital" is created, and this is increasingly seen as the central input to growth."[176]

Technical education is argued to play a significant part in technological change. During the nineteenth century, technical educational institutions were gradually established with the aim of providing technicians, engineers and other specialists for industries. There was an increasing conviction that technical education led to industrial development. Peter Lundgreen finds that:

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[175] G. S. Becker, *Human Capital* (New York, 1975), pp. 19-37

[176] K. Bruland, "Education" in *Oxford encyclopedia of economic history*, *vol. II* (Oxford, 2003), pp. 161-162

> "(d)uring the late nineteenth century a general belief in education as a key to international competition joined forces with a thorough transformation of the economy in providing new job markets for engineers graduating from colleges and universities."[177]

In particular, the civil engineer Göran Ahlström stresses that: "engineers and technicians are seen as particularly important for industrial growth because they play a crucial role in applying science and inventions in productions."[178] More broadly, Ahlström underlines that:

> "(a) thorough theoretical and practical technical education is necessary and has been so at least from those nineteenth-century years when the science-based industries generally assumed a leading position in the industrial sector of the economies."[179]

Especially in Germany, technical education is used as one of the primary causes to why this country took to the leading industrial role in science-based and large-scale industries from the late nineteenth century. A number of comparative studies suggest that one of the main reasons why Germany developed significantly from the late nineteenth century and caught up with Britain, during what is called the "second industrial revolution" was a highly developed technical education system.[180] Although many other elements are pointed out as causes for the country's industrial lead Roderick and Stephens stress that:

> "… at the beginning of the nineteenth century Germany embarked on a policy of creating a highly organised, technically trained society based on a State-aided national system of education. From an early date Germany developed a cohesive system of schools, universities and technical high schools

[177] P. Lundgreen, "Engineering Education in Europe and the U.S.A, 1750-1930: The Rise to Dominance of School Culture and the Engineering Professions", *Annals of Science*, vol. 47, Issue 1 (1990), pp. 33-75

[178] G. Ahlström, "Technical Competence and Industrial Growth", *Lund Papers in Economic History*, No. 14, (1992), p. 1

[179] G. Ahlström, *Engineers and Industrial Growth* (London & Canberra, 1982), p. 94

[180] G. Ahlström, *Engineers and Industrial Growth* (London & Canberra, 1982); R. Fox, A. Guagnini, *Education, technology, and industrial performance in Europe, 1850-1939* (Cambridge, 1993)

> which services industry and provided the manpower; and training at all levels, from apprentice to research-scientist, was generally superior. Germany's later industrial success, therefore, was seen as a reaping of the reward for her earlier investment in science and technical education."[181]

From the late 1870s and early 1880s, high-voltage electrical technology enabled the building of machines, lightening and transportation, as well as to the production, storage and distribution of current via central power stations. It is found that this technology was created because of close linkages between industry and scientific institutions in Germany. Both big firms and the "Technische Hochschulen" were involved in this development.[182] Much in the same way the author Charles Day concurs that:

> "… countries where governing and business elites who control the state have concertedly instituted educational and training policies as part of a broader plan for technological and industrial development (Germany, Japan, and more recently Singapore) and who have co-opted labour in one way or another have had considerable success in achieving growth, despite their diverse approaches to development."[183]

In the same line of argument, England's relative economic lag from the late nineteenth century is explained by the country's less developed education system and the scarcity of technically skilled technicians and engineers. The author Michael Sanderson examines the British educational system and finds that:

> "…near the heart of Britain's industrial deficiencies lies a chain of problems which starts with the paucity of pupils inclined to science, technology and industry produced by the schools. It ends with the

[181] G. W. Roderick and M. D. Stephens, *Scientific and Technical Education in Nineteenth-Century England* (Newton Aboot, 1972), p. 8
[182] P. Lundgreen, "Engineering Education in Europe and the U.S.A, 1750-1930: The Rise to Dominance of School Culture and the Engineering Professions", *Annals of Science*, vol. 47, Issue 1 (1990), p. 58
[183] C. Day, *Schools and Work Technical and Vocational Education in France since the Third Republic* (Montreal, 2001), p. 4

> under-production of skilled and practically capable labour at different levels. Had the well-springs of the technical schools been retained, things might have been different."[184]

Specific types of education is also understood as important for development in natural resource industries. The main argument is that a high-quality education and infrastructure system foster natural resource wealth. For instance, Nicolai Petrovsky finds that education, among other factors, may affect natural resource development positively and reduce potential negative economic effects.[185] Mike Smart finds a finds a causal chain from diversity of natural resources and educational attainment to democratisation and from democratisation to per capita GDP.[186] In their historical analysis of the mining sector in the United States, David and Wright find that an important factor, which explains its success, is that the United States had more than twenty schools which granted degrees in mining during 1860-1890 and in 1893 the United States "…had more mining students than any country in Europe, except Germany."[187] Recent studies come to similar conclusions. Brooks and Kurtz argue that human capital resources condition development in oil rich countries, because they "…make possible the management of resources in ways that encourage the absorption of technology and development of new economic sectors." When human capital is absent, however, the "resource curse" is more likely to present itself.[188] Ronald Mendoza, Harold McArthur and Anne Ong Lopez argue that "… notably human capital – appear to have transformed the natural resource curse into a boon for development."[189] Gøril Bjerkhol Havro and Javier Santiso draw on experiences from Chile and Norway and argue both countries have benefited from natural resources in recent years. They

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[184] M. Sanderson, *The Missing Stratum Technical School Education in England 1900-1990s* (London, 1994), p. 145

[185] N. Petrovsky, "Does Natural Resource Wealth Spoil and Corrupt Governments? A New Test of the Resource Curse Thesis" (August 2004).

[186] M. Smart, "Natural Resource Diversity and Democracy", *The Economic Society of Australia*, vol. 28 (December 2009), pp. 366-375

[187] P. David, G. and Wright, "Increasing Returns and the Genesis of American Resource Abundance", *Oxford Journals*, vol. 6, issue 2 (1997), p. 231

[188] S. M. Brooks and M. Kurtz, "Conditioning the "Resource Curse": Globalization, Human Capital, and Growth in Oil-Rich Nations". *Comparative Political Studies* (March 2011)

[189] R. U. Mendoza, H. J. McArthor and A. O. Lopez, "Devil's Excrement or Manna from Heaven? A Survey of Strategies in Natural Resource Wealth Management". (April 2012), p. 8

suggest that natural resource wealth is dependent on macro-economic policy, but also capable civil servants, a developed business community and human capital.[190]

Also specific studies about multinationals suggest that a proper education system is required for host countries to benefit from such companies, or reduce negative effects. Establishing a certain level of education is part of an institutional process on behalf of the host country actively to facilitate an environment for knowledge transfers and enable positive impacts from multinational companies. It is argued, in particular, that high illiteracy rates and low technical educational levels have restricted knowledge transfers and employment of workers and managers at multinationals.[191] E. Borensztein, J. De Gregorio and J-W. Lee measure human capital level in countries based on average years of male secondary schooling and find that foreign direct investment is an important vehicle for technology transfer in the countries with "…a minimum threshold of human capital."[192]

Despite much research on basic and technical education and industrial development, there is not much evidence of a direct causal link to innovation. Analyses about literacy often show how schooling and high literacy correlate with high economic growth, but do not demonstrate how these skills were used in practice. The economist Richard Easterlin, for example, examines formal education in a long-term perspective. He shows that there is a correlation between a high education level and strong economic growth and argues that much of the reason why technology has not been adopted in many countries is a lack of formal schooling. He explains how the establishment of a good education system subsequently led to industrial development:

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[190] G. B. Havro, and J. Santiso, "Rescuing the Resource Rich: How Can International Development Policy Help Tame the Resource Curse?" *Working Paper Series*, (June 2010)
[191] G. Jones, *Multinationals and Global Capitalism* (Oxford, 2005), p. 262
[192] E. Borensztein, J. De Gregorio and J-W. Lee, "How does foreign direct investment affect economic growth?" *Journal of International Economics* 45 (1998), pp. 115-135

> "Within Europe the most advanced nations educationally, those in northern and western Europe were the ones that developed first. Not until the end of the nineteenth century did most of southern and eastern Europe start to approach educational levels comparable to the initial levels in the north and west, and it was around this time that these nations began to develop. With regard to the overseas descendants of Europe the picture is the same: the leader in schooling is the leader in development, the United States. Within Latin America, Argentina, the most developed nation there today, took the lead in educational growth in the last half of the nineteenth century. In Asia, Japan's nineteenth-century educational attainment is clearly distinctive, and this was true even before the Meiji Restoration, though important reforms were introduced in 1872."[193]

One of his main points is that: "…the more schooling of appropriate content that a nation had, the easier it was to master the new technological knowledge becoming available."[194] Using much of the same line of argument, the economic historian Lars Sandberg emphasises the importance of human capital in Swedish industrial and economic growth before World War I.[195] In another paper Sandberg shows that there is a correlation between countries with high literacy in 1850 and the ones with high income per capita in 1970, even if they were poor in 1850. In spite of the many years between growth of literacy and economic growth, his argument is that a literate population did not necessarily lead to immediate economic growth, but gradually changed and prepared people for a capitalist way of thinking.[196] A correlation between schooling, literacy and economic growth does not link education directly to economic growth and does not explain why, or how, this type of learning was important for innovation.

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[193] R. A. Easterlin, "Why Isn't the Whole World Developed?", *Journal of Economic History*, Vol. 41, Issue 1 (1981), p. 7

[194] R. A. Easterlin, "Why Isn't the Whole World Developed?", *Journal of Economic History*, Vol. 41, Issue 1 (1981), p. 6

[195] P. Sandberg, "The Case of the Impoverished Sophisticate: Human Capital and Swedish Economic Growth Before World War 1", *Journal of Economic History*, vol. 49, No. 1 (1979), pp. 225-241

[196] P. Sandberg, "Ignorance, Poverty and Economic Backwardness in the Early Stages of European Industrialization: Variations on Alexander Gerschenkron's Grand Theme", *Journal of economic history*, vol. 11 (1982)

Some scholars consider the effect general schooling and literacy have on economic growth to be an exaggeration. Joel Mokyr, for instance, does not emphasise literacy in his explanation of the causes of the British Industrial Revolution:

> "Overall literacy rates can hardly have mattered as much as they are believed to in modern economies, given Britain's backwardness in that dimension. The quality of the average worker may have mattered much less for the generation and adoption of new and more productive techniques than the quality of the skilled artisans and mechanics…"[197]

At the eve of Britain's industrialisation, the adult literacy was between fifty to seventy per cent, which was lower than other European countries.[198] Scandinavia, for example, represented countries where the population became literate early, and before Britain, but they industrialised long after.[199] The economic historian Kevin O'Rourke and economist Jeffrey Williamsen also downgrade schooling in their analysis of Sweden. According to them it was only "modestly important" to the catching-up of Sweden and Scandinavia between 1870 and WWI. They conclude that: "…while schooling certainly helped make the late nineteenth century Scandinavian catch up possible, it was not the central carrier implied by so much of the literature."[200]

Much in the same way as basic education, the link between technical education and economic growth is still subjected to debate. Although it is assumed that technical education is an important requirement for economic growth, the studies are suggestive, and there are few, if any, clear connections between technical education and industrial performance. Robert R. Locke sums up previous studies on education and industrial performance the following way:

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197 J. Mokyr, "Knowledge, Enlightenment, and the Industrial Revolution: Reflections on *Gifts of Athena", History of Science*, vol. 45, part 2, (June 2006), p. 1
198 C. M. Cipolla, *Literacy and Development in the West* (Baltimore, 1969), p. 114
199 J. Mokyr, *Gifts of Athena*, (Princeton and Oxford, 2005), p. 292
200 K. O'Rourke and J. Williamsen, "Education, Globalization and Catch-Up: Scandinavia in the Swedish Mirror", *Scandinavian Economic History Review*, XLIII, 3 (1995), p. 309

> "(A) closer inquiry has shown that this imposing body of knowledge, if of especial value to the study of technical education, has not treated higher education and entrepreneurial performance adequately. Actually it has, with few exceptions, not considered the subject at all. Scholars have, for the most part, discussed higher education, even in the technical and commercial sciences, comprehensively, that is, they have regarded it as part of the history of engineering or applied science or as a particular aspect of the general social and institutional transformation of a country. Rarely, moreover, have they engaged in comparative histories, for the literature is overwhelmingly nationally oriented. As for the two variables, education and entrepreneurial performance, education historians have just assumed that a relationship existed between them and then proceeded to demonstrate how both French and British higher education were deficient."[201]

As Locke suggests, conclusions of technical education and industrial development are based on the assumptions that the more skilled workers, the better. The argument is that rich and developed countries have a high number of engineers, technicians or architects, while poor and underdeveloped countries have fewer. Ahlström, for example, establishes that there are "…positive correlations between industrial output and number of scientists and engineers employed in industry – on the presumption than an increase in the number of these personal categories will increase industrial output."[202]

Much of the research is focused on the supply and demand of education from a quantitative point of view. Goldin and Katz use the increase of professional workers in the United States as an explanation for why this country became the richest country in the world. They provide an analysis of the general educational system of this country in a historical perspective and conclude that a larger part of the population, compared to European countries, acquired primary and secondary schooling. Both

[201] R. R. Locke*, The End of the Practical Man* (London, 1984), p. 2
[202] G. Ahlström, *Engineers and Industrial Growth* (London & Canberra, 1982), p. 19

primary and secondary education increased in the nineteenth century and the general population acquired secondary level education by 1900.[203] The supply of high school graduates relative to those without high school degrees increased by sixteen per cent from 1890 to 1910, by forty per cent from 1910 to 1920 and by fifty per cent from 1920 to 1930.[204] Similarly, analyses of technical education and industrial performance usually base their analysis on the number of universities and schools providing engineering and technical studies. Sometimes the number of students or graduates are compared to total workers or population. Göran Ahlström does this for four European countries:

> "Although the number of graduates grew substantially in Sweden during the nineteenth century, the number of qualified engineers in society as a proportion of the economically active male population was lower than in Germany. If we take only engineers trained in the technical university, it was not until the WWI that Sweden attained the figure of 2.0 per thousand – a figure that Germany achieved as far back as the early 1880s. When engineers from technical colleges and comparable schools are included, the difference between Germany and Sweden becomes even more marked."[205]

Starting with the common supposition that Germany took the lead in industrial growth from the late nineteenth century, G. W. Roderick and M. D. Stephens determine that in 1900 the number of scientists and technicians was around five times as more in Germany compared to England.[206] In the case of Australia, a drastic increase in the number of engineers is used to explain how the mining sector in grew in the beginning of the first part of the twentieth century. Ferranto and colleagues argue that the country "…lagged behind the United States until after 1920 – with 47 engineers per 100 000 people to 128 per 100 000 – but would reach 163 by 1955."[207] The percentage of engineers

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[203] C. Goldin and L. Katz, *The Race between Education and Technology* (the United States, 2008)
[204] C. Goldin and L. Katz, "The decline of non-competing groups: changes in the premium to education, 1890 to 1940", *NBER Working Paper* No. 5202 (1995)
[205] G. Ahlstrøm, "Technical education, engineering, and industrial growth: Sweden in the nineteenth and early twentieth centuries" in R. Fox, A. Guagnini, *Education, technology, and industrial performance in Europe, 1850-1939* (Cambridge, 1993), p. 122
[206] G. W. Roderick and M. D. Stephens, *Scientific and Technical Education in Nineteenth-Century England*, (Newton Aboot, 1972), p. 16
[207] D. De Ferranti et al. *From Natural Resources to the Knowledge Economy* (Washington D. C., 2002), pp. 58-59

and architects per worker is argued to explain differences in growth in general comparative studies. The economist W. F. Maloney affirms that:

> "…Australia had at least 5 times the numbers of Chile or Colombia in 1920 and…[…]… by 1926, Australia had 27 times more graduates of technical schools per capita than Argentina, perhaps the most educated country in Latin America. Sweden had almost 10 times the density of engineers as Colombia or Chile and…[…]…, in this period Scandinavia was exporting engineers innovating at the frontier. The persistence of this deficit, measured as the percentage of architects and engineers per worker continued into the 1960s: Sweden (5.03), Finland (2.52), and Denmark (1.03) had the highest densities, compared to the lows of Argentina (0.55), Chile (0.7), Educator (0.18), and Uruguay (0.42)."[208]

Moreover, Chile had six engineers per 100 000 workers compared to eighty-for in Sweden in 1890 and 128 in the United States in 1920.[209] The functions, use and importance of professionals, however, are not described in such analyses. The numbers of engineers or architects do not give us any information about how and why these professionals were important.

Some studies go further and use the fact that formally trained workers were used in leading positions to suggest that industries were innovative and developed. In his explanation for Germany's leading position, Ahlström concludes that Germany held a proportionally larger number of engineers in leading positions than France and England:

[208] W. F. Maloney, "Missed Opportunities: Innovation and Resource-Based Growth in Latin America", *World Bank Policy Research Working Paper* 2935 (2002), p. 10
[209] W. F. Maloney, "Missed Opportunities: Innovation and Resource-Based Growth in Latin America", *World Bank Policy Research Working Paper* 2935 (2002), 37

> "(A) dominating proposition of the German industry, irrespectively of company size, possessed technically qualified engineers in management and leading positions towards the end of the nineteenth century and during the early twentieth century."[210]

In their explanation for why the mining sector in the United States became more successful than any other country, David and Wright point out that the Mining and Scientific Press wrote in 1915 that "nearly every successful mining operation, old or new, is today in the hands of experienced technically trained men."[211] Furthermore, "…mining engineers increasingly assumed managerial and executive roles within large firms."[212] Clark Spencer finds that six out of seven mining engineers in the United States in 1921 were college-trained.[213] An increasing number of formally trained engineers in leading positions suggest that their knowledge and experience were appreciated, and perhaps necessary, for the industry. However, the specific role that professional workers played in company management, decision-making and use of technology is not explained by simply saying that they acquired leading positions. The economist Michael Spence even suggests that there is no apparent relations between formal education and increased productivity. In Spence's job-market signalling model the employer assumes that there is a correlation between the qualifications of the employee and having greater skills.[214] Education is one way for the job applicant to give "signals" to the employer of his or hers abilities. In this approach, education is understood as part of a selection process of capable workers into suitable positions and certain abilities indicate that the person is appropriate for a work or position:

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[210] G. Ahlström, *Engineers and Industrial Growth* (London & Canberra, 1982), p. 98
[211] P. David, G. and Wright, "Increasing Returns and the Genesis of American Resource Abundance", *Oxford Journals*, vol. 6, issue 2 (1997), 231
[212] P. David, G. and Wright, "Increasing Returns and the Genesis of American Resource Abundance", *Oxford Journals*, vol. 6, issue 2 (1997), p. 231
[213] C. Spence, *Mining engineers & the American West* (New Haven and London, 1970), p. 18
[214] M. Spence, "Job Market Signaling", *The Quarterly Journal of Economics*, vol. 87, No 3 (1973), pp. 335-374

> "It is not an indicator that the individual thus educated has acquired cognitive knowledge that will raise his or her productivity when employed, but, rather, signals that the person is likely to be readily, hence less expensively, trainable."[215]

Others argue that education contributes primarily to critical thinking. In a similar line of argument, Peter Lundgren argues that the need for higher education has been exaggerated:

> "(O)nce the academic training of experts or professionals has been established, it gains momentum and serves the interests of the professions for their own sake. Any study of the relations between education and occupations, therefore, should pay due heed to two methodological warnings: never confuse qualifications in the sense of job requirements with the educational credentials granting entry into the occupation; and never believe in educators if they argue in favour of better (higher) education as being necessary for appropriate qualifications."[216]

Still, I would assume that at least some of the knowledge learned at school could be used directly in a work situation. In an innovation process where the introduction of new complex machines and techniques are introduced, it seems evident that skills in reading (at least), writing and numeracy were necessary in order to for instance understand technical manuals, user's guides and instructions. Yet, the different findings in the literature suggest that the specific role of education and engineers in industrial development should be analysed in more detail. According to Locke, cataloguing number of students, rates of growth etc. accounts for only part of the story:

> "To determine comparative educational effectiveness, from the entrepreneurial viewpoint, one needs (aside from data on numbers, size of student body, rates of growth of schools, and background of

[215] M. Abramovitz and P. David, "Technological change and the rise of intangible investments: the US economy's growth-path in the twentieth century", in OECD, *Employment and Growth in the Knowledge-based Economy* (Paris, 1996), p. 52

[216] P. Lundgreen "Engineering Education in Europe and the U.S.A, 1750-1930: The Rise to Dominance of School Culture and the Engineering Professions", *Annals of Science*, 47, 1990, p. 34

> students) information about the conditions of entrepreneurship within an economy and about the extent to which the educational institutions were able to satisfy these conditions. It cannot be assumed…[…]…that schools in countries did not differ significantly in curricula, instruction, and in the way they were associated with business and industry even if each country had the same number of schools and they were of equal size. An investigation into the curricula of competing national systems of higher education …[…]… is crucial for an analysis of higher education and entrepreneurial performance."[217]

The argument of Wolfgang König is relevant here:

> "So long as we lack research on the careers of the technical intelligentsia or on the selection processes and recruitment of industrial engineers, the question regarding the relations between technical education and economic performance cannot be answered properly".[218]

To obtain a complete picture of the role of engineers and technicians in innovation processes, empirical analyses of their formal learning through education, careers and practical learning through travelling and work would be required.

5.4 An empirical approach to learning and innovation

Analyses of innovation are challenging because there is no general prototype for how technological changes actually occur. One of the problems is that innovations happen randomly and without any specific order. They are regarded as processes rather than isolated events. Introducing new and more efficient working methods, or improving a product, are subject to a number of different experiments and testing and vary from case to case. Kline and Rosenberg state that: "…the processes and systems used are complex and variable; that there is no single correct formula, but rather a complex of

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[217] R. R. Locke*, The End of the Practical Man* (London, 1984), p. 5

[218] W. Kőnig,"Technical education and industrial performance in Germany: a triumph of heterogeneity", *Education, Technology and Industrial Performance in Europe, 1850-1939,* in R. Fox and A. Guagnini (eds) (Cambridge, 1993), p. 81

different ideas and solutions that are needed for effective innovation."[219] They stress that:

> "(i)nnovation is complex, uncertain, somewhat disorderly, and subject to changes of many sorts. Innovation is also difficult to measure and demands close coordination of adequate technical knowledge and excellent market judgment in order to satisfy economic, technological, and other types of constraints – all simultaneously. The process of innovation must be viewed as a series of changes in a complete system not only of hardware, but also market environment, production facilities and knowledge, and the social contexts of the innovation organization."[220]

One of the challenge in innovation studies is to identify how knowledge accumulation occurs and how learning is transformed into technological innovation. Simple modifications, such as new ways of using a device, are often harder to detect than the adoption of a new machine. They are, nevertheless, important. Bruland and Mowery confirm that "radical" innovations:

> "…typically assume their economic importance as a result of numerous, individually modest but cumulatively significant, "incremental" improvements after the introduction of a new product. The importance of incremental innovation also underscores the complex relationship between the appearance of a new technology and its adoption."[221]

Bruland shows how complex innovation processes can be in her study of the textile industry in Norway in the mid-nineteenth century. The development of this industry involved multifaceted technology transfers from Britain in collaboration with local workers. Not only equipment and machinery were imported to enable successful operations, but also knowledge, expertise and information were transferred through travels abroad used in operation with the help from foreign

[219] D. Kline and N. Rosenberg, "An Overview of Innovation", in R. Landau and N. Rosenberg (eds.) *The Positive Sum Strategy: Harnessing Technology for Economic Growth* (Washington, 1986), p. 279
[220] D. Kline and N. Rosenberg, "An Overview of Innovation", in R. Landau and N. Rosenberg (eds.) *The Positive Sum Strategy: Harnessing Technology for Economic Growth* (Washington, 1986), p. 275
[221] K. Bruland and D. C. Mowery, "Technology and the spread of capitalism", in *Cambridge History of Capitalism, vol. II*, L. O'Neil and J. G. Williamson (Cambridge, 2014), p. 84

skilled workers and labour.[222]

How, then, can knowledge and innovation be examined and understood? The complex, random and unsystematic processes that characterise learning and innovation makes standardisation and general models problematic. To understand technological changes, we should instead analyse empirically how these practices in fact occurred. Charles Edquist highlights this in a review of innovation studies. He finds that: "…the best way of doing this is by actually using the approach in empirical (and comparative) research."[223] In the same line of argument, in an analysis of the Nordic countries in the eighteenth and nineteenth centuries, Bruland and Smith base their choice of approach on the argument that:

> "(i)f economic growth essentially reflects changing technological capability, and capability reflects learning and knowledge accumulation, then the key questions about Nordic growth concern how knowledge was acquired, diffused, and used."[224]

Fundamental for this approach, is the belief that formal and informal knowledge institutions and organisations were connected and actively collaborated with each other to transfer, use, modify and diffuse knowledge.[225] Joel Mokyr argues that what was crucial to the Industrial Revolution was an "Industrial Enlightenment", which involved an expansion of knowledge and the circulation of it.

[222] K. Bruland, *British technology and European industrialization* (Cambridge, 1989)
[223] C. Edquist, "The Systems of Innovation Approach and Innovation Policy: An account of the state of the art" (Aalborg, 2001), p. 3
[224] K. Bruland and K. Smith, "Knowledge Flows and Catching-Up Industrialization in the Nordic Countries The Roles of Patent Systems", in H. Odagiri et al. *Intellectual property rights, development and catch-up an International comparative study* (Oxford, 2010), pp. 63-94
[225] See for instance J. Mokyr, *Gifts of Athena*, (Princeton and Oxford, 2005); J. Mokyr, *The Enlightened Economy* (New Haven, 2009); K. Bruland, "Kunnskapsinstitusjoner og skandinavisk industrialisering" in *Demokratisk konservatisme,* Engelstad, F and Sejersted, F (eds.) (Oslo, 2006); K. Bruland, "Skills, learning and the International Diffusion of Technology: a Perspective on Scandinavian Industrialization", in *Technological Revolutions in Europe,* M. Berg and K. Bruland (eds.) (Cheltenham, 1998); K. Bruland and K. Smith, "Knowledge Flows and Catching-Up Industrialization in the Nordic Countries The Roles of Patent Systems", in *Intellectual property rights, development and catch-up an International comparative study,* H. Odagiri et al. (Oxford, 2010), pp. 63-94

Specific knowledge institutions aimed to carry out innovation were in the core of the Industrial Enlightenment. He sustains that:

> "(t)he economies that were most successful in the second Industrial Revolution were those in which the connections were most efficient. The institutions that created these bridges are well understood: universities, polytechnical schools, publicly funded research institutes, museums, agricultural research stations, research departments in large financial institutions."[226]

In contrast, economies in which connections between such institutions were inefficient and did not encourage innovation, were not as successful. Yet, the mere presence of such types of a specific institutional setting did not to guarantee development. Innovation depended on a whole set of institutions, which worked actively together to support innovation. We need to analyse these institutions and their direct and indirect links to innovation. The specific aims, functions and outcomes of the institutions, and how they worked together, should be analysed in order to understand their role in innovation processes.

How, then, did knowledge institutions develop and function? Research has been done on the Nordic countries in this respect. Economists and historians find that a number of knowledge institutions functioned as channels for knowledge transfer and knowledge development. Technical magazines and journals, for instance, were important channels for knowledge diffusion. In such publications, engineers and professionals obtained information about new and existing technology and descriptions of its use. Their function was, in particular, to spread information and publish updates on new technology and patents. Technical and scientific societies were founded in many countries from the eighteenth century and often published magazines and journals for members and others. Many industrialists and engineers were members of such societies and had access to such journals. In

[226] J. Mokyr, *Gifts of Athena* (Princeton and Oxford, 2005), p. 102

addition to making publications, societies functioned as a meeting place for exchange of relevant and useful knowledge. At least five important societies were launched in Norway in the late eighteenth century and had regular meetings.[227] The establishment of technical societies continued in the nineteenth century. Royal Society for the Welfare of the Kingdom was a private society founded in 1809, which aim was to stimulate economic development.[228] The Technical Society was founded in 1847. This Society was concerned with the implications for Norway of the new technology being developed abroad.[229] The Norwegian Polytechnical Society was founded in 1852 and organised lectures and courses for engineers and workers.[230] How technical magazines and journals were used to acquire and accumulate knowledge and the role of technical societies in the development of specific industries should be further explored.

Education systems were perhaps particularly important to generate innovation, as one of their main purpose was to encourage learning and spread knowledge. First of all, their scientific expertise were sometimes used directly in innovation processes. In the case of Norway, the historian Anne Kristine Børresen finds that professors at the University and other educational institutions from the early nineteenth century worked as consultants for companies in different industries. She explains that they used their laboratories and scientific as they gave advices with regard to start-up of companies, surveying or selection of new techniques.[231] Second of all, in many European countries, educational institutions began to provide industries, firms and other organisations with the broader section of

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[227] K. Bruland and K. Smith, "Knowledge Flows and Catching-Up Industrialization in the Nordic Countries The Roles of Patent Systems", in H. Odagiri et al. *Intellectual property rights, development and catch-up an International comparative study* (Oxford, 2010), pp 63-94; K. Bruland, "Skills, learning and the International Diffusion of Technology: a Perspective on Scandinavian Industrialization", in M. Berg and K. Bruland (eds.), *Technological Revolutions in Europe* (Cheltenham, 1998), p. 177

[228] K. Bruland and K. Smith, "Knowledge Flows and Catching-Up Industrialization in the Nordic Countries The Roles of Patent Systems", in H. Odagiri et al. *Intellectual property rights, development and catch-up an International comparative study* (Oxford, 2010), pp 63-94

[229] K. Bruland, *British technology and European industrialization* (Cambridge, 1989), p. 57

[230] K. Bruland, *British technology and European industrialization* (Cambridge, 1989), p. 58

[231] See A. K. Børresen and A. Wale (red.), *Vitenskap og teknologi for samfunnet? Bergfagene som kunnskapsfelt* (Trondheim, 2005); A. K. Børresen, *Bergtatt: Johan H. L. Vogt – professor, rådgiver og familiemann* (Trondheim, 2011)

skilled workers, technicians, engineers and specialists from the nineteenth century. There is much research on basic and technical education and industrial development in different countries, but there is not much evidence of a direct causal link to innovation. Professor Peter William Musgrave has perhaps made the most in-depth detailed comparative analysis of education and industrial development of metal extraction. This study differs from other analyses in that the use of technology and knowledge requirements in the industries at any given time are accounted for before considering the actual supply of professionals. He compares the British and German iron and steel industries from the mid-nineteenth century to the mid-twentieth century and links education to innovation through a systematic examination of the education, knowledge requirements in the industry and the supply of professionals. He detects the use of specific skills, which appear to be important for operations, in relation to particular knowledge domains and qualifications. As an example, he finds that changes in technology were based on new capabilities and specialisations from the 1860s:

> "The growing stress on science was leading to the employment of chemists in the industry. Here can be seen the beginning of the grade of "technician". Another growing point was associated with the expansion of the counting house, calling for more clerks whose education ranked them in this grade. The export trade would demand some knowledge of foreign language. Such men needed a broad education with specific attention to science and mathematics for potential works chemists."[232]

I believe that more studies, including the actual formal instruction and relating this to specific knowledge requirements, are essential to understand whether education actually provided knowledge that could be used to develop industries.

At the same time, it is important to consider that there are other ways of acquiring knowledge than from formal theoretical and scientific instruction. A vital point made in the literature is that

[232] P. Musgrave, *Technical Change the Labour Force and Education* (Oxford, New York, 1967), p. 27

innovation includes learning by doing and contact and transfer of knowledge from person to person, much due to the large degree of tacit knowledge. With respect to the transfer of technology, Nathan Rosenberg explains that: "…production function as a "set of blueprints" comes off very badly if it is taken to mean a body of techniques which is available independently of the human inputs who utilize it."[233] Therefore, apart from the knowledge that was developed at educational institutions, it is likely that knowledge accumulation also was connected to practical learning, observation and work experience. In particular, Everett Rogers emphasises hands-on knowledge in his explanation of how innovation occurs. Selecting technology, which was an important part of technology transfer, required observing and practice with the relevant technology.[234] In relation to the building of the workshop industry in Norway, Kristine Bruland describes how engineers and other workers went abroad to learn. Some went abroad to study at a foreign institution; others went to acquire technical experience at foreign companies, predominantly in Britain and later Germany and the United States. It was also common to go abroad to consult with experts and buy specific equipment or order materials.[235] Both in the textile and mechanical workshop industries "…foreign trips sometimes gave the original incentive to establish firms."[236]

Public and private scholarships and other funds were often given for the purpose of travelling abroad to learn. Technical societies sponsored visits to foreign countries with the specific aim of learning about foreign technology and transfer knowledge back.[237] The state also saw the importance of such trips and facilitated them by providing public scholarships to cover expenses. For instance, during the second half of the nineteenth century it granted 1006 travel stipends, of which 187 went to

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[233] N. Rosenberg, *Perspectives on Technology* (London, New York and Melbourne, 1977), p. 155
[234] E. M. Rogers, *Diffusion of Innovations* (New York, 2003)
[235] K. Bruland, "Norsk mekanisk verkstedindustri og teknologioverføring 1840-1900", in *Teknologi i virksomhet: verkstedindustri i Norge etter 1840*, E. Lange (ed.) (Oslo, 1989), p. 46-47
[236] K. Bruland, "Norsk mekanisk verkstedindustri og teknologioverføring 1840-1900", in *Teknologi i virksomhet: verkstedindustri i Norge etter 1840*, E. Lange (ed.) (Oslo, 1989), p. 45
[237] K. Bruland and K. Smith, "Knowledge Flows and Catching-Up Industrialization in the Nordic Countries The Roles of Patent Systems", in H. Odagiri et al. *Intellectual property rights, development and catch-up an International comparative study* (Oxford, 2010), pp 63-94

"mechanics".[238] In the early phase of technology transfers, late eighteenth century, espionage was a common method and governments often organised and financed such activities too.[239]

Industrial exhibitions were held in a number of European cities during the nineteenth century and were crucial in presenting "the state of the art" in mechanical and industrial technique.[240] Engineers, technicians and other workers visited exhibitions to learn about newest technology. Some exhibited products and technology from a variety of industries while others focused on the state of the art of a specific sector, such as agriculture or mining. Bruland finds that visits to exhibitions led to the import of reaping equipment, which was diffused in Norway via further local farm fairs.[241] The state sometimes financed industrial exhibitions, together with technical and scientific societies. The Kingdom of Norway and Sweden made various efforts to participate in international exhibitions during the nineteenth century. The Norwegian parliament funded travel for two mechanics to an exhibition in London in 1851. To another exhibition in London in 1862, the participation was organised via a committee with royalties and members of the elite. Sweden sent 511 exhibitors and Norway 216.[242] According to Göran Ahlström, industrial exhibitions were of great importance to the diffusion of technology and knowledge. They were considered "the milestones of progress" and "the measure of the dimensions of the productive activity of the human race".[243] The idea is that, even though knowledge was transferred through technical magazines and journals, contact with new

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238 K. Bruland and K. Smith, "Knowledge Flows and Catching-Up Industrialization in the Nordic Countries The Roles of Patent Systems", in H. Odagiri et al. *Intellectual property rights, development and catch-up an International comparative study* (Oxford, 2010)

239 K. Bruland, "Skills, learning and the International Diffusion of Technology: a Perspective on Scandinavian Industrialization", in M. Berg and K. Bruland (eds.), *Technological Revolutions in Europe* (Cheltenham, 1998), p. 176

240 K. Bruland, "Skills, learning and the International Diffusion of Technology: a Perspective on Scandinavian Industrialization", in M. Berg and K. Bruland (eds.), *Technological Revolutions in Europe* (Cheltenham, 1998), p. 182

241 K. Bruland and K. Smith, "Knowledge Flows and Catching-Up Industrialization in the Nordic Countries The Roles of Patent Systems", in H. Odagiri et al. *Intellectual property rights, development and catch-up an International comparative study* (Oxford, 2010), pp. 63-94

242 K. Bruland and K. Smith, "Knowledge Flows and Catching-Up Industrialization in the Nordic Countries The Roles of Patent Systems", in H. Odagiri et al. *Intellectual property rights, development and catch-up an International comparative study* (Oxford, 2010)

243 G. Ahlström, *Technological Development and Industrial Exhibitions 1850-1914* (Lund, 1995), p. 11

technology was vital. Empirical research, which demonstrates the transfer and use of technology that was presented at industrial exhibitions, may establish some of the functions of these institutions.

In addition to shorter study trips abroad and participation at industrial exhibitions, work experience from other countries is shown by Per-Olof Grönberg to have been highly valued among Swedish firms. In his analysis of Swedish engineers from 1880 to 1930, he uses directories of technical educational institutes, a number of books, letters, newspapers and newsletters, lectures and other material to account for transfer of knowledge from the United States to Sweden. He makes in-depth case studies of specific engineers, their experiences and work abroad and shows how they used this knowledge in concrete work situations after their return.[244] These engineers often attained strategic positions at Swedish companies:

> "The engineers were informed about technical development in the leading industrial countries and this spurred an interest to work with technology that was largely unknown in Sweden at the time. The engineers emigrated to learn the technology and the contemporary spirit in Sweden increased the power and influence of engineers with this experience."[245]

Such type of analyses, which account for transfer and use of practical knowledge, show that this type of knowledge was relevant, useful and perhaps vital for industrial development. Following engineers and technicians in detail through their education, travels, visits and work, is one way of analysing this subject.

Then again, the development of industries often relied on considerable inputs from foreign workers. Bruland and Smith show that workers were recruited to the Nordic countries to assist with glass

[244] P-O. Grönberg, *Learning and Returning. Return Migration of Swedish Engineers from the United States, 1880–1940* (Sweden, 2003), p. 1
[245] P-O. Grönberg, *Learning and Returning. Return Migration of Swedish Engineers from the United States, 1880–1940* (Sweden, 2003), p. 1

making, leather, production of salt, steam engines, production of cobalt, porcelain, textiles, iron and steel and mining industries.[246] For instance, the Norwegian Bærum Iron Works successfully operated steelmaking equipment smuggled from Sheffield and the Carron Iron Works, with the aid of two British workers by mid-nineteenth century.[247] British workers were heavily involved in diffusing technological knowledge to the emerging Norwegian textile industry in the mid-nineteenth century. British immigrants provided technical service and supervised the operation of new machinery. British agents and machinery making firms provided equipment, information, technical services and foreign labour, so called "packages", which enabled successful technology transfers to the Norwegian textile industry. The work of British skilled workers and foremen facilitated the start-up of operations and eased the initial technical problems in the development of the Norwegian industry.[248] The use of foreign workers in the development of industries has long traditions. David Landes stress the export of British trained workers to European countries after the industrialisation process was well on its way in Britain. By 1825, there were at least two thousand skilled British workers on the continent providing indispensable assistance in the adoption of the newly developed techniques.[249] I assume that the examination of the particular expertise of foreign workers, their travels, work, teaching of local workers and transfer of knowledge is highly relevant.

Some of the knowledge institutions through which knowledge were developed in the eighteenth and nineteenth centuries, highlighted in the literature, are summed up as follows:

[246] K. Bruland and K. Smith, "Knowledge Flows and Catching-Up Industrialization in the Nordic Countries The Roles of Patent Systems", in H. Odagiri et al. *Intellectual property rights, development and catch-up an International comparative study* (Oxford, 2010), pp 63-94
[247] D. Christensen, *Det moderne projekt* (København, 1996), p. 517
[248] K. Bruland, *British technology and European industrialization* (Cambridge, 1989)
[249] D. Landes, *The Unbound Prometheus* (Cambridge, 1969), pp. 148-49

Selected channels for development of technological knowledge in the nineteenth century

Institution	Function
Technical education	Provision of skilled workers to industries
Technical magazines (technical societies)	Diffusion of codified information about technology and descriptions of its use (patents)
Scholarships for travels	Acquisition of practical knowledge, experience of new technology, contacts and select new techniques
Research institutions and laboratories	Provision of scientific knowledge to companies for industrial development
Firms	Acquisition of work experience and hands-on practice
Industrial exhibitions	Presentation of new and up-to-date technology
Foreign workers	Provision assistance from experts and professionals with relevant knowledge

I seek to supplement this literature of knowledge institutions and organisations with a comparative analysis of the mining sectors in Chile and Norway.

5.5 Summary and concluding remarks

The idea that resource-based economies only experience slow growth lacks empirical evidence. It is true that many countries rich in natural resources have stagnated and experienced slow economic growth, but some of the richest countries in the world, such as the Nordic countries, Australia and New Zealand, are also resource-based economies. A large share of their economies, as Latin American and African countries, rest on utilisation of natural resources, such as minerals, forests, fish and agricultural production. The fundamental problem with the resource curse hypothesis seems to be generalisations of countries and oversimplied models. A closer look to these countries reveals that there are clearly large differences in growth among them. Why have some natural resource-based countries become rich? This question leads to another problem, which is the assumption that natural resource industries are less innovative than manufacturing and high-tech industries. New research suggests that this is not the case. Some natural resource industries are in fact based on complex knowledge, intensive learning and dynamic upstream and downstream linkages to other industries, much like manufacturing and high tech industries. The challenge for resource-based economies is not to move away from natural resource industries and develop other types of industries, but to take advantage of their comparative advantage in terms of natural resources. Differences between successful and unsuccessful countries seem to be linked to whether the natural resource potential in the country is benefitted and used to develop innovative and competitive natural resource industries, or not. The analysis by David and Wright about developments of mining sectors demonstrates such discrepancies across resource-based economies. They show that from the late nineteenth century, the United States took more advantage of its mineral potential than any other country of the time. Mineral and metal productions in other countries remained underdeveloped. If some natural resource industries are innovative, while others are not, which institutions determine growth in the successful ones?

There is a strong argument in the literature that knowledge is the underlying foundation of economic growth and an institutional setting, which encourage and facilitate innovation, is crucial for technological knowledge accumulation and innovation. Both historical analyses and economic studies with reference to recent decades agree that a favourable and innovative-friendly institutional setting has been indispensable for economic growth. It is how actors, in terms of entrepreneurs, company leaders, workers, traders etc. operate and interact with each other, which determine the economic result. Successful countries have actually established institutions, which encourage and enable the development of natural resource industries, instead of insisting to move away from them. Yet, there are major inconsistencies about what a favourable institutional setting looks like. Scholars emphasise different types of institutions and largely disagree about which institutions determine growth. Models of institutions and economic growth make general typologies based on only a few countries and present broad comparisons and classifications of poor and rich countries. These models ignore specificities of each country and do not reveal the complex development paths which characterise each society. Another problem is that there is scarce empirical evidence of direct links between institutions, innovation and economic growth. Few attempts have been made to actually explore how learning and innovation occur and the actors involved. This problem is related to the fact that there is a lack of understanding of how institutions actually influence innovation. The types of institutions, which determine innovation and economic growth, is still not clear. The focus in the literature is largely on incentives and constraints of economic transactions and not on the actual events of knowledge accumulation. Scholars often assume that certain institutions encourage and motivate to innovation, while other institutions do not. Certain “right” institutions should be in place: defined property rights, good and extensive infrastructure, high quality education and research institutions, free trade policy, democratic institutions and so on. Other institutions, such as rent-seeking, non-democratic institutions, are understood as negative for economic growth. Secure property rights probably give motivation to invest; an efficient and clear system for imports and exports facilitates trade and transparent and open institutions motivates honest transactions. Nevertheless, these incentives or motivations to invest and innovate, understood as conditions, do not themselves explain how actors acquire and use technological capabilities. An institution, which actually aims to encourage learning and the spread of knowledge, is education. However, although a number of studies argue that education is important for the fostering of industries; few studies actually link the scientific knowledge and skills to actual building of industries. Even innovation system approaches are criticised for not capturing the complexity, uncertainty and lack of order, which characterise learning and innovation processes. To understand more about the foundation of modern economic growth, the institutions and organisation involved in the accumulation and use of knowledge to build companies and industries should be explored further.

Economic historians have recently started to analyse knowledge institutions and organisations, which aimed to develop useful knowledge from a historical perspective. Institutions, such as education and technical education systems, industrial exhibitions, technical magazines, research institutions, espionage activities, study travel by engineers and workers, foreign workers and firms interacted with each and actively transferred, used, modified and diffused knowledge. More than providing incentives for innovation, these institutions and organisations seem to have been far more involved in actual learning and innovation processes. In some countries, the state encouraged and created some of these institutions, which gave it a special role. I seek to supplement this literature by looking to the past and implement a comparative empirical examination of the functions, outcomes and direct and indirect links of knowledge institutions and organisations, which aimed to develop knowledge for mining.

Diverging paths of Chile and Norway

6 An overview of development in Chile and Norway

6.1 Similar historical, geological and sectorial basis

Chile and Norway are both long, narrow and mountainous countries in the outskirts of their respective continents. They were both colonies for hundreds of years. Norway was under Danish rule from 1536 to 1814 and entered a union with Sweden, with its own Constitution, before becoming an independent country in 1905. The country was considered poor in Europe in the eighteenth and nineteenth century compared to other Western European countries. In the early twentieth century, economic growth was characterised by foreign debt and losses in the balance of trade.[250] Chile was a Spanish colony in the mid-sixteenth century and became independent in 1810. The country was after this time also considered poor and the economy was characterised by inflation, deficit and debt problems.[251]

In addition to these historical similarities, the two countries have similar geological conditions and natural resources. They have both long coasts with possibilities for fishing and shipping, large mountain areas, forests and waterfalls. Both countries fit the definition of a resource-based economy and have been characterised as such in the literature.[252] Actually, they have developed many of the same natural resource industries (see below):

[250] A. K. Linderud, «Norges fordringer og gjeld overfor utlandet i et historisk perspektiv» (Oslo, 2008) p. 36

[251] M. Blomström and P. Meller (eds.), *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development* (Washington, 1991), p. 1.

[252] See for example M. Blomström and P. Meller (eds.), *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development* (Washington, 1991); S. Ville and Wicken, The Dynamics of Resource-Based Economic Development: Evidence from Australia and Norway, 2012; Richard Willis, Warwick Murray, Breaking the Resource Curse: the cases of New Zealand and Australia"; N. H. Barma et al. *Rents to Riches The political economy of natural resource-led development* (Washington D. C., 2012); G. B. Havro and J. Santiso, "Rescuing the Resource Rich: How Can International Development Policy Help Tame the Resource Curse?", *Working Paper Series* (June 2010)

Selected natural resource industries (simple overview)

Norway		Chile	
nineteenth century	**twentieth century**	**nineteenth century**	**twentieth century**
Agriculture	Agriculture/canning/dairy production	Agriculture/exports of wheat	Agriculture/wine production
Fish	Fish/aquaculture	Fish	Fish/aquaculture
Timber	Timber/cellulose/paper	Timber	Timber/cellulose/paper
Mining (silver, iron, copper)	Mining/metals/electro-metallurgical and chemical processing/oil and gas	Mining (copper, silver, coal, saltpetre)	Mining/metals (copper, coal, iron)
	Hydroelectric power		Hydroelectric power

Based on Bergh, T. et al. (1983): *Norge fra u-land til i-land: vekst og utviklingslinjer 1830-1980*. Oslo: Gyldendal; Carmagnani, M. (1998): *El desarollo industrial y subdesarrollo económico*. Santiago: Ediciones de la Dirección de Bibliotecas, Archivos y Museos; Hodne, F. and Grytten, O. H. (2000): *Norsk økonomi i det nittende århundre.* Bergen: Fagbokforlaget; Hodne, F. and Grytten, O. H. (2002): *Norsk økonomi i det tyvende århundre*. Bergen: Fagbokforlaget; Pinto Santa Cruz, A. (1959): *Chile, un caso de desarrollo frustrado*. Santiago: Editorial Universitaria; Sutter, C. C. and Sunkel, O. (1990): *Un siglo de historia economica de Chile, 1830-1930*. Santiago: Edic. Cultura Hispánica.

In the nineteenth century, both countries had a large agricultural sector, which gradually reduced its share of GDP during the twentieth century. In Norway agriculture, timber and fishing stood for 45, 3 per cent in 1865, but had reduced to 23,7 per cent in 1910 and to 4,6 per cent in 1980. The agricultural sector in Chile accounted for 22,56 per cent in 1865, 9, 57 per cent in 1910 and 5,81 per cent in 1980. In Norway, the production of fish, shipping, mining, timber and timber-related industries were also important industries in the nineteenth century. The proportion of mining as share of GDP for Norway is not obvious, because it was categorised together with industry, construction and power supply. However, of the numbers it is evident that the sector was much smaller than the Chilean one, which some years accounted for over twenty per cent of GDP alone. Manufacturing industries have varied in both countries, but remained relatively small compared to other sectors (see tables below):

GDP in current prices by main sectors in Norway (percentage)*

Sector	1865	1875	1890	1910	1930	1950	new national accounts definitions	
							1965	1980
Agriculture, timber, fishing (whaling)	45,3	35,4	31,6	23,7	16,6	13,7	7,9	4,6
Industry, construction, mines and power supply	17,8	21,8	24,3	26,2	30,1	40	32,8	40,7
Shipping and transport	9,7	13,6	11,7	11,3	12,7	15,8	15,4	10,5
Commerce and business	8,6	10,1	13,3	17,8	16,9	15,2	25,8	23,6
Public and private services, adjusting entries	18,6	19,1	19,1	21,0	23,7	15,3	22,4	20,7

*Numbers before 1900 are uncertain.
Source: T. Bergh et al., *Norge fra u-land til i-land: vekst og utviklingslinjer 1830-1980* (Oslo, 1983), p. 237

Sectorial composition of GDP in Chile (percentage)

Sector	1865	1875	1890	1910	1930	1950	1965	1980
Agriculture	22,56	20,03	8,99	9,57	12,51	9,21	6,34	5,81
Mining	10,80	11,66	21,74	23,85	26,38	15,80	9,81	9,41
Manufacture	12,58	12,93	14,48	10,47	11,01	20,87	24,84	21,52
Government services	2,07	2,95	4,09	6	2,75	7,60	7,65	6,36
The rest: *Construction* *Commerce* *Services (electricity, gas, water)*	51,98	52,42	50,69	50,11	47,35	46,53 *8,72*	51,38 *8,83* *10,94* *2,19*	56,90 *6,04* *12,67* *2,70*

Source: J. Braun et al., *Economía chilena 1810-1995 Estadísticas históricas* (Santiago, 2000), pp. 31-33

Natural resource products have represented a large share of exports in both Chile and Norway. In Norway, timber and fish traditionally dominated the foreign trade.[253] Timber accounted for the largest export industry in the late nineteenth century and after the turn of the century, timber, pulp and paper represented more than forty per cent. Agricultural products stood for over thirty per cent in the late nineteenth century and continued to be important export goods together with fish, food and beverage products after the turn of the century. In addition to agricultural products, minerals, metals and chemicals were important export products, especially from the early twentieth century with new electro-metallurgical products, such as aluminium and artificial fertilizer. Exports of all minerals and metals increased from under six percent before 1913, to over twenty percent in 1930. From the 1970s, the mineral production branched out the extraction of oil and gas, which in turn developed to be the most important economic industry. Some years it has accounted for more than

[253] F. Hodne and O. H. Grytten, *Norsk økonomi i det nittende århundre* (Bergen, 2000), p. 97

fifty per cent of exports (see tables below):

Exports from Norway

Export 1880-1913. Selected principle products (percentage)

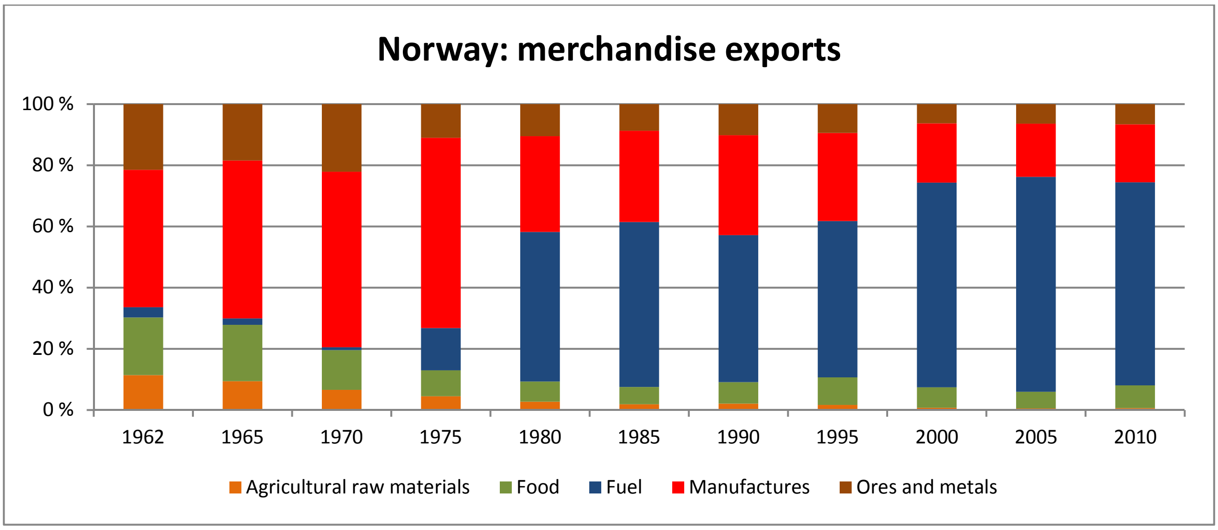
Products	1876-80	1886-90	1896-1900	1906-10	1913
Edible animal products	34,7	34,5	32,3	33,1	37,7
Hair, feather, skin	5,4	6,1	4,0	4,9	8,7
Timber	41,9	23,5	24,8	16,3	6,1
Wood products Paper	0,2	3,3	5,3	7,9	8,1
Minerals, crude and semi-manuf.	3,7	1,7	3,0	5,7	5,1
Metals, crude and semi-manuf.	1,2	1,1	1,1	2,0	4,6
Other export sectors	12,3	16,8	8,9	14,4	15,3
TOTAL	100	100	100	100	100

Source: O. Wicken, "The Norwegian Path Creating and Building Enabling Sectors", working paper, Centre for Technology, Innovation and Culture, University of Oslo, (Oslo, 2010), p. 17

Exports in current million NOK and percentage*

Year	Total	agriculture, forestry, hunting, fishing, whaling	Mining and metallurgical products**	Chemical products	Oil and fat	Timber, pulp and paper	Leather, rubber, textile and clothing	Food and beverage	Other
1900	167,3	17,7	10,9	2	4,9	67,4	1,1	52,3	11
	100	***10,6***	***6,5***	***1,2***	***2,9***	***40,3***	***0,7***	***31,3***	***6,6***
1910	279,7	31,8	26,2	12,9	8,8	95,6	2,3	86,5	15,6
	100	***11,3***	***9,3***	***4,6***	***3,1***	***34,2***	***0,8***	***30,9***	***5,6***
1920	1202,9	59,2	94	128,8	80,3	554,5	8,5	214,8	62,8
	100	***4,9***	***7,8***	***10,7***	***6,7***	***46,1***	***0,7***	***17,9***	***5,2***
1930	664,8	51,6	141,1	73,6	58,9	208,8	8,6	121,3	0,9
	100	***7,7***	***21,1***	***11,1***	***8,9***	***31,4***	***1,3***	***18,2***	***0,1***
1939	770,6	86,5	225,2	84,3	73	192,5	8,4	100,2	0,5
	100	***11,2***	***29,2***	***10,9***	***9,5***	***25***	***1,1***	***13***	***0,1***
1948	2004,6	183,5	397,1	131,5	277,8	613,6	26,9	373,4	0,8
	100	***9,1***	***19,8***	***6,6***	***13,9***	***30,6***	***1,3***	***18,6***	***0***

Calculations based on official statistics
*Included in the foreign statistics
** Including Coal and ore mines, stone and mineral quarries, electrometallurgy, earth and stone and iron and metal, non-metallic minerals
Sources: Norges Officielle Statistikk, *Nasjonalregnskap 1900-1929* (Oslo, 1953); Norges Offisielle Statistikk, *Nasjonalregnskap 1930-1939 og 1946-1951* (Oslo, 1952).



Source: World Data Bank, World Development Indicators (WDI) & Global Development Finance (GDF)

In Chile, agricultural products, notably wheat, and minerals have dominated exports from the early nineteenth century up until today. Mineral and metal products' share of exports increased from sixty-three percent in 1850 to over ninety per cent in 1890. After the turn of the century, exportation of these goods declined to under ninety per cent and represented 55,3 per cent in 1990, but increased to over sixty per cent in 2010. It is clear that mineral and metal productions have stood for the absolute largest share of exports of this country, both historically and today (see table below):

Exports from Chile

Composition of exports (percentage of total exports)

Year	Mining	Agriculture	Manufacture	Other
1850	63	24,9	0	12
1860	74,3	18,6	0	7,1
1870	63,6	32,1	0	4,3
1880	76,1	19,6	4,3	0
1890	90,5	6,6	2,9	0
1900	91,2	6,4	2,5	0
1910	89,1	8,7	2,2	0
1920	84,8	10,9	4,3	0
1930	83,7	12,3	4	0
1940	85	11,6	3,4	0
1950	83,7	11,8	4,5	0
1960	86,6	6,5	6,9	0
1970	84,8	3,1	12,1	0
1980	59,4	7,3	33,4	0
1990	55,3	11,4	33,1	0,2

Source: J. Braun et al., Economía chilena 1810-1995 Estadísticas históricas (Santiago, 2000), pp. 165-167

Source: World Data Bank: World Development Indicators (WDI) & Global Development Finance (GDF)

Currently, each of the two countries possesses one key natural resource, which represents the largest sector for export: in the case of Chile; copper, and in the case of Norway; oil. In 2012, oil and gas accounted for around 68 per cent of total merchandise exports in Norway and ores and in Chile metals stood for 60, 9 per cent of merchandise exports.[254]

6.2 A gap in social development and economic growth

Chile grew significantly after Independence, and prospered from natural resource productions, such as silver, saltpetre and copper. The country had an important economic growth between 1830 and 1880, based on natural resources, stimulated by participation in the world economy.[255] An industrialisation process started in the 1860s with an adoption of a modern transport system and a large number of goods and services entered the market.[256] Apart from the landowner elite, new economic groups started to grow, such as investors in mining and commercial and financial

[254] World Data Bank: World Development Indicators (WDI) & Global Development Finance (GDF)

[255] L. Ortega Martínez, "Acerca de los origenes de la industrialización chilena 1860-1879" in *Nueva Historia* año 1 no. 2 (London, 1981); O. Muñoz Gomá, *Chile y su industrialización* (Santiago, 1986); M. Carmagnani, *Desarrollo Industrial y Subdesarrollo Económico El Caso Chileno (1860-1920)* (Santiago, 1998); A. Pinto Santa Cruz, *Chile, un caso de desarrollo frustrado* (Santiago, 1959)

[256] L. Ortega Martínez, "Acerca de los origenes de la industrialización chilena 1860-1879" in *Nueva Historia* año 1 no. 2 (London, 1981), p. 4; see also memoria chilena (www.memoriachilena.cl) for description and literature

businessmen. They were from the colonial middle class and many of them were foreigners.[257] Foreigners, mostly Germans, French, Italians and English, became involved in imports and exports, either independently or as representatives of foreign trade chambers. This development benefitted Valparaíso, which became one of the most important ports in South America and the Pacific. The city was often called the "Manchester of South America".[258]

Until the 1930s, Chile and Norway had similar growth in GDP per capita. Both countries grew slowly and were under the United States and Western European average. However, from around 1930, an economic gap started to emerge and from the mid-1940s, after the recession during the Second World War, Norway took a step forward. Norway stayed ahead and continued to grow considerably more than Chile. Notwithstanding slow economic growth during the nineteenth and early twentieth century, Norway is today one of the richest countries in the world. Productivity and income are among the highest in the world, even without the extra contribution of the country's oil and gas sector.[259] The country even surpassed Western European average. The Chilean economy, on the other hand, continued to grow slowly and was characterised as instable, with inflation problems, trade deficits and foreign debts.[260] It is not until recent decades that the country has had strong economic growth. Thus, in spite of similar historical, geological and industrial patterns, the two countries have developed in different ways (see graph below):

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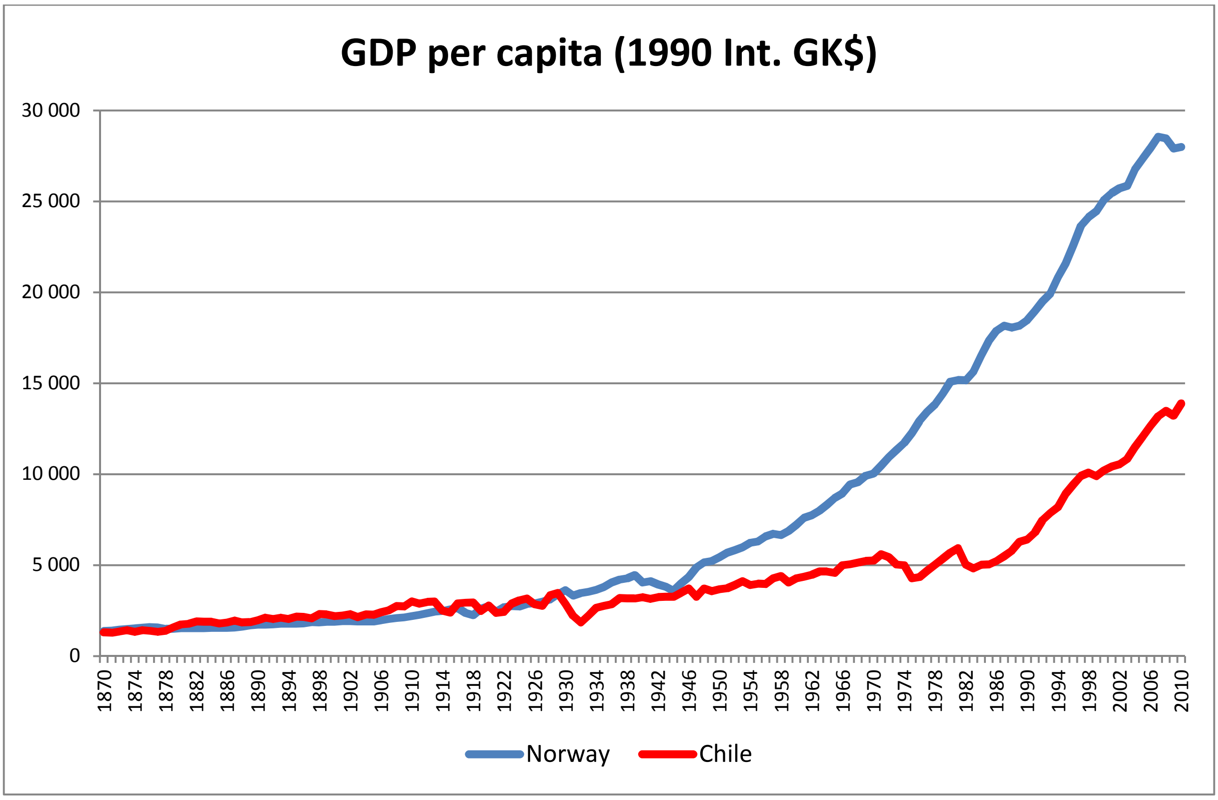
[257] M. Carmagnani, *Desarrollo Industrial y Subdesarrollo Económico El Caso Chileno (1860-1920)* (Santiago, 1998), p. 20

[258] O. Muñoz Gomá, *Chile y su industrialización* (Santiago, 1986), p. 53

[259] J. Fagerberg et al. "Innovation-systems, path-dependency and policy: The co-evolution of science, technology and innovation policy and industrial structure in a small, resource-based economy", DIME Working paper in the series on "Dynamics of Knowledge Accumulation, Competitiveness, Regional Cohesion and Economic Policies" (2008)

[260] See for example M. Carmagnani, *El desarollo industrial y subdesarrollo económico* (Santiago, 1998); A. Pinto Santa Cruz, *Chile, un caso de desarrollo frustrado* (Santiago, 1959); M. Vernengo, "Technology, Finance, and Dependency: Latin American Radical Political Economy in Retrospect", *Review of Radical Political Economics,* Vol. 38, No. 4 (2006); For a detailed description of the Chilean foreign debt in a historical perspective see A. Ferranda Urzúa, *Historia comentada de la deuda externa de Chile: (1810-1945): nociones de la deuda pública* (Santiago, 1945) and L. Vitale, "La deuda externa en Chile entre 1822 y la decada de de 1980" (Chile, 1990)



Source: Angus Maddison, Historical Statistics of the World Economy: update, 1st of January 2013.

GDP per capita is only one way of measuring the economy. Although it measures economic growth, it does not capture the social development and human well-being in countries.[261] Then again, the economic growth in Norway has been based on a fairly equal income distribution. The country had practically no land nobility, Catholic Church or military caste. Nobility privileges were abolished when the country became independent from Denmark in 1814.[262] The feudal tendencies were week and in the nineteenth century, small private farmers owned the majority of the soil. Self-owned farming represented eighy-one per cent in 1855 and to ninety-five per cent in 1875.[263] This was a particular situation in Europe.[264] The equal income distribution was accompanied by a national alphabetising. Campaigns to improve the reading and writing skills of the Norwegian population have roots back to

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[261] R. Costanza et al., “Beyond GDP: The need for new measures of progress” (Boston, 2009), p. 1
[262] H. Hveem, “Developing an Open Economy: Norway’s Transformation, 1845-1975”, in *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development,* M. Blomström and P. Meller (eds.) (Washington, 1991), p. 130; F. Hodne and O. H. Grytten, *Norsk økonomi i det nittende århundre* (Bergen, 2000), pp. 16-17
[263] There was, however, an increase of smallholders (67 000 in 1855): T. Bergh et al. *Norge fra u-land til i-land: vekst og utviklingslinjer 1830-1980*, (Oslo, 1983), p. 36
[264] T. Bergh et al. *Norge fra u-land til i-land: vekst og utviklingslinjer 1830-1980*, (Oslo, 1983), p. 36

the seventeenth century.[265] The Church encouraged reading through religious texts from early on and the first school law in Denmark-Norway was introduced in 1731. The oldest primary school in the Nordic countries opened in Bergen in 1740 and was financed by the Cross Church. During the nineteenth century, the government gradually increased public funds to education.[266] From 1827, all children in the country between seven and forteen years old should receive teaching in reading, writing and some calculation for at least three months a year.[267] In 1837 86, 4 per cent of the children in the appropriate age obtained instruction.[268] In 1860, a law, which established a school system with regular school for all during seven years, was introduced.[269] The share of literate people in Norway was very high from early on compared to other European countries. Fritz Hodne finds that in 1873, around eighty-seven per cent were able to write and read and ninety-nine per cent were able to read.[270] Other sources show that by the 1890s the literacy estimate rate was near a hundred per cent.[271] According to Carlo Cipolla, more than seventy per cent of the adult population was literate by 1850 and Norway became one of the countries with highest literacy in Europe.[272] The social differences have maintained small and Norway is today one of the countries in the world with less social differences.[273] The country has developed and maintained a welfare state, which covers health, education and social protection for the whole population and is ranked highest at the Human

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[265] K. Bruland, ”Kunnskapsinstitusjoner og skandinavisk industrialisering” in *Demokratisk konservatisme,* Engelstad, F and Sejersted, F (eds.) (Oslo, 2006), p. 271

[266] F. Hodne and O. H. Grytten, *Norsk økonomi i det nittende århundre* (Bergen, 2000), p. 151

[267] F. Hodne, *Norges økonomiske historie 1815-1970* (Oslo, 1981), pp. 242-243

[268] F. Hodne, *Norges økonomiske historie 1815-1970* (Oslo, 1981), p. 244

[269] F. Hodne, *Norges økonomiske historie 1815-1970* (Oslo, 1981), pp. 242-243

[270] The survey were carried out in Denmark, but according to Fritz Hodne it is seems likely to believe that the conditions were similar in Norway: F. Hodne, *Norges økonomiske historie 1815-1970* (Oslo, 1981), p. 250

[271] O'Rourke and Williamsen, "Education, Globalization and Catch-Up: Scandinavia in the Swedish Mirror" in *Scandinavian Economic History Review*, 43, 1995, p. 299.

[272] Denmark, Faroe Islands, Finland, Germany, Holland, Iceland, Scotland, Sweden, Switzerland: C. M. Cipolla, *Literacy and Development in the West* (Baltimore, 1969), p. 113

[273] Norway has had small differences in income distribution according to UNDP Income Gini coefficient: Gini Coefficient. Retrieved from UNDP: http://hdr.undp.org/en/content/income-gini-coefficient [accessed 29th June 2015]. It measures the deviation of the distribution of income among individuals or households within a country from a perfectly equal distribution. A value of 0 represents absolute equality, a value of 100 absolute inequality.

Development Index.[274]

Chile has different social patterns. In Chile, the Colonial system was feudal and characterised by an exclusive elite with political and economic control.[275] Aníbal Pinto Santa Cruz explains that the Chilean state established republican norms and maintained the social-economic structure of the old regime, which in essence did not change much, "…except as to the expulsion of a couple of Spanish."[276] After independence, the country preserved the feudal system with big "haciendas" in which the landlords controlled the majority of the land and resources and the bigger part of the population worked as permanent or seasonal tenant farmers. This system represented the Chilean hierarchical social system, which was characterised as somewhat of a state society.[277] Chile has been considered one of the most stable democracies in Latin America (from 1831 to 1973), but the political and social system meant a restricted access to capital, property rights, resources and education for others than a small limited group.[278] In Latin American countries, the Church and other volunteers were much less involved in the development of an education system, as often was the case in European countries. The limited education system from early times is in this sense related to a passive elite. A strong argument in the literature is that the elite, in a large degree agrarian and mercantile, did not see the value of a literate and disciplined working class. Literate and disciplined workers were not understood as necessary.[279] According to the historian María Loreto Egaña Baraona, it was not obvious for the

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[274] United Nations Development Programme, Human Development Reports: http://hdr.undp.org/en/data [accessed 29th June 2015]

[275] See for example M. J. Mamalakis, *The growth and structure of the Chilean economy* (London and New Haven, 1976), p. 353; D. De Ferranti et al. *From Natural Resources to the Knowledge Economy* (Washington D. C., 2002), p. 65

[276] A. Pinto Santa Cruz, *Chile, un caso de desarrollo frustrado* (Santiago,1959), p. 20

[277] Haciendas represented big, to a large extent autosufficient, systems of production in large properties (plantations), with landlords, tenant farmers and laborers. For a description of the hacienda system see Memoria Chilena (National Library of Chile): http://www.memoriachilena.cl/602/w3-article-695.html [accessed 29th March 2015]

[278] See for example O. Muñoz Gomá, *Chile y su industrialización* (Santiago, 1986), p. 44; D. De Ferranti et al. *From Natural Resources to the Knowledge Economy* (Washington D. C., 2002), p. 65

[279] M. L. Egaña Baraona, *La Educación Primaria Popular en el Siglo XIX en Chile* (Santiago, 2000); C. Gazmuri Riveros, *El "48" Chileno Igualitarios, Reformistas; Radicales, Masones y Bomberos* (Santiago, 1998); L. Galdames, *Valentín Letelier y su obra: 1852-1919* (Santiago, 1937); M. Monsalve Bórquez, *Documento para la*

Chilean elite that an educated working class would lead to economic growth. Instead, the elite saw basic education as an effort to solve the "social problem" of poverty and inequality through "moralisation and civilisation" of the poor sectors:

> The need for primary education, in terms of economic and productive development was not evident to the elites; people performed work which required low or no skills; nor was a disciplined and accostumed work force needed…"[280]

Yet, some public measures to educate the population were undertaken during the nineteenth century in Chile. The state was by law the principal support to education from 1860 with a reform, which guaranteed free elementary education and fiscal responsibility.[281] However, only 17, 34 per cent of the age appropriate population attended primary school that year.[282] Travel chronicles and descriptions suggest that only some groups and social classes had access to educational opportunities.[283] Perhaps the underlying problem was that primary and secondary education was not given top priority. Pablo Castillo shows that public expenditure on education between 1870 and 1920 was far below that of security:

> "[P]ublic expenditure allocated to order was several times the one assigned on primary education, which makes clear what the States' priorities were: order by means of repression instead of order through augmenting society's human capital." [284]

Other areas were understood as more important than general education, which meant that the latter

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Historia de la Instrucción Primaria 1840-1920 (Santiago, 1998); A. Orrego Luco, *La Cuestion Social* (Barcelona, 1884)

[280] My translation: M. L. Egaña Baraona, *La Educación Primaria Popular en el Siglo XIX en Chile* (Santiago, 2000), p. 123

[281] *Ley de Instrucción Primaria* [Primary Education Act] (24th November, 1860)

[282] J. Braun et al. *Economía chilena 1810-1995 Estadísticas históricas* (Santiago, 2000), p. 236

[283] C. C. Sutter and O. Sunkel, *Un siglo de historia economica de Chile* (Santiago, 1990), p. 17

[284] P. Castillo, "Land, Inequality and Education in Chile's 1870-1920. The Onset of Contemporary Divergence" (Barcelona, 2011), p. 5

was not prioritised. This is demonstrated by comparing public expenditure on education and social order:

> "Primary education's share of the national budget ranged from a bottom figure of 1, 08% to an upper amount of 10, 02%, whereas the expenditure in order did it from a 4, 18% up to a 13, 02%. The ratio E/DO has an average value of 45, 49% for the whole period analyzed, which means that during a period 71 years the expenditure allocated on primary public education was not even half the amount allotted to social order."[285]

In 1920, more than a century after independence, obligatory primary education was introduced, which meant compulsory primary schooling for both sexes for four years before the age of thirteen.[286]

The restricted educational system in Chile was reflected in low school attendance. B. R. Mitchell's statistics from 1875 and onwards indicate that there was a smaller school attendance in Chile than in Norway.[287] Until the 1920s, the current number of pupils attending primary school was larger in Norway. Considering the fact that the Chilean population was growing faster than in Norway, the share of children of appropriate age attending primary school was probably much smaller in Chile (see table below):

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[285] P. Castillo, "Land, Inequality and Education in Chile's 1870-1920. The Onset of Contemporary Divergence" (Barcelona, 2011), p. 19

[286] *Ley de Instrucción Primaria Obligatoria* and Documento IV/4 *Lei Sobre Educación Primaria Obligatoria* (1920)

[287] B.R. Mitchell, *International Historical Statistics The Americas 1750-2005* and *International Historical Statistics Europe 1750-2005* (New York, 2007)

School attendance (in thousands)

Students in primary school			Students in secondary school			Population (in thousands)		
Year	**Norway**	**Chile**	**Year**	**Norway**	**Chile**	**Year**	**Norway**	**Chile**
1875	245	--	**1875**	4	--	**1875**	1 803	2 100
1885	244	79 (year 1886)	**1885**	7,6	--	**1885**	1 944	2 434
1895	320	140	**1895**	12	4,7	**1895**	2 083	2 783
1905	359	201	**1905**	11	14	**1905**	2 309	3 136
1915	382	376	**1915**	18,5	44	**1915**	2 498	3 509
1925	396	507	**1925**	23,7	62	**1925**	2 747	3 970
1935	370	542	**1935**	29,1	42	**1935**	2 889	4 625
1945	287	682	**1945**	35,7	64	**1945**	3 091	5 552
1955	421	976	**1955**	49,1	127	**1955**	3 427	6 743
1965	458	1 517	**1965**	107	320	**1965**	3 723	8 510
1975	583	2 299	**1975**	64,2	449	**1975**	4 007	10 252
1985	534	2062	**1985**	210	668	**1985**	4 152	12 068
1995	474	2 150	**1995**	236	679	**1995**	4 359	14 207
2002	433	1 713	**2002**	175	1 557	**2002**	4 536	15 504

Sources: B.R. Mitchell, International Historical Statistics The Americas 1750-2005 (New York, 2007) and B.R. Mitchell, International Historical Statistics Europe 1750-2005 (New York, 2007)

According to statistics on attending pupils 100 per cent, primary school attendance was not obtained until the end of the 1950s in Chile.[288] This problem of general education continued for several decades. Rudolph Blitz refers to a heavy rate of school desertion on the primary level and found that between 1950 and 1959 approximately 9 per cent of the school age population never attended school. 30 per cent of those who entered the first grade abandoned school within the first two years and only 28, 6 per cent of the school age population completed their primary education.[289] The small number of students at primary schools had effects on the admission to secondary schools. Although the number of students attending secondary school increased dramatically from the 1950s, Blitz finds that as late as 1960 only about 20 per cent of a given age cohort entered secondary education. Moreover, only one half, or fewer, of the high school graduates succeeded in passing the final high

[288] Between 1957 and 1985 the enrollment coverage of primary school showed more than 100 per cent. This can be due to a national literacy campaign where also adults were enrolled in primary schools. J. Braun et al. *Economía chilena 1810-1995 Estadísticas históricas* (Santiago, 2000), p. 238

[289] R. Blitz, "Some observation concerning the Chilean Educational System and its Relation to Economic Growth" in *Education and Economic Development*, C. A. Anderson and M. J. Bowman (Chicago, 1965), pp. 305-306

school exam.[290] At the same time, a large share of the population in Chile was illiterate up until recent decades. In 1865 only 18 per cent of the population was literate, while it had increased to 30, 3 per cent in 1885.[291] In 1950 19, 8 per cent of the population was still illiterate.[292] The result was that a large share of the population was excluded from working opportunities.

Challenges with the provision of education has persisted until today. In 2006, started the largest student demonstration in several decades. Several thousand students across Chile have protested for radical changes in the education system. The persistence of the large social differences can be illustrated by the income distribution today. Although poverty has been reduced during the last 20 years and the country is ranked highest in Human Development Index among the Latin American countries, Chile are among the countries with largest social differences in the world. In 2013 the income Gini coefficient was 52, 1 compared to 25, 8 in Norway.[293]

Large social differences and the path dependence of non-inclusive institutions are argued to be negative for economic growth. There are different beliefs with regard to income inequalities and their effect on savings and investments, but analyses suggest that high inequality in wealth, education and health have been linked to lower growth.[294] The large differences between Chile and Norway in terms of income distribution possibly contributes to explain differences in economic growth between the two countries. The question remains, however, how Norway developed to become one of the most

[290] R. Blitz, "Some observation concerning the Chilean Educational System and its Relation to Economic Growth" in *Education and Economic Development*, C. A. Anderson and M. J. Bowman (Chicago, 1965), p. 306
[291] S. L. Engerman and K. L. Sokoloff, "The Evolution of Suffrage Institutions in the New World", Journal of Economic History, vol. 65, No. 4 (2005)
[292] P. Meller, "Chilean Economic Development 1880-1990", in *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development,* M. Blomström and P. Meller (eds.) (Washington, 1991), p. 7
[293] Income Gini Coefficient. Retrieved from UNDP: http://hdr.undp.org/en/content/income-gini-coefficient [accessed 29th March 2015]
[294] For a literature review see H. Boushey and C. C. Price, "How are economic inequality and growth connected?" (Washington, 2014); S. Tiah You, "Inequality does cause underdevelopment: Comprehensive analyses of the relationship" (Berkeley, 2013); W. Easterly: "Inequality does cause underdevelopment: Insights from a new instrument", *Journal of Development Economics*, Vol. 84, Issue 2 (2007); D. Acemoglu and J. A. Robinson, *Why Nations Fail* (London, 2012)

richest, or developed, countries in the world, while Chile did not? How can the differences in economic growth be explained? My argument here is that the countries' institutions, in particular specific knowledge institutions, contribute to explain these differences and should be explored further.

6.3 Summary and conclusions

Chile and Norway are both long, narrow and mountainous countries on the periphery of their respective continents. They are similar in geophysical conditions, they posess similar natural resources and have developed many of the same natural resource industries, such as agriculture, fish, extraction of minerals, timber and timber-related industries. Until the 1930s, the two countries had comparable growth in terms of GDP per capita. However, from this time the Norwegian GDP began to grow slightly more and from the 1940s and 50s the economic gap between the two countries was obvious. Another factor, which have separated Chile and Norway, is social differences and access to primary and secondary education. Norway has historically had small social differences. The Norwegian population became literate very early compared to other European countries. Today the country is one of the richest countries in the world and has a welfare state, which covers health, education and other needs for the whole population. Chile's development path, on the other hand, has been different. The country's economy has had slower and more uneven growth than Norway with large foreign debts, trade deficits and poverty. Perhaps as far back as Colonial times, the country has had large social differences and has been slow to provide a general education system for the whole population. There was a high level of illiteracy until the mid-twentieth century. The restricted access to education for a large share of the population have probably affected economic growth negatively. The aim of this thesis is to explore some the underlying factors that explain why Chile and Norway have had such differences in economic growth. Why did the two countries, which started out with similar growth patterns, develop so differently? How can we explain these discrepancies?

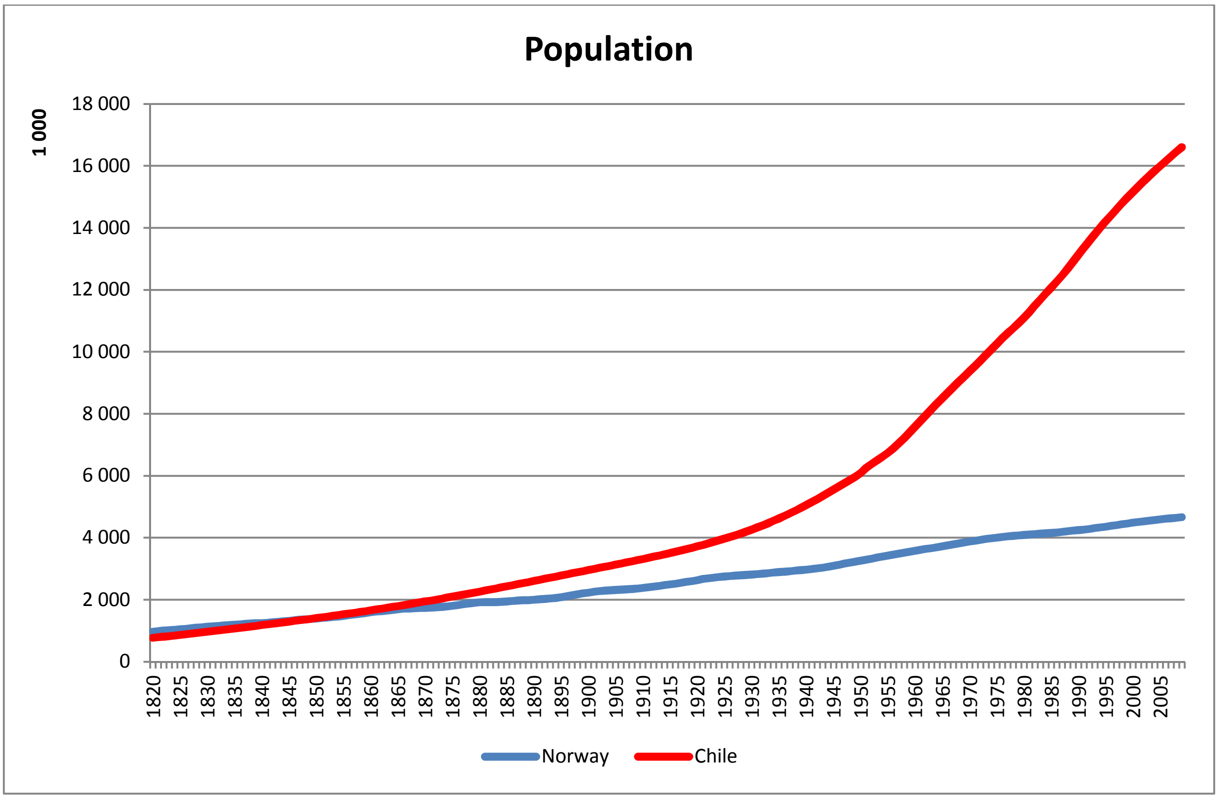
7 Factors explaining the diverging paths of Latin America and Scandinavia

Before drawing specific attention to the mining sectors in Chile and Norway, some of the theories explaining the diverging paths between large groups of countries are revised. General comparisons have been made of Latin America and Scandinavia. In *From Natural Resources to the Knowledge Economy* David de Ferranti and colleagues compare Scandinavia and Latin American countries from a historical perspective. In *Diverging paths: Comparing a Century of Scandinavian and Latin American Economic Development* Magnus Blomström and Patricio Meller (eds.) compare the Scandinavian countries with Latin American countries, focusing on Chile, Colombia, Ecuador and Uruguay. They consider a number of features, mainly demography, level of exports, education, agricultural reforms, economic policy and the use of foreign technology and find that the two country groups have differed when it comes to these factors. They further argue that these aspects to a large degree explain the economic gaps and different social patterns across the two country groups. W. F. Maloney looks at some of these issues, notably education and economic policy.[295] In this section, I review some of the aspects that these scholars point out and discuss these specifically for Chile and Norway. Can these factors really explain the different development paths of these two countries?

7.1 Demography

Blomström and Meller stress the demographic differences between Scandinavia and Latin America. Demography is a factor, which clearly separates Norway and Chile. Chile has had considerably more growth in population than Norway. Both countries had populations of a little less than two million people in 1870, before the Chilean population took off and rapidly grew from the 1940s (see graph below):

[295] W. F. Maloney, "Missed Opportunities: Innovation and Resource-Based Growth in Latin America", *World Bank Policy Research Working Paper* 2935 (2002), pp. 4-5



Source: A. Maddison, Historical Statistics of the World Economy (2010)

While Chile was a "settler economy" with people, notably from Europe, moving to the country, people emigrated from Norway. The first emigration wave from Norway began in the late 1860s. Until the turn of the century 500 000 people had left the country, mostly to the United States. The majority of these came from the country-side and the agricultural sector.[296] Internationally, only Ireland was ahead of Norway when it came to share of population leaving the country.[297] Blomström and Meller argue that "(m)ost likely, the rapid demographic growth in Latin America has diverted savings into widening rather than deepening capital, with possible negative effects on economic growth."[298] They even suggest that Chile's GDP per capita would have been close to the level of Italy and above the level of Spain in 1980 if the country had followed the Scandinavian demographic growth between 1950 and 1980 and at the same time kept its own GDP growth.[299]

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[296] T. Bergh et al. *Norge fra u-land til i-land: vekst og utviklingslinjer 1830-1980* (Oslo, 1983), p. 41
[297] F. Hodne and O. H. Grytten, *Norsk økonomi i det nittende århundre* (Bergen, 2000), p. 131
[298] M. Blomström and P. Meller (eds.), *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development* (Washington, 1991), p. 5
[299] M. Blomström and P. Meller (eds.), *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development* (Washington, 1991), p. 5

On the other hand, is a rapid growing population synonymous with low economic growth? In the case of Norway, the emigration was to some degree seen as an obstacle to growth. Although emigration possibly eased the Malthusian pressure and perhaps reduced social problems, many resourceful people left the country and drained the country of "talent and labor".[300] At the same time, countries with significant growth in population have grown considerably more than Chile. Australia, another resource-based economy, had similar radical growth in population as Chile and turned out to be one of the richest countries in the world. In 1870, the population was fewer than two million, but it grew faster that both Norway and Chile in the decades after.[301] Therefore, although demography perhaps played a role, other factors were probably more important. Blomström and Meller also point this out. They consider Latin America's population growth rate to be of importance, yet explain that "… there are other important factors that to a large extent seem to explain the diverging development paths between the two regions."[302]

7.2 Level of exports

Blomström and Meller show that the level of exports has been considerably lower in Latin America than in Scandinavia. According to them, the difference in the level of exports, may to some degree explain the gap in economic growth because "…international trade has played an important role in Scandinavian development. Economic growth has been export led."[303]

Looking specifically to Chile and Norway, were they different when it came to exports? Both countries

[300] T. Bergh et al. *Norge fra u-land til i-land: vekst og utviklingslinjer 1830-1980*, (Oslo, 1983), p. 223
[301] A. Maddison, *Historical Statistics of the World Economy* (2010)
[302] M. Blomström and P. Meller (eds.), *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development* (Washington, 1991), p. 6
[303] M. Blomström and P. Meller (eds.), *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development* (Washington, 1991), pp. 5-6

have historically actually been characterised as “export-led” economies.[304] There were, however, considerable differences in exports as share of GDP, as Blomström and Meller suggest. Norwegian exports increased from 26, 5 per cent of GDP in 1865 to 46, 6 per cent in 1920; in the 1930s and 1940s it remained between twenty and thirty per cent before it rose to almost forty per cent in the 1950s.[305] It has later remained around forty per cent, sometimes up to fifty per cent until today.[306] In Chile, exports’ share of GDP was in 1865 around fourteen per cent and increased to over twenty per cent at the turn of the century. In the 1950s, it declined to around fifteen per cent but increased again to over twenty per cent in the 1980s and over thirty per cent after 2000 (see table below):[307]

Exports as share of GDP (percentage)

Year	Norway	Chile
1865	26,5	14,3
1870	29,2	13,8
1880	29,8	13,6
1890	32,6	21,9
1900	29,6	22,4
1910	32,8	22,1
1920	35,3	24,5
1930	29,7	19,7
1939	28,2	17,8
1946	24,6	16,9
1950	36,7	14,2
1960	36,3	13,5
1970	36,7	14,6
1980	43,2	22,8
1990	40,1	33,9
2000	46,5	29,3
2010	40,5	38,1
2012	40,7	34,2

Sources: Norges Offisielle Statistikk (1978): *Historisk statistikk*. Oslo: Statistisk Sentralbyrå; J. Braun et al. *Economía chilena 1810-1995 Estadísticas históricas* (Santiago, 2000); from the year 1960 World Data Bank: World Development Indicators (WDI) & Global Development Finance (GDF)

[304] For Norway see F. Hodne and O. H. Grytten, *Norsk økonomi i det nittende århundre* (Bergen, 2000), pp. 235-265. For Chile see A. Pinto Santa Cruz, *Chile, un caso de desarrollo frustrado* (Santiago,1959), p. 39 and M. Carmagnani, *El desarollo industrial y subdesarrollo económico* (Santiago, 1998), p. 12

[305] Norges Offisielle Statistikk, *Historisk statistikk* (Oslo, 1978), pp. 96-97; M. Blomström and P. Meller (eds.), *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development* (Washington, 1991), p. 4

[306] World Data Bank, World Development Indicators (WDI) & Global Development Finance (GDF)

[307] J. Braun et al. *Economía chilena 1810-1995 Estadísticas históricas* (Santiago, 2000), pp. 161-164

Export per capita in prices has also been much larger in Norway than in Chile. Due to lack of data it is hard to compare the two countries historically, but from the 1950s numbers show that 1 282 USD per person were exported in the case of Norway whereas only 217 USD per person in the case of Chile. This increased to 8 442 US dollars in 1985 in the case of Norway and 566 US dollars in the case of Chile.[308] Level of exports is, thus, an economic factor, which distinguishes the two countries.

Does difference in level of exports really explain the gap? We would then have to assume that economies with high levels of exports have had more economic growth than other economies. However, this does not seem to be the case. Economies grow in different ways. Looking to other continents there are resource-based countries with similar share of exports as Chile, but with higher economic growth. The level of exports indicates the degree to which an economy is integrated in international trade, but economic growth may also be generated in other manners. New Zealand, for instance, one of the richest natural resource-based economies in the world, have had similar export levels as Chile. The country had a share of exports between 1870 and 1940 between sixteen and twenty-five per cent of GDP.[309] In 1970, its share of exports was twenty-two per cent, before increasing gradually to around 30 per cent in the 1980s.[310]

Besides, it is frequently argued that economies, which are dependent on exports, such as Norway, often become very vulnerable to foreign markets. Economic crises in Norway have repeatedly been justified as a result of international crises. As crises gradually passed, economic growth are explained by improved economic conditions abroad.[311] In this sense, the fact that Norway exported more than Chile does not explain that much. This difference does not tell us *why* Norway exported more than

[308] M. Blomström and P. Meller (eds.), *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development* (Washington, 1991), p. 4
[309] E. Bilancini, "Agricultural Insitutions, Industrialization and Growth: The Case of New Zealand and Uruguay in 1870-1940", *Center for Economic Research Working Paper* 53 (2010)
[310] World Data Bank, World Development Indicators (WDI) & Global Development Finance (GDF)
[311] T. Bergh et al. *Norge fra u-land til i-land: vekst og utviklingslinjer 1830-1980*, (Oslo, 1983), p. 229

Chile or *how* the two countries produced their export goods and services. I argue that further research should be implemented on Chile's production and export potentials and whether the country would have been able to produce and export more than it did.

7.3 Agriculture and agricultural reforms

Agriculture dominated both the Latin American and Scandinavian economies during the nineteenth century. Blomström and Meller compare the Scandinavian and Latin American agricultural systems and argue that the agrarian reforms in Scandinavia encouraged "a more efficient and intensive cultivation of land".[312] According to them, these reforms maintained small- and medium-sized privately owned farms and an equal distribution of income, which in turn encouraged an increase in markets and consumption.[313] Moreover, additional income from the modernisation in the agricultural sector increased the tendency to invest and fostered supporting sectors.[314] In Latin America, on the other hand, the hacienda system was very inefficient and had a negative effect on domestic demand. Land reforms were not implemented until the 1960s-70s, and they did not, perhaps, involve large changes.[315] In their comparison of North and South America during the eighteenth and nineteenth centuries, Engerman and Haber confirm that the agricultural system in Latin America was inefficient. They argue that patterns of settlement led to unequal distribution of income in the slower-growing areas in Latin America, and subsequently slower growth.[316]

Looking particularly to Chile and Norway, land was distributed in two very different ways. In Norway, the countryside was traditionally divided into many small parcels. In 1821 and 1857, "replacement

[312] M. Blomström and P. Meller (eds.), *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development* (Washington, 1991), p. 6
[313] M. Blomström and P. Meller (eds.), *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development* (Washington, 1991), p. 6
[314] M. Blomström and P. Meller (eds.), *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development* (Washington, 1991), p. 6
[315] M. Blomström and P. Meller (eds.), *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development* (Washington, 1991), p. 7
[316] S. L. Engerman et al. "Chapter 11: Inequality, institution and differencial paths of growth among New World economies" in Institutions, Contracts and Organizations, C. Ménard (ed.) (Cheltenham, 2000)

laws"[317] were ratified and legitimatised larger land parcels. Scholars emphasise the importance of these reforms for increase in production. The larger land parcels simplified the organisation of work and an intensification of production started with the use of new techniques. New labour saving equipment was adopted and farmers began to use less work-intensive methods.[318] To some degree, these laws can be compared to the "enclosure acts" in England.[319] Production in arable farming was quadrupled between 1809 and 1855.[320] Livestock husbandry also started to replace cultivation of the soil to some degree and dairies represented an industrial form of production.[321] Fritz Hodne affirms that farmers slowly but surely made room for saving some of the profit, which in turn led to new investments.[322] In parallel, the number of farmers was reduced from 421 000 in 1875 to 362 000 in 1900.[323] There was a gradual decline in the share of population that subsisted on agriculture, forestry and fishing. In the beginning of the nineteenth century 80, 4 per cent of the population had agriculture, forestry or fishing as their source of livelihood, in 1900 the share had decreased to 44, 3 per cent and in 1970 to 11, 6.[324] Bergh and colleagues describe the replacement laws as "the most consequential reform in agriculture in this and the previous centuries".[325] In Chile, on the other hand, the feudal hacienda system involved a concentration of land in much fewer hands. According to Chilean authors, the system was "backward" and adopted few new techniques. A lack of land reforms and a major concentration of wealth in the higher classes are seen as underlying factors for slow economic growth.[326]

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317 *Lov angående Jords og Skovs Udskiftning af Fællesskap* (17 August 1821); *Lov om Jords og Skovs Udskiftning af Fællesskab* (12 October 1857)
318 T. Bergh et al. *Norge fra u-land til i-land: vekst og utviklingslinjer 1830-1980*, (Oslo, 1983), pp. 40-41
319 F. Hodne and O. H. Grytten, *Norsk økonomi i det nittende århundre* (Bergen, 2000), pp. 173-187
320 T. Bergh et al. *Norge fra u-land til i-land: vekst og utviklingslinjer 1830-1980*, (Oslo, 1983), p. 32
321 T. Bergh et al. *Norge fra u-land til i-land: vekst og utviklingslinjer 1830-1980*, (Oslo, 1983), p. 45
322 F. Hodne and O. H. Grytten, *Norsk økonomi i det nittende århundre* (Bergen, 2000), pp. 173-187
323 T. Bergh et al. *Norge fra u-land til i-land: vekst og utviklingslinjer 1830-1980*, (Oslo, 1983), p. 40
324 T. Bergh et al. *Norge fra u-land til i-land: vekst og utviklingslinjer 1830-1980*, (Oslo, 1983), p. 240
325 T. Bergh et al. *Norge fra u-land til i-land: vekst og utviklingslinjer 1830-1980*, (Oslo, 1983), p. 39
326 A. Pinto Santa Cruz, *Chile, un caso de desarrollo frustrado* (Santiago, 1959); M. Carmagnani, *El desarollo industrial y subdesarrollo económico* (Santiago, 1998); C. Gazmuri Riveros, *El "48" Chileno Igualitarios, Reformistas; Radicales, Masones y Bomberos* (Santiago, 1998)

However, taking a closer look at the two agricultural sectors, such a conclusion is probably too simplistic. Cariola Sutter and Osvaldo Sunkel argue that the agricultural sector in Chile was certainly not as backward as some claim. Actually, they find evidence that the industry went through a number of changes. They show that productivity in the sector increased between 1875 and 1930 and conclude that: "…agriculture during the period 1880-1930 experienced a considerable expansion and diversified its production."[327] Specifically, productivity increased in a variety of productions, such as wheat, barley, beans, potatoes, corn and peas, especially during the periods 1877-78 and 1912-13.[328] They base their argument on several points. First, they show that several technological changes were adopted. These were, for example, irrigation channels, expansion of irrigated areas, experimentation with new seeds and crops, gradual introduction of a crop rotation system, instead of the traditional fallow system, cattle household for milk and meat production, formation of artificial grassland, replacement of traditional rural methods for imported machinery and tools, changes in the organisation of agribusiness and experimentation with different remuneration systems.[329] They find that a major expansion and transformation of agriculture occurred in the central part of the country from 1850 and onwards. From being a relatively restricted and isolated industry, it became a widespread activity throughout central regions. With the export of wheat and flour, especially between 1850 and 1870, as well as livestock, wood and agricultural products such as dry grass, potatoes, nuts, honey, dried meat, fruits, eggs and cheese, the sector developed close trade ties with distant global markets like California, Australia and England, Bolivia and Peru.[330] Second, they argue that the export of wheat and flour did not decline after the 1870s, as other scholars sustain, but rather remained the same.[331] At the same time there seem to have been an increase in productivity. There was a gradual decrease of the share of total population living in the countryside. Around 78 per cent lived in the countryside in 1865, before it decreased to 71 per cent in 1885, to 62 per cent in

[327] C. C. Sutter and O. Sunkel, *Un siglo de historia economica de Chile* (Santiago, 1990), p.112
[328] C. C. Sutter and O. Sunkel, *Un siglo de historia economica de Chile* (Santiago, 1990), p.112
[329] C. C. Sutter and O. Sunkel, *Un siglo de historia economica de Chile* (Santiago, 1990), p. 113
[330] C. C. Sutter and O. Sunkel, *Un siglo de historia economica de Chile* (Santiago, 1990), pp. 73-75
[331] C. C. Sutter and O. Sunkel, *Un siglo de historia economica de Chile* (Santiago, 1990), pp. 107-108

1907, 57 per cent in 1920 and 49 per cent in 1940.[332] Moreover, between 1875 and 1930, the population in the core centre of agricultural production fell from 48 per cent of the total population to 24 per cent and the rural population in this area fell from 71 per cent to 44 per cent.[333]

Taken the previous in consideration, can reforms in the agricultural sector explain differences in growth of Chile and Norway? It is often claimed that larger pieces of land are needed to intensify agricultural operations and increase productivity. Industrialisation require "a very skewed income distribution" because poor people do not save and growth is stimulated by large differences.[334] "A very skewed income" fits better with the agricultural sector in Chile than the one in Norway, which would make the former country better fit for higher savings, new investments and growth. At the same time, some scholars argue that the progress in the agricultural industry in Norway is overrated. The small land properties meant small-scale production, which according to some actually slowed down progress and modernisation.[335] Within this line of argument, Sima Lieberman finds that Norway lacked a commercialised agricultural system and that there was really no effective enclosure movement in the nineteenth century. According to him the general system of agricultural production remained tied to centuries-old open-field methods and the farmers were ignorant of efficient methods, such as crop rotation; seed selection etc.[336] How, then, can we understand differences in the two agricultural sectors? It is clear that the distribution of land was different in the two countries and that the agricultural sector was organised in two different ways. However, it is not clear whether the agricultural sector in Norway was more productive and more developed than the one in Chile. In fact, it is not evident which system was better for economic growth. A more detailed comparative analysis of the two agricultural sectors is required to understand the underlying factors for their growth and their role in the Chilean and Norwegian economies.

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[332] C. C. Sutter and O. Sunkel, *Un siglo de historia economica de Chile* (Santiago, 1990), p. 118
[333] C. C. Sutter and O. Sunkel, *Un siglo de historia economica de Chile* (Santiago, 1990), p. 95
[334] T. Bergh et al. *Norge fra u-land til i-land: vekst og utviklingslinjer 1830-1980* (Oslo, 1983), p. 233
[335] F. Hodne and O. H. Grytten, *Norsk økonomi i det nittende århundre* (Bergen, 2000), pp. 16-17
[336] S. Lieberman, *The Industrialization of Norway, 1800-1920* (Oslo, 1970), pp. 152-54

7.4 Education

Blomström and Meller find that an "…important prerequisite for Scandinavia's success is undoubtedly the high level of education of its population. At a very early stage, the Scandinavian countries began to support education."[337] The large inequalities in Latin America, in contrast, was accompanied by a marginalisation of a large share of the populations, restricted the access to education and high illiteracy rates.[338]

The previous chapter describes how primary and secondary education started much earlier in Norway and that school attendance was higher from early on. This contributed to a much more literate population in Norway than in Chile. So, how can we understand the differences in the level of literacy and schooling in Chile and Norway? The fact that Norway started earlier with primary schooling and a higher share of the population was literate indicates that workers were more receptive to absorb knowledge. Codified knowledge would eventually spread easier there. Nevertheless, a higher level of literacy does not explain how knowledge was benefited and used and how innovation occurred.

Then again, some scholars focus on other types of education, namely tertiary and technical schooling. William N. Parker claims that "…the spread of technological knowledge, narrowly considered, is not a matter of mass education, but the training of a small elite."[339] Higher and technical education is also used as an argument for Latin American countries' underdevelopment. Ferranti and colleagues emphasise:

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[337] M. Blomström and P. Meller (eds.), *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development* (Washington, 1991), p. 7

[338] D. De Ferranti et al. *From Natural Resources to the Knowledge Economy* (Washington D. C., 2002), p. 65

[339] W. P. Parker, "Economic Development in Historical Perspective", *Economic Development and Cultural Change*, vol. x, No. 1 (1961), p. 1

> "…the historical lack of an infrastructure for scientific learning and innovation … [...]… Chile's rich culture would produce two Nobel Prize winners in literature, a major surrealist painter, and first-class musicians. But it lagged behind in engineering sciences."[340]

Blomström and Meller argue that:

> "(t)he heavy investment in learning and human capital in Scandinavia not only facilitated the emergence of domestic entrepreneurs, capable of absorbing new ideas from abroad, but also provided the entrepreneurs with an educated and skilled work force. This never happened in Latin America…[…]… if Chilean governments had more actively promoted the development of domestic human capital and entrepreneurial capacity, the Chilean economy could have gained much more than it did from the nitrate and copper exploitation of the foreign investors."[341]

In the same line of argument, W. F. Maloney argue the following:

> "Sweden possessed the fundamentals of a modern engineering industry by about 1850…[…]… and was exporting engineers by 1900. In the same year, serious research in chemistry was undertaken at the University of Oslo that would lay the foundation for the dominant fertilizer, electrochemical, and electrometallurgical industries in Norway… […]… Latin America for the most part lagged behind Spain and Portugal in developing a technical class." [342]

This is in accordance with Chilean scholars who emphasise the lack of technical capacity in Chile. According to Aníbal Santa Cruz and Oscar Muñoz Gomá learning processes, which would enable the adaption and development of techniques in mining, never took place. The capacity to manage large

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[340] D. De Ferranti et al. *From Natural Resources to the Knowledge Economy* (Washington D. C., 2002), p. 60

[341] M. Blomström and P. Meller (eds.), *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development* (Washington, 1991), p. 12

[342] W. F. Maloney, "Missed Opportunities: Innovation and Resource-Based Growth in Latin America", *World Bank Policy Research Working Paper* 2935 (2002), pp. 8-9

copper mining projects, copper being one of the largest industries in Chile, was not developed until the 1950s.[343]

Yet, how different were Chile and Norway with regard to technical and higher education? At first glance, it is not obvious that they differed in this respect. First, Chile actually opened its first university before Norway did (Chile in 1758 and Norway in 1811). Norway had some more students at University level than Chile in the late nineteenth century, but the number of students increased dramatically in Chile in the early twentieth century (see table below):

Students at Universities (in thousand)

Year	Norway	Chile
1875	0,8	--
1885	1,4	0,9 (year 1886)
1895	1,1	1,2
1905	1,3	1,2
1915	1,5	4,5
1925	3,2	6,3
1935	3,9	6,0
1945	6,0	7,1
1955	3,7	17
1965	14,4	44
1975	40,8	147
1985	41,7	197
1995	85,7	272
2002	80,6	--

Sources: B.R. Mitchell, International Historical Statistics The Americas 1750-2005 (New York, 2007) and B.R. Mitchell, International Historical Statistics Europe 1750-2005 (New York, 2007)

Furthermore, during the nineteenth century, both countries established technical study programs and schools at both intermediate and tertiary level. Engineering programs in engineering were provided at the University of Oslo from 1814. In addition, three intermediate technical schools in Bergen, Trondheim and Oslo were established from the 1870s with different technical programs and specialisations. Other technical schools and evening schools were founded in a number of towns and

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[343] See A. Pinto Santa Cruz, *Chile, un caso de desarrollo frustrado* (Santiago,1959) and O. Muñoz Gomá, *Chile y su industrialización* (Santiago, 1986)

near industrial areas, such as Bergen Drawing School of 1772, Horten Technical School of 1855, Skienfjorden Technical School of 1887 and the School of Agriculture of 1854 (Higher School of Agriculture from 1897).[344] Technical evening schools were founded in cities such as Stavanger and Kristiansand in the late 1870s.[345] The Norwegian Institute of Technology (NIT), much based on the German Technische Hochschulen, was founded in 1910 and provided engineering programs on a tertiary level.[346] In Chile, technical education was established much in the same way. Engineering programs were provided from 1856 at the University of Chile. The aim of the Faculty of Mathematics was to function as a polytechnic educational institution.[347] Additionally, intermediate technical schools of different kinds were founded in the second half of the nineteenth century. These were the Industrial Schools of Concepción and Temuco, the Mining Schools of Copiapó, La Serena, Santiago, and later Antofagasta, among others. The Chemical and Industrial Laboratory was established in Iquique in 1898. It provided analysis, tests and services to the saltpetre and mining industry. It also provided courses of two years in chemistry, industrial chemistry and chemical analysis.[348] Perhaps the most famous one is the School of Arts and Crafts, which was established in 1849. Evening schools were also founded.[349] Additionally, private mining companies organised seminars and evening schools for their employees. The North American Braden Copper Mining Company, for instance, provided courses in mathematics and mechanical drawing.[350] A course in industrial electricity was provided at the same company.[351] In both countries the study programs at these technical schools were diverse and were either practical programs directed towards a specific industry, such as mining, carpentry or architecture, or general programs which provided the students with more general preparations, such

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[344] T. Bergh et al. *Norge fra u-land til i-land: vekst og utviklingslinjer 1830-1980*, (Oslo, 1983), p. 52
[345] F. Hodne, *Norges økonomiske historie 1815-1970* (Oslo, 1981), p. 245
[346] T. J. Hanisch and E. Lange, *Vitenskap for industrien NTH – En høyskole i utvikling gjennom 75 år* (Oslo, 1985), p. 23
[347] I. Domeyko, “Reseña de los trabajos de la Universidad desde 1855 hasta el presente”, in *Anales de la Universidad de Chile* (October 1872), p. 20
[348] A. A. Muñoz Sierpe; *Enseñanza Universitaria y Técnica de Chile* (Santiago, 1909), p. 31
[349] A. A. Muñoz Sierpe; *Enseñanza Universitaria y Técnica de Chile* (Santiago, 1909)
[350] *Topicos del Teniente Periodico quincenal dedicado a los intereses del personal de la Braden Copper Co*, No 1 (6 April, 1919), p. 8
[351] *Topicos del Teniente Periodico quincenal dedicado a los intereses del personal de la Braden Copper Co*, No 13 (January, 1920), p. 16

as chemistry, mathematics or civil or electrical engineering (see table below):

Selected formal educational institutions

with intermediate and higher technical and engineering study programs

Chile		Norway	
Institution	***Year of foundation***	***Institution***	***Year of foundation***
eighteenth century			
Real Academy of San Luis (Real Academia de San Luis)	1797	Mining seminar in Kongsberg	1757
nineteenth century			
National Institute	1813	The Royal Frederick University	1811
University of Chile (Universidad de Chile)	1842	Horten Technical School	1855
Potifical Catholic University	1888	Higher School of Agriculture	1859
School of Arts and Crafts of Santiago	1849	Kongsberg Silver Work's Elementary Mining School	1866
Mining School of Copiapó	1857	The Technical Training Institution in Trondhjem	1870
Mining School of La Serena	1887	Kristiania Technical School	1873
Mining School of Santiago	1887	Bergen Technical School	1875
School of Naval Engineers	1896	Skienfjorden Technical School	1887
Early twentieth century			
Industrial School of Chillán	1905	Norwegian Technical Institute	1910
Industrial School of Concepción	Early twentieth century		
Industrial School of Temuco	Early twentieth century		
Mining School of Antofagasta	1918		
University of Concepción	1919		
Federico Santa María Technical University	1931		

Sources: A. K. Børresen and J. T. Kobberrød (red.), *Bergingeniørutdanning i Norge gjennom 250 år* (Trondheim, 2007); L. Thue et al. *Statens kraft 1890-1947* (Oslo, 2006); C. O. G. Gjesdal, *Med teknikken på timeplanen Bergen Tekniske Skole 1875-1975*, bind I (Bergen, 1975); H. O. Christiansen et al. *25-års jubileumsberetning 1912-1937 Bergen Tekniske Skole Oslo Tekniske Skole Trondheim Tekniske Skole* (Norway, 1937); *Festskrift i anledning af Kristiania Tekniske Skoles 25 aars jubilæum* (Kristiania, 1898); R. Baggethun, R. Horten *Ingeniørhøgskole Horten tekniske skole En beretning om landets eldste tekniske skole gjennom 125 år* (Horten, 1980); Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966); *Trondhjems Tekniske Mellomskoles virksomhet i de 3 første læseaar 1912-1915* (Trondhjem, 1916); A. A. Muñoz Sierpe, *Enseñanza Universitaria y Técnica de Chile*; *Chile en la Exposición de Quito*, (Santiago, 1909); S. Villalobos et al., *Historia de la ingenieria en Chile* (Santiago, 1990); J. G. Muñoz C. et al. *La Universidad de Santiago de Chile: Sobre sus orígenes y su Desarrollo Histórico* (Chile, 1987)

This historical overview indicates that initiatives were taken in both countries to create educational institutions, at both intermediate and higher levels. At this stage, it does not seem like the two countries differed considerably in terms of technical capacity. On the other hand, a more detailed analysis of the aims and functions of these institutions and their direct impacts on industrial development is appropriate.

7.5 Industrial policy and natural resources

Malmström and Meller find that "(w)hile the Scandinavian countries based their future industries and comparative advantages on natural resource endowments, the Latin American countries did not."[352] According to them "(f)ew competitive industries …[…]… have grown out of natural resources" in Latin America.[353] In the same line of argument, Ferranti and colleagues confirm that one of the biggest historical mistakes often committed by Latin American countries is to have turned their backs on their natural advantages.[354] They even have found that "…natural resources have been treated with suspicion. The fact that foreign firms controlled most of the exports of natural resources in Latin American countries helps to explain this attitude."[355] W. F. Maloney refers to the Haig technical mission to Chile of 1944, which revealed the "indisputable truth that an adequate management of our forests could become the basis for a great industry of forest products." However, he stressed, "…nothing remotely similar to the dynamic Scandinavian experience appeared in this country until the late 1970s.[356] An important point in this context is that Latin American countries introduced import substitution policies instead of developing industries based on natural resources. In retrospect, these policies have been understood as negative for the Latin American economies (see previous chapter about natural resources and economic growth).

How does these arguments fit in the cases of Chile and Norway? In the case of Norway, growth has largely been based on linkages between industries and specialisations within natural resource sectors. Development has been characterised by industries naturally encouraging one another.[357] For

[352] M. Blomström and P. Meller (eds.), *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development* (Washington, 1991), p. 8
[353] M. Blomström and P. Meller (eds.), *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development* (Washington, 1991), p. 9
[354] D. De Ferranti et al. *From Natural Resources to the Knowledge Economy* (Washington D. C., 2002), p. 8
[355] M. Blomström and P. Meller (eds.), *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development* (Washington, 1991), p. 9
[356] W. F. Maloney, "Chile" in *The Political Economy of Latin America in the Post-War Period,* L. Randall, ed. (Austin, 1997), p. 25
[357] See publications by Keith Smith, Olav Wicken and Jan Fagerberg

instance, mechanical workshops grew from the 1840s and supplied equipment and machinery from early on to natural other sectors, such as the growing timber- and timber processing industry, the shipping industry, the mining industry etc. (see chapter about the mining sector in Chile).[358] Shipping, one of the important non-resource industries, has long traditions in Norway. This industry has functioned as a driving force for other industries. In recent years, marine electronics have developed and created the first automated navigation systems. Norway continues to be a leader in surface and sub-sea marine electronics applications.[359] Fishing, another natural resource industry, also has long traditions in Norway. The export of fish was intimately linked with the shipping industry and the canning industry from the 1860s.[360] Another example is the electro-metallurgical and chemical industries, which from the late nineteenth century developed due to hydroelectric capacity, another natural resource of which there is a lot in Norway. From the 1970s, the ship building industry diversified and expanded their activities to supply equipment for the important oil and gas sector. Other industries, such as engineering, information technology and business services, also developed to become suppliers to this sector.[361]

But, were the two countries really so different in terms of industrial policy, encouraging industries and linkages? There are examples in Chile of the use of "natural advantages" and new productions emerging from old natural resource-based activities. The mining sector grew during the nineteenth century and the country became one of largest producer of copper in the world. The historians Julio Pinto Vallejos and Luís Ortega Martínez find that in the late nineteenth century, the mining industry encouraged the national manufacturing production. The demand for different types of goods increased, such as intermediate goods and industrial machinery for the mining companies, as well as

[358] See E. Lange (ed.), *Teknologi i virksomhet: verkstedindustri i Norge etter 1840* (Oslo, 1989)
[359] K. Smith, "Innovation and growth in resource-based economies", in CEDA, *Competing from Australia* (Australia, 2007), p. 9
[360] T. Bergh et al. *Norge fra u-land til i-land: vekst og utviklingslinjer 1830-1980* (Oslo, 1983), pp. 71-100
[361] Fagerberg et al. "The evolution of Norway's national innovation system", *Science and Public Policy*, vol. 36, No. 6, July (2009), pp. 434-435

consumer goods for the high number of workers, and they find that this led to an emergence of industrial enterprises in the mining provinces.[362] There are also other examples. Cellulose and paper productions started from second part of the nineteenth century and emerged based on the large forests in the Southern part of the country. Wine production started with small quantities in the 1870s and developed to become an export sector.[363] In fact, the wine industry has grown considerably in recent decades based on complex technology, knowledge and competence.[364] In recent years, fresh fruit has become an increasingly important natural resource export sector. These industries, as well as the timber- and timber-related industries and the fishing industries, notably salmon production, have recently grown with the support of the government and CORFO.[365]

On the other hand, Chile was not the only country, which introduced protectionist economic policies and substituted imports. Tariffs were gradually set on a number of products in Norway too, although they were perhaps slightly lower than in Chile. Until 1873, most trade barriers were non-existent in Norway. Later, import substitution was introduced through taxes on several imported goods. In 1905, for instance, taxes were set on cotton products, fishhooks and machinery, among other things.[366] In the 1930s, the average Norwegian tariffs increased from 10 to 15 percent, and in certain growth sectors such as textiles and clothing, the rates raised to 25 percent.[367] At the same time, previously imported goods and services started to be produced in Norway to a certain extent. These were for instance consumer goods, such as furniture, stoves and other electrical devices, sports equipment, textiles and clothing products.[368] Furthermore, in 1927 the Parliament introduced the "10 per cent rule", which meant that 10 per cent was to be added to foreign bids before choosing between foreign

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[362] J. Pinto Vallejos and L. Ortega Martínez, *Expansión minera y desarrollo industrial: un caso de crecimiento asociado (Chile 1950-1914)* (Santiago, 2004), p. vii
[363] C. C. Sutter and O. Sunkel, *Un siglo de historia economica de Chile* (Santiago, 1990), p. 156
[364] K. Smith, "Technological and Economic Dynamics of the World Wine Industry", *International Journal of Technology and Globalisation*, vol. 3 (2007), pp. 127-137
[365] D. De Ferranti et al. *From Natural Resources to the Knowledge Economy* (Washington D. C., 2002), p. 71
[366] F. Hodne, *Norsk økonomi i det tyvende århundre* (Bergen, 2002), pp. 138-140
[367] F. Hodne, *Norsk økonomi i det tyvende århundre* (Bergen, 2002), p. 156
[368] F. Hodne, *Norsk økonomi i det tyvende århundre* (Bergen, 2002), pp. 138-140

and domestic suppliers. This was in practice a measure of import substitution.[369]

Taking the previous in consideration, can economic policy really explain the economic gap of the two countries? Although tax policies might have differed to some degree, both countries had periods of free trade and export-led policy, but also adopted political measures for import substitution for certain industries. In overall terms, the industrial policies of the two countries were perhaps not so different. In this respect, it is relevant to mention that there probably do not exist "… any prosperous state today which have not previously had a protectionist phase with public promoter – protective and development policies."[370] This argues strongly in favour of protectionism and import substitution. To find out whether industrial policy contributes to explain the economic divergence, I believe that further, deeper and more detailed comparative analyses of policy-making and direct connections between political decisions, industrial development and economic growth, is required

7.6 Foreign technology and capital

The dominant role of foreign investments in Latin American countries has been a subject of debate. Blomström and Meller argue that Latin American countries have not been able to take advantage of foreign investments the same way as Scandinavian countries. They determine that foreign technology and multinational companies have "…never had the same impact on Latin American development as it had on Scandinavian development."[371] This argument is related to the idea that these countries were too far behind to be able to benefit from technologically advanced and up-to-date multinationals.

[369] A. Stonehill, *Foreign Ownership in Norwegian Enterprises* (Oslo, 1965), p. 48
[370] F. Hodne and O. H. Grytten, *Norsk økonomi i det nittende århundre* (Bergen, 2000), p. 13
[371] M. Blomström and P. Meller (eds.), *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development* (Washington, 1991), pp. 11-12

Foreign investments started to enter Chile immediately after independence from Spain in 1810.[372] The economist Markos Mamalakis stresses the large share of foreigners in Chilean industries:

> "The ownership transformation that started almost immediately after independence involved an increased share of factors of production contributed by foreigners and included a wide range of patterns. This was accelerated after 1880, and its magnitude, speed, and nature differed among sectors."[373]

Francisco Antonio Encina, a Chilean historian and politician of the time, argued that: "(b)y 1890 almost all the industries of any importance that existed in the country were held by foreigners and their immediate descendants."[374] The building of railroads from the mid-nineteenth century, for instance, was to a large degree carried out with British capital.[375] Official statistics from 1895 confirm that foreign investments were large in most industries: in the mechanical workshop industry, the foreign capital was more than double the national was and the shipping industry was developed mostly with English capital.[376] Actually, maritime movement through Chilean ports increased tenfold between 1890 and 1900, but foreign-owned international companies dominated the trade and the share of Chilean tonnage decreased. In this period, Chileans handled around 20 per cent of the maritime traffic, while British, Americans, Norwegians and other foreigners, dominated the rest.[377] Foreigners also played a crucial role in banking, industry and other services.[378] Furthermore, foreigners invested in clothing, printing, books, food processing industry, chemical and pharmaceutical products, glassware, window glass, ceramics, foodstuffs, furniture, utensils and

[372] A. Sutulov, "Antecedentes históricos de la producción de cobre en Chile", in *El cobre chileno,* A. Zauschquevich, A. and A. Sutulov (Santiago, 1975), p. 18
[373] M. J. Mamalakis, *The growth and structure of the Chilean economy* (London and New Haven, 1976), p. 50
[374] Quote taken from A. Pinto Santa Cruz, *Chile, un caso de desarrollo frustrado* (Santiago,1959), p. 58
[375] S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990); L. Ortega Martínez, "Acerca de los origenes de la industrialización chilena 1860-1879" in *Nueva Historia* año 1 no. 2 (London, 1981)
[376] Sociedad de Fomento Fabril, *Boletín de la Estadística Industrial 1894-95* (Santiago, 1895)
[377] M. J. Mamalakis, *The growth and structure of the Chilean economy* (London and New Haven, 1976), pp. 50-51
[378] M. J. Mamalakis, *The growth and structure of the Chilean economy* (London and New Haven, 1976), p. 54

construction.[379] This trend continued. In 1915 one-third of the manufacturing companies confirmed that their capital was foreign.[380] In 1925 and 26, one-third of the owners of commercial establishments were foreigners with Spanish, Italians and Ottomans being the leading groups.[381]

With the War of the Pacific (The Saltpetre War) from 1879 to 1884, Chile acquired the territory, which today is the northern part of the country. These territories contained large deposits of caliche (raw material containing nitrate) and the country became subsequently a large producer of saltpetre. Foreign investors, especially British, dominated the Chilean saltpetre industry from the 1870s. John Thomas North, a British mechanic, was a dominant figure in this industry.[382] He came to Chile in 1865, started to work in a Peruvian nitrate company in 1871, and began building a series of small enterprises in Iquique. He formed the Liverpool Nitrate Company Limited in 1883, which turned him into the "King of Saltpetre".[383] Other important British saltpetre companies were Anglo-Chilean Nitrate and Railways Company Ltd. and Saltpetre Company of Tarapacá and Antofagasta.[384] In 1884, the Chilean investments in the saltpetre production represented 36 per cent; the English had 34 per cent of the investments and non-nationalised European capital represented 30 per cent. In 1901, the British capital represented 55 per cent; other European investments amounted 30 per cent and Chilean investments 15 per cent (see tables below of nationality of producers in 1925):[385]

[379] M. J. Mamalakis, *The growth and structure of the Chilean economy* (London and New Haven, 1976), p. 53
[380] The actual figure was possibly higher because this did not include foreign capital invested in anonymous corporations.
[381] M. J. Mamalakis, *The growth and structure of the Chilean economy* (London and New Haven, 1976), p. 51-52
[382] M. Monteon, "North the Nitrate King, Chile's lost future", *Latin American Perspectives*, vol. 30, No. 6, Chile since 1990: The Contradictions of Neoliberal Democratization, part 2, (2003), p. 71
[383] M. Monteon, "North the Nitrate King, Chile's lost future", *Latin American Perspectives*, vol. 30, No. 6, Chile since 1990: The Contradictions of Neoliberal Democratization, part 2, (2003), p. 75
[384] A. Soto Cardenas, *Influencia británica en el salitre: origen, naturaleza y decadencia* (Santiago, 1998), pp. 382-383
[385] A. Pinto Santa Cruz, *Chile, un caso de desarrollo frustrado* (Santiago,1959), p. 55

Nationality of saltpetre producers in 1925

Nationality	Number of works in operation	Production	
		Tons	Percentage corresponding to each country
Chilean	34	978 334	38,76
English	48	1 231 107	48,78
Yugoslavian	6	117 200	4,64
North-American	6	170 574	6,76
Peruvian	2	26 721	1,06
Total	**96**	**2 523 936**	**100**

Source: Anuario Estadistico, *Mineria y Metalurgia* (Santiago, 1925), p. 34

In 1925 Chilean investors had increased their share in saltpetre production to 34 per cent, but North American capital, primarily the Guggenheim Brothers, started taking over the industry by the end of the 1920s.[386] In 1924 the Guggenheim Company purchased the British-owned Anglo-Chilean Nitrate and Railway Co and formed Anglo-Chilean Consolidated Nitrate Corp.[387] In 1929 the company acquired the majority of Lautaro Nitrate Co Ltd, a giant British producer. With these investments, the Guggenheims acquired leadership in Chile's largest industry.[388] Actually, one of the largest North American investments in Latin America was in the Chilean saltpetre production, in addition to the immense investments in Chilean copper.[389]

From the early twentieth century, North American companies invested large sums in the Chilean copper production. Copper production in Chile stagnated from the 1880s, due to the exhaustion of high-grade ores, and the industry had not been able to recover after this.[390] William Braden, a North American engineer and industrialist, initiated what was called "Big Mining" and large-scale production of low-grade ores of under four per cent copper content.[391] He came to Chile in 1894 to

[386] A. Soto Cardenas, *Influencia británica en el salitre: origen, naturaleza y decadencia* (Santiago, 1998), pp. 382-383
[387] M. Wilkins, *The Maturing of Multinational Enterprise: American business abroad from 1914 to 1970* (Cambridge, 1974), p. 104
[388] M. Wilkins, *The Maturing of Multinational Enterprise: American business abroad from 1914 to 1970* (Cambridge, 1974), p. 104
[389] G. Jones, *Multinationals and Global Capitalism* (Oxford, 2005), p. 47
[390] S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 174
[391] M. C. Baros Mansilla, *Una historia de pioneros* (Santiago, 2006), p. 44

participate and present North American machinery at the National Exposition of Mining and Metallurgy in Santiago. He met the Italian engineer Marcos Chiapotti and together they planned and developed large-scale mining production at the large copper deposit El Teniente, near Santiago. In 1905, the Braden Copper Company was authorised to start operation in Chile.[392] In 1913, large-scale mining was also initiated with open-pit mining in the Chuquicamata mine in the northern part of Chile. Chile Exploration Company, a subsidiary of the North American Anaconda Copper Mining Co., started operation there in 1912. With these greenfield projects the North American companies Braden Copper Co. (Kennecott Corporation), Chile Exploration Company and Andes Copper Company (owned by Anaconda Copper Company), started dominating the Chilean mining sector.[393] The table below shows Chilean share of the mineral production. In 1920, it was lower than 50 per cent in almost all the mineral productions, except coal:

Chilean share in mineral production in 1920

Principal products	*Production in millions of Chilean pesos of 18 pence*		*Chilean percentage*
	Total	*Chilean*	
Nitrate	473.0	264.7	55.96
Copper	107.5	12.0	11.21
Coal	71.2	65.1	91.35
Iodine	8.1	3.8	47.27
Silver	8.1	3.1	38.14
Sulphur	1.7	0.9	56.96
Gold	1.8	0.6	35.13
Borax	4.1	0.016	0.39

Source: S. Macchiavello Varas, *El problema de la industria del cobre en Chile y sus proyecciones económicas y sociales* (Chile, 2010), p. 91

The foreign investments was seen as negative among politicians and industrialists. Some Chileans became anxious. In the Chilean press, it was argued that:

[392] M. C. Baros Mansilla, *Una historia de pioneros* (Santiago, 2006), p. 44
[393] Home page CODELCO (www.codelco.cl).

> "…our rich ground, filled with treasures, is passing slowly into the hands of strangers. The great deposits of copper, iron, nitrate that constitute incalculable fortunes are taken year after year by the capital and by the industry of strangers…"[394]

Moreover, the hydroelectric potential was in a large degree utilised by foreigners, notably the North American copper companies. In 1920, the lawyer and politician Santiago Macchiavello Varas stated that:

> "Chile is one of the privileged countries, because the Andes Mountains have countless waterfalls; the only thing we regret is the fact that almost every major natural waterfalls are being gradually monopolised by foreign capitalists."[395]

The foreign companies were criticised for contributing to a "denationalisation" of the mining industry. The argument was that the foreign companies extracted saltpetre, and later copper, and fled the country with the earnings. In turn, Chileans lost, both in terms of capital and local industrial development.

Then again, taking a closer look at Norway foreign companies also stood for a large share of investments there. Foreign investments, notably English, started to enter the mining industry from the early nineteenth century. From 1880 to 1904 around 5 657 500 pounds were invested in several Norwegian mining productions, such as gold, copper, iron, diatomite, uranium, wolfram, zinc and others.[396] In 1885, foreigners owned 5 out of 8 large mining works.[397] Between 1875 and 1900, the

[394] Quote taken from M. Wilkins, *The Maturing of Multinational Enterprise: American business abroad from 1914 to 1970* (Cambridge, 1974), p. 11
[395] S. Macchiavello Varas, *El problema de la industria del cobre en Chile y sus proyecciones económicas y sociales* (Santiago, 2010), p. 186
[396] *Tidsskrift for kemi og bergvæsen* (Oslo, 1930), p. 60
[397] G. A. Blom, *Fra bergseminar til teknisk høyskole* (Oslo, 1958), p. 147

average foreign ownership in this sector was around 41 per cent.[398] From the end of the nineteenth century, foreign investments were made in national projects such as railroad network and the development of hydroelectric power stations.[399] Electrochemical and electrometallurgical industries, as well as extraction and exports of pyrite and iron ore dominated increased in Norway from the late nineteenth century. These industries were also implemented based on large foreign direct investments.[400] Important companies, such as Elektrokemisk and Norsk Hydro, were established with Swedish capital (Wallenberg).[401] Total foreign capital in Norwegian industry represented 38, 8 per cent in 1909[402] (see table below):

Distribution of capital stock by industry in Norway, year 1909

Industry group	Absolute figures in NOK			Relative figures		
	Norwegian capital	Foreign capital	Total	Norwegian capital	Foreign capital	Total capital
Mining Open pit mining	6 145 450	24 975 490	31 120 940	19,7	80,3	100
Quarrying	12 131 128	697 700	12 828 828	94,6	5,4	100
Metal industry	4 719 380	2 268 700	6 988 080	67,5	32,5	100
Machinery and transport	22 898 031	1 219 500	24 117 531	94,8	5,2	100
Chemical industry	7 095 140	40 048 815	47 143 955	15	85	100
Heating and lightning	11 106 835	9 722 000	20 828 835	53,3	46,7	100
Textile industry	13 522 538	1 188 400	14 710 938	91,9	8,1	100
Paper, leather, rubber	40 298 100	32 071 111	72 369 211	55,7	44,3	100
Wood processing	24 597 782	258 910	24 856 692	99	1	100
Food processing	30 586 316	1 145 245	31 731 561	96,4	3,6	100
Clothing industry	1 163 000	627 500	1 790 500	65	35	100
Publishing	4 727 325	198 500	4 925 825	96	4	100
Other	1 306 285	56 200	1 362 485	95,9	4,1	100
Total	**180 297 310**	**114 478 071**	**294 775 381**	**61,2**	**38,8**	**100**

Source: A. Stonehill, *Foreign Ownership in Norwegian Enterprises* (Oslo, 1965), p. 32

Norwegian politicians became sceptic to the large foreign investments. Some were concerned that

[398] Norges offisielle statistikk, *Norges Bergverksdrift 1894-95* (Oslo, 1895); Norges offisielle statistikk, *Norges Bergverksdrift 1899-1900* (Oslo, 1900)
[399] A. Stonehill, *Foreign Ownership in Norwegian Enterprises* (Oslo, 1965), pp. 31-32
[400] A. Stonehill, *Foreign Ownership in Norwegian Enterprises* (Oslo, 1965), p. 32
[401] A. Stonehill, *Foreign Ownership in Norwegian Enterprises* (Oslo, 1965), p. 34
[402] A. Stonehill, *Foreign Ownership in Norwegian Enterprises* (Oslo, 1965), p. 36

foreigners would control whole industries. From a political and social perspective, the rapid increase of foreign investments was not considered desirable.[403] In fact, a substantial part of the political community looked at the new and mostly foreign-owned energy intensive industries as “big, ugly and alien” and feared that the companies would transfer most of the resource rent abroad.[404] In Technical Magazine, articles were published about the negative impact of foreign companies. Wood processing factories, mining companies, and others, were “… lost for Norwegians”. Furthermore, “(o)ur country’s solar thermal storage, our waterfalls, what makes Norway the land of the future is developed by foreigners.”[405] However, foreign investments continued to increase. The total value of foreign-held capital stock increased from 250 million NOK in 1919 to 318 million NOK in 1939.[406] Foreign investments decreased somewhat after WWII, but represented still 287.8 million NOK in 1947.[407]

Can foreign investments explain the economic gap between the two countries? At first glance, it is not clear whether the role of foreign companies can explain Chile’s underdevelopment and Norway’s development. Both countries experienced a large inflow of foreign capital and many industries in both countries were dominated by foreign investments. Scepticism towards multinationals was present both places. The point here is that a more detailed comparative analysis is relevant and necessary further to understand the direct impacts of foreign companies in the two host economies (see the chapter about the two mining sectors).

In this general introduction, we can instead ask why both Chile and Norway were dominated by foreign investments. There are many factors, which would make domestic companies have competitive advantages over foreign firms, such as shorter distance, knowledge of local idiosyncrasy

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[403] A. Stonehill, *Foreign Ownership in Norwegian Enterprises* (Oslo, 1965), p. 20
[404] P. Thonstad Sandvik, *Multinationals, Subsidiaries and National Business Systems* (London, 2012), pp. 14-15
[405] *Teknisk Ukeblad*, (Oslo, 23 January 1896), p. 33
[406] A. Stonehill, *Foreign Ownership in Norwegian Enterprises* (Oslo, 1965), p. 45
[407] A. Stonehill, *Foreign Ownership in Norwegian Enterprises* (Oslo, 1965), p. 58

and laws etc.[408] At the same time, in both Chile and Norway, capital accumulation was low. Scholars from both countries explain the large flow of foreign investments in part with a lack of strong local business classes and entrepreneurs. In the case of Norway, scholars find that the country lacked a large capital accumulation and a strong bourgeoisie.[409] As for the large aluminium production that started in the early twentieth century, Espen Storli argues that Norway had energy, but the Norwegian entrepreneurs lacked capital, raw materials and technology.[410] A number of Chilean scholars has pointed out the lack of continuity of a national business sector and scarcity of a consistent national capitalisation.[411] The start-up of operation of the large low-grade copper mines in Chile required enormous investments. It is estimated that total investments in the North American copper mine projects were 150 million USD. Around half of the investments corresponded to imported machinery and materials.[412] National groups, on the other hand, were not interested in developing the important mining sector, as explained by Francisco Encina. There was actually a decline of "the spirit of enterprise" within the national business class.[413] Marcello Carmagnani, for instance, argues that there was no emerging "…national business community with decisive modern attitudes and long-term projects" in Chile.[414] Therefore, a relevant question would be; with a lack of capital and a strong domestic business class in both countries, would large industrial projects have been initiated without the foreign investments?

7.7 Tax system, state regulations and control

Blomström and Meller point out that government policy towards the private sector have differed

[408] G. Jones, *Multinationals and Global Capitalism* (Oxford, 2005), p. 9
[409] See for instance F. Hodne and O. H. Grytten, *Norsk økonomi i det nittende århundre* (Bergen, 2000); P. Fuglum, *Norges historie Norge i støpeskjeen: 1884-1920* (Oslo, 1995); S. Lieberman, *The Industrialization of Norway, 1800-1920* (Oslo, 1970)
[410] E. Storli, *Out of Norway Falls Aluminium* (Trondheim, 2010), pp. 71-72
[411] See for example F. A. Encina, *Nuestra inferioridad Económica Sus Causas, sus Consecuencias* (Santiago, 1912); A. Pinto Santa Cruz, *Chile, un caso de desarrollo frustrado* (Santiago,1959); M. Carmagnani, *El desarollo industrial y subdesarrollo económico* (Santiago, 1998)
[412] S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 297
[413] A. Pinto, *Chile, un caso de desarrollo frustrado*, 1959, pp. 55-58
[414] M. Carmagnani, *El desarollo industrial y subdesarrollo económico* (Santiago, 1998), p. 17

between the Latin American and Scandinavian countries. They argue that:

> "(a)s long as firms in Scandinavia invest their profits, they pay very low taxes. If, however, they decide to distribute the profits to their stock owners, the tax share increases dramatically since the owners have to pay income taxes. Such tax system favors and stimulates investment, and it has played a very important role in the Scandinavian industrialization process. Latin American governments, on the other hand, lack the infrastructure to implement and collect personal income taxes. The tax burden is, therefore, on firms rather than individuals…"[415]

Looking to Chile and Norway in the early twentieth century, they differed when it came to state regulations of private, notably foreign, companies. However, it is not obvious that Norwegian regulations encouraged investments more than in Chile. Perhaps the actual tax percentage in Norway was lower, but there was a general agreement that the regulative framework discouraged investments and industrial growth. This was due to the Concession laws, which were introduced from 1906 to control foreign rights to own property, forests, mines and waterfalls.[416] The laws specified certain conditions, which were always attached to the granting of a concession. If the company did not operate according to the law, the concession could be withdrawn. After 40-80 years, depending on the sector, the natural resources with equipment, installations, buildings etc. should automatically be returned to the state without compensation.[417] These laws were ratified because of the scepticism towards the increasing foreign investments in Norway from the late nineteenth century and resulted in more control over the natural resources. Even Lange explains that:

> "There was a great degree of unanimity at the time that the laws would retard industrial growth. One of the main arguments put forth by opponents of the concession laws was that Norway required a lot

[415] M. Blomström and P. Meller (eds.), *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development* (Washington, 1991), p. 10
[416] For a detailed description of these laws see E. Lange, "The concession laws of 1906–09 and Norwegian industrial development", *Scandinavian Journal of History*, vol. 2, Issue 1-4 (1977)
[417] http://www.lovdata.no/all/nl-19171214-016.html [accessed 29 March 2015]

> of foreign capital for her industrial development and that the laws would keep this capital out of the country. It was clearly understood by those who pushed through the legislation that it would inhibit the country's industrial development."[418]

Compared to other Scandinavian countries it was argued that Norway had a particularly damaging institutional framework. For instance, the economist and historian Wilhelm Keilhau wrote:

> "(w)hen… Sweden eclipsed Norway in economic power during the 1920s and 1930s, a principal cause was probably that the Swedes had had a courage to exploit the international capital market for the expansion of large-scale industry in their country, while the Norwegians had not dared to do so and in consequence allowed the most suitable period for development to pass by without taking advantage of it…[…] It was especially unfortunate that the fear of domination by foreign capital led the radical parties to pursue an industrial policy that was inimical to economic progress."[419]

If some believed that the first Concession laws from 1906 to 1909 inhibited industrial growth, even more conditions were set to the foreign companies with the Concession Act of 1917. This Act gave the state directly control over foreign direct investments. Norwegian companies which had a foreign capital stock of more than 20 per cent, or of which all members of the local board of directors were not Norwegians with address in Norway, were required to ask for concession to rent or own real estate.[420] The law also specified a number of conditions, which favoured Norwegian capital and control and gave preference to domestic citizens. The mandatory conditions included the following:

1) The corporation's seat be in Norway
2) A majority of the board of directors be Norwegian citizens
3) A certain part of the capital stock be in the hands of Norwegians

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[418] E. Lange, "The concession laws of 1906–09 and Norwegian industrial development", *Scandinavian Journal of History*, vol. 2, Issue 1-4 (1977), p. 312
[419] Quote taken from E. Lange, "The concession laws of 1906–09 and Norwegian industrial development", *Scandinavian Journal of History*, vol. 2, Issue 1-4 (1977), p. 313
[420] A. Stonehill, *Foreign Ownership in Norwegian Enterprises* (Oslo, 1965), pp. 28-29

4) Norwegian capital had equal opportunity to share in any extension of a corporation's share capital
5) Fringe benefits be granted to employees, including, if in isolated areas, adequate housing, commissary facilities, and schools
6) Any damage to roads, quays, or other public property be repaired
7) A certain production fee be paid to the Norwegian government
8) The property not to be sold or transferred without permission
9) Preference be given to Norwegian labour and materials[421]

These conditions on foreign companies could certainly prevent them from investing and discourage industrial development. There was a decline in foreign direct investments in Norway after 1917, which indicates that these laws had a negative effect.[422] On the other hand, whether or not there would have been more foreign investments without the ratification of these laws is very difficult to say.

In Latin America, there were generally few barriers to the entry of foreign firms and little control over the behaviour of foreign firms during the nineteenth century.[423] How did this apply to the Chilean case? The laws concerning private and foreign companies were related to taxes. The tax system, as it was established, assured income for the state, but was not seen as investment-friendly. Culver and Reinhart argue that:

> "(t)he Chilean method of copper taxation had specific unfortunate consequences. The tax policy established in 1810 set a rate of two pesos per pound of copper when the market price was eight to

[421] *Lov om erverv av vannfall mv. [industrikonsesjonsloven]* [Industrial Concession Act] (14 December 1917)

[422] However, in spite of disagreements on this matter foreign investments continued to represent a large share of total investments also after the introduction of the laws, as seen. The fact that foreign companies invested in Norwegian natural resource sectors also after the ratification of the laws indicate that Even Lange's argument that their criticism are unfounded, is valid: E. Lange, "The concession laws of 1906–09 and Norwegian industrial development", *Scandinavian Journal of History*, vol. 2, Issue 1-4 (1977).

[423] G. Jones, *Multinationals and Global Capitalism* (Oxford, 2005), p. 201

> ten pesos. The tax basis remained the values of production, not profit. After mid-century, when copper prices began to fall, the tax became proportionally higher and harder to pay. As the tax was on volume, not profits, it had to be paid even during periods in which the market price fell below the cost of production."[424]

There were, thus, tax laws, but few measures to regulate and control the entry and operations of foreign companies. Private and foreign companies had traditionally freedom to exploit raw materials and there was a belief that the state should not intervene in industry.[425] The state showed a more passive attitude than in Norway and gave private and foreign companies freedom to operate. Mira Wilkins finds evidence that the government was "anxious to cooperate" with foreign mining companies and was instead concerned about establishing a taxable industry.[426] From the early twentieth century, the main focus of discussion was still on the level of taxation on the foreign companies, rather than regulating their operations.[427]

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[424] W. W. Culver and C. J. Reinhart "Capital dreams: Chile's Response to Nineteenth-Century World Copper Competition", *Comparative Studies in Society and History*, vol. 31, No. 4 (October 1989), p. 739
[425] See for example A. Pinto Santa Cruz, *Chile, un caso de desarrollo frustrado* (Santiago,1959)
[426] M. Wilkins, *The Emergence of Multinational Enterprise: American business abroad from the colonial era to 1914* (Cambridge, 1970), p. 182.
[427] It should be mentioned here that much later, in 1955, Chile introduced a new tax law, which was seen as production and investment-friendly. The law sought to increase taxes even more, but at the same time encourage investments and production. With the "New Deal Act" a fixed basic tax of 50 per cent was established and another 25 per cent which varied according to production. A beneficiary tax was introduced to increment production on the electrolytic copper. To encourage increase of production tax was removed if the production increased 100 per cent in relation to a fixed figure. But, if the production was lower than 80 per cent of the "basic production" the tax increased with 80 per cent. In addition, benefits were given to companies which invested in education, social-, health or housing projects in favour of the workers: A. Sutulov, "Antecedentes históricos de la producción de cobre en Chile", in *El cobre chileno,* A. Zauschquevich, A. and A. Sutulov (Santiago, 1975), p. 80
Some measures were taken to control the saltpetre industry from the 1920s. There was an idea of "…increasing the participation of the state in industrial utilities which produced saltpetre, with the objective of fulfilling with its social obligations." The Chilean Association of Saltpetre Producers was founded in 1919 with the aim of acquiring more information about the production and comercialisation of saltpetre and influence in decision making. Furthermore, the President Arturo Allesandri Palma suggested putting several foreign companies under state control. This was seen as necessary for two reasons. First of all because it was necessary to find financial means to "…give the social and economic welfare to the people of Chile." Secondly, because the saltpetre industry found itself in a crisis which it was not able to resolve. However, projects to acquire more control were not approved by the Congress. Thus, the British companies could continue to influence the Chilean saltpetre as they had done for four decades, although under the custody of the Chilean Association of Saltpetre Producers. Later, in 1927 the Minister of Finance published a long declaration in the newspaper El Merucrio in March 1927 under the title "As the government raises the nitrate problem." The government would not permit the continuation of the sale system, which "…only had produced big profits for the

The question remains: why did the two countries take different approaches to foreign investments? Chilean politicians of the time were also concerned about how foreign investors operated in the country and expressed the need for change. In 1920, Santiago Macchiavello Varas argued that foreign companies should be incorporated in the national economy in a more beneficial way for Chile.[428] An argument against foreign investment was that:

> "…nothing justifies that foreign investors continue acquiring a disproportionate advantage of the high income derived from the operation of the Chilean deposits, which is unrelated to the contribution they have provided to the development of the sector."[429]

companies." Two new entities were created in 1927; the Saltpetre Counsil and the Superintendent of Saltpetre and Iodine. The first would consist of a number of people who were to advise the President with regard to the policy should be adopted in relation to the saltpetre industry. The latter was a higher state institution which would control the saltpetre industry. In 1930 the Saltpetre Company of Chile (COSACH) was created to put an end to British control in the sector with the purpose of participating in production, export and commercialisation of saltpetre. COSACH was replaced by the Sale Corporation of Saltpetre and Iodine of Chile (CONVENSA) in 1934 and functioned until 1968. Both institutions aimed to normalise the saltpetre activity and pay the external debt, which had worsened after the Wall Street Crash in 1929. In spite of these measures the North American companies acquired control over the saltpetre industry from the late 1920s: A. Soto Cardenas, *Influencia británica en el salitre: origen, naturaleza y decadencia* (Santiago, 1998), pp. 208-214
In the 1960s further regulations were introduced which sought to control the private sector, especially the large copper production. Laws were ratified which determined jointed ventures in which the Chilean state should own 51 per cent of the companies. The main motivation behind the "Chilenisation process" policy was the conception that it was not convenient that this industry was managed from abroad and that the sector needed to be better integrated in the national economic life. In this regard a comprehensive plan of gradual transfer of ownership of these industries to national interests was outlined; 1) a definite course towards national participation and intervention in the international copper trade, 2) improvement of structures and full integration of operations with special emphasis on domestic smelting and refining, 3) drastic increase in domestic manufacturing and semi-manufactures, 4) an active incorporation of the copper companies to the national economy through an increase of domestic inputs, 5) creation of new sources of production and new activities. The control went further from the 1970s. A complete nationalisation was carried out between 1970 and 1973, during Salvador Allende and the Unidad Popular government coalition. During this time the big copper companies were nationalised, and taken over by the state for a fee. The dominance of foreign investments was seen by the majority as negative for national development and a unanimous parliament voted in favour of acquisition: P. Meller, "Chilean Economic Development 1880-1990", in *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development,* M. Blomström and P. Meller (eds.) (Washington, 1991), p. 42; A. Sutulov, "Antecedentes históricos de la producción de cobre en Chile", in *El cobre chileno,* A. Zauschquevich, A. and A. Sutulov (Santiago, 1975), pp. 43-64
[428] S. Macchiavello Varas, *El problema de la industria del cobre en Chile y sus proyecciones económicas y sociales* (Santiago, 2010), p. 97
[429] P. Meller, "El cobre chileno y la política chilena" (2003), p. 21

According to him "…all funds coming into the country should be incorporated in a direct or indirect way to the national economy, at the same time as the Chilean effort should fill the place it deserves."[430] Principally, the tax rate of the foreign companies was not considered fair, according to Macchiavello Varas. For Chile to benefit from the foreign companies it was important to 1) focus on tax on export so that a part of the profit would stay in the country, 2) ensure that management of foreign companies resided in the country, and 3) guarantee a minimum interest in the invested capital.[431] His argument reflected some of the ideas behind the Norwegian Concession laws. Moreover, in the Mining Congress organised by the National Mining Society in 1916, part of the analysis was to find out:

> "…the best way of procuring for the national element an effective participation in foreign enterprises, by requesting them for example to admit a certain number of Chilean employees of proper attainments in their staff."[432]

This last point was apparently taken into account at some foreign companies. Internal regulations of the Andes Copper Company confirmed that the firm was "…to hire when possible, Chilean engineers, and all the employees of this nationality proportionally always higher than that fixed by the law, both in the period of the construction and the phase of operation."[433]

It seems clear that in spite of the fact that debates were raised, and many were sceptic to foreign investments, the results in the two countries were different. In Norway, the majority of the members of the Parliament voted in favour of the Concession laws, despite being aware that the laws would

[430] S. Macchiavello Varas, *El problema de la industria del cobre en Chile y sus proyecciones económicas y sociales* (Santiago, 2010), p. 96
[431] S. Macchiavello Varas, *El problema de la industria del cobre en Chile y sus proyecciones económicas y sociales* (Santiago, 2010), p. 249
[432] *Topicos del Teniente Periodico quincenal dedicado a los intereses del personal de la Braden Copper Co*, Vol. 1 (December, 1915), p. 14
[433] M. C. Baros Mansilla, *Una historia de pioneros* (Santiago, 2006), p. 106

probably prevent industrial growth. Actually, "most of them saw this as an advantage, and many presented it as one of the purposes of the concession laws."[434] These measures ensured control over the resources, local participation and administration of the companies. An illustrating example of the effect of this law reform was the change of management at the Bede Metal & Chemical Company, an English company that invested in Killingdal mines in 1895. Until 1919, English engineers led the company. This year, just after the Concession Act of 1917 was ratified, the Norwegian mechanical technician Vilhelm Birkedal Lange, after a long working career in mining, became director of the company.[435] The laws reflect the idea that the natural resources in the country should be managed by and belonged to "the whole population", which in turn was represented by the state.

The action against foreign investments can be seen in light of the political situation in the early twentieth century. Norway became independent from Sweden in 1905 and economic nationalism was strong in the country.[436] Chile, in contrast, did not implement such control, even though the country had become independent almost 100 years before Norway. Geoffrey Jones understands the unfavourable operations of the foreign companies in Latin America in relation to general weak states. He argues that:

> "…the lack of bargaining skills and technical know-how on the government side, and the control over technology, capital, and markets on the company side, made most of the concessions appear in retrospect remarkably favorable to the foreign companies."[437]

In contrast to Blomström and Meller's argument, this "remarkably favourable" conditions for foreign

[434] E. Lange, "The concession laws of 1906–09 and Norwegian industrial development", *Scandinavian Journal of History*, vol. 2, Issue 1-4 (1977), p. 312
[435] O. Alstad (red.) *Trondhjemsteknikernes Matrikel Biologiske meddelelser om samtlige faste og hospiterende elever av Trondhjems Tekniske Læreanstalt 1870-1915*, (Trondhjem, 1916). The members of Executive Board and administrating directors at Norwegian Aluminium Company and the Nordic Aluminium Company were all Norwegians, in accordance with the Concession laws: K. Fasting, *Norsk Aluminium gjennom 50 år* (Oslo, 1965)
[436] P. Thonstad Sandvik, *Multinationals, Subsidiaries and National Business Systems* (London, 2012), pp. 14-15
[437] G. Jones, *Multinationals and Global Capitalism* (Oxford, 2005), p. 56

companies in Chile would in theory contribute to more foreign investments, and not prevent them. On the other hand, Jones' argument about weak and absent states in Latin America is unclear in the Chilean case. In Chile, the state became involved in industries by establishing regulations, only that these laws focussed on other matters, such as taxes, rather than direct control over the management of natural resources. Thus, perhaps more than being absent or weak, the government prioritised differently.

What can we say about the institutional framework of the two countries? It is clear that the conditions for investments in the two countries were different, but it is not obvious that the conditions for investments in Chile were worse than in Norway. If companies prefer freedom to operate, they did not acquire this in Norway. In spite of differences in regulations, foreign investments stood for a large share of total investments in many economic sectors in both countries. The questions that remain are related to "best" conditions for investments. What were the effects of these laws in the two countries? Were the conditions in Norway actually better for investments than in Chile?

7.8 Concluding remarks

Why did Chile and Norway develop in such different ways even though they have had similar geophysical conditions and industrial patterns? In *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development* and *From Natural Resources to the Knowledge Economy* a number of factors are outlined to explain the different social patterns and economic gaps across Latin American and Scandinavian countries. In these broad comparisons, the scholars emphasise differences in level of exports, demography, agricultural reforms, education, economic policy and foreign investments, and argue that these aspects have developed in a much more favourable way in Scandinavia than in Latin America. For these reasons, Scandinavia had considerable more growth than Latin America.

However, there are at least two problems with these comparisons. First, when looking specifically to Norway and Chile, many aspects which are pointed out as different between the two country groups, and important for explaining the economic gaps, turn out not to be so different after all. These features might actually contribute to explain differences in growth between the two country groups, but there is a need for more detailed analyses. Second, there is no consensus about which factors have in fact generated economic growth. Thus, the underlying reasons for the divergence of the two economies are still inconclusive. I argue that an in depth analysis of the countries is required to understand (1) which factors that actually distinguish the two countries and (2) if these features can explain differences in growth.

A comparative empirical analysis of knowledge institutions and organisations for mining – late nineteenth century to 1940

8 Setting a framework for mining: use of complex technology

During the nineteenth century, mining became increasingly challenging in terms of finding, removing and processing of ores. Challenges emerged as high-grade ore deposits were largely exhausted, mines became larger and deeper and the demand for minerals increased. By the late nineteenth century, operations were rationalised with new techniques and large-scale production of low-grade minerals became more common. What type of knowledge was used to carry out technologically advanced mining? Which institutions and organisations were involved in developing technological knowledge and capabilities? Terms, such as scientific knowledge domains, tacit and codified knowledge, know-what, know-how, know-who and know-why are used here to detect and identify different aspects of knowledge involved in innovation processes. An introduction to new geological challenges in mining worldwide, and technological solutions to these challenges, is presented first.

8.1 Introduction - new challenges in mining worldwide

During the nineteenth century, the demand for metals and minerals increased because of the on-going industrialisation processes that was happening in many countries at the time. Traditional metal and mineral productions, such as iron, copper, silver and nickel, increased and the industry diversified with new products, such as steel alloys, aluminium and molybdenum. In this context, from the late nineteenth century, many of the high-grade easy accessible mineral deposits were exhausted and only low-grade ores remained. New minerals and low-grade ores in more isolated places and deeper underground were given attention. This meant that companies were met with new challenges in terms of finding, removing and processing ores. Undoubtedly, mining became more complex over time, in terms of locating, identifying, extracting and processing ores.[438] Engineers and mining workers experimented with new ways of finding, removing and extracting ores and companies adopted new technology and power sources to increase production and maintain profit. Global

[438] See the general development of inventions and use of technology in mining in Singer et al., *A History of Technology,* 5 volumes.

developments in mining led to radical technological changes in the sector. New technology had often origin in industrial powers, such as Britain, Germany, France and the United States, with some important exceptions (see table below. See also appendix 6 for detailed descriptions of commonly used technology):

Simple overview of challenges and changes in global mining from the late nineteenth century

Activity	New challenges	Technological solutions
Finding ores	Less available and low-grade mineral deposits.	Systematic and organised ore surveys with the use of techniques to identify and detect specific metals, minerals and mineral compositions.
Removal of ores	Deeper, larger and more solid mines for large-scale production to avoid collapse.	More precise surveys and mine measurement with the use of mechanised and electric equipment.
Processing ores	Making pure products with ores less than four per cent.	New concentration- separation- and refining techniques.

Finding ores traditionally occurred randomly or by accident. Old prospecting methods often consisted of looking for signs of minerals in the outcrop of rocks with the use of tools, such as picks, shovels and other equipment to separate the different metals in the gangue.[439] Geological surveys were later carried out in a more organised and systematic way and new and more efficient techniques to find ores were developed, such as geophysical methods. Organised and directed efforts led to more ore discoveries.[440] Surface boring tools, such as augers and hand bores were used to analyse the mineral deposits, their size, angles, directions, concentration etc. For deeper holes, horses were traditionally used to rotate drills, but were later replaced by machines. In the middle of the nineteenth century, industrial diamonds for rotary drilling and prospecting were adopted (see appendix 6 for descriptions

[439] J. A. S. Ritson, "Metal and Coal Mining, 1750-1875", in *A History of Technology, volume IV The Industrial Revolution The Industrial Revolution 1750 to 1850,* C. Singer et al. (eds) (Oxford, 1958), pp. 66-67
[440] J. A. S. Ritson, "Metal and Coal Mining, 1750-1875", in *A History of Technology, volume IV The Industrial Revolution The Industrial Revolution 1750 to 1850,* C. Singer et al. (eds) (Oxford, 1958), pp. 66-67

of techniques).[441]

Making mines and removing ores had traditionally been based on animal and human power. Most of the rock underground was extracted manually with picks, crowbars and wedges. Men or animals transported the ore by carrying the load on their backs and pushed or pulled a wheeled tram.[442] Mines became gradually deeper and bigger, which in turn required more precise work and accuracy to prevent them from collapsing. Intricate mathematical calculations enabled deep and large mines more secure. Some mines were very complicated to make and involved great challenges.[443] Machines of different types were developed, such as steam engines, and later turbines, to give power to lifts, transport and for drainage inside mines. Shaft-sinking and vertical excavations from the surface were implemented in deeper mines.[444] From the late nineteenth century, large-scale mining was adopted. Radical changes were made to permit this increase of production. Before 1900, it was common in the United States to exploit ores containing more than ten per cent copper, normally around twenty per cent. In 1899, Daniel C. Jackling, an American mining and metallurgical engineer, and Robert C. Gemmell, an American engineer, wrote a plan on how to mine and mill the ore at the rate of 2000 tons per day. Their idea was realised in open-pit copper mines at Bingham, Utah, by 1910. The method proved that if the scale was large enough, low-grade disseminated copper ores of only two per cent copper could be extracted with profit.[445] The new techniques included the use of mechanical shovels driven by electric power to load mineral, pneumatic drills, rail transport and blasting to remove large mineral blocks.[446]

[441] J. A. S. Ritson, "Metal and Coal Mining, 1750-1875", in *A History of Technology, volume IV The Industrial Revolution The Industrial Revolution 1750 to 1850,* C. Singer et al. (eds) (Oxford, 1958), p. 68
[442] J. A. S. Ritson, "Metal and Coal Mining, 1750-1875", in *A History of Technology, volume IV The Industrial Revolution The Industrial Revolution 1750 to 1850,* C. Singer et al. (eds) (Oxford, 1958), p. 77
[443] J. A. S. Ritson, "Metal and Coal Mining, 1750-1875", in *A History of Technology, volume IV The Industrial Revolution The Industrial Revolution 1750 to 1850,* C. Singer et al. (eds) (Oxford, 1958), pp. 70-71
[444] J. A. S. Ritson, "Metal and Coal Mining, 1750-1875", in *A History of Technology, volume IV The Industrial Revolution The Industrial Revolution 1750 to 1850,* C. Singer et al. (eds) (Oxford, 1958), 1958, p. 69
[445] J. Temple, "Metal Mining", *A History of Technology, volume VI The twentieth century 1900 to 1950 part 1*, in Williams, T (ed.), (Oxford, 1978), p. 413
[446] S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 174

After the ore was removed, it was transported to an ore dressing plant. Ore dressing consisted of separating the metal from the barren rock, called gangue. The product was then crushed into smaller pieces, half an inch, or finer. In the nineteenth century, hand-operated machines often did this, although John Taylor introduced a mechanical type in 1804 at the Wheal Crowndale mine in Devon.[447] In the mid-nineteenth century, the first mechanical machine to crush the rock into smaller parts called "jaw breaker" was invented by Eli. W. Blake of New Haven, the United States.[448] The next advance in crushing was the gyratory crusher, introduced by P. W. Gates in 1881. This machine had more capacity than the previous jaw breaker.[449] A number of grinding machines were made to pulverise the ore. Perhaps the most common ones were the cylindrical-type mill and the ball mill.[450]

Processing techniques were adapted to and used for ores with lower percentage of minerals:

> "The second half of the nineteenth century was characterized by tremendous advances both in the method and scale of operation of metallurgical processes for the established metals, and in the invention and development of method of extracting metals hitherto regarded as chemical curiosities."[451]

New processing techniques developed and spread rapidly. For instance, a separation method, which spread very quickly, was the flotation technique, which separated minerals from the gangue in a liquid pulp by means of air bubbles. This process eventually dominated ore processing and was by the early twentieth century used for the separation of low-grade ores of metals, such as copper and gold,

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[447] W. H. Dennis, *Metallurgy 1863-1963* (London, 1963), p. 22
[448] W. H. Dennis, *Metallurgy 1863-1963* (London, 1963), p. 22
[449] W. H. Dennis, *Metallurgy 1863-1963* (London, 1963), p. 22
[450] W. H. Dennis, *Metallurgy 1863-1963* (London, 1963), pp. 24-27
[451] R. Chadwick, "New Extraction Processes for Metals", in *A History of Technoloy, volume V The Late Nineteenth Century 1850 to 1900,* C. Singer et al. (eds.) (Oxford, 1958), p. 72

from gangue.[452] The Manhés process, developed in the 1880s for copper processing, was based on Henry Bessemer's iron processing technique. This technique produced purer copper in much shorter time than previous methods, rationalised the processing of ores and revolutionised copper production.[453] In 1885, the New Zealander newspaper the Colonist described the Manhés process the following way:

> "(T)he principle of the Manhés patent is to force cod air through the molten ore, in order to slag or volatilize the foreign matters, and at the same time to use a converter of such a design as to allow the cold blast to be forced through the upper surface of the mass without chilling the melted copper, which is thus protected from the action of the former in order to avoid the choking of the blast-holes. By the adoption of this process it is claimed that 80 per cent in fuel and much time can be saved…[…] The ores are, as usual, subjected to simple fusion in any kind of furnace, but preferably in a cupola furnace, for the purpose of slagging away the earthy substances, and obtaining a matt more or less rich in copper. The matt is then tapped into the converter, which is so designed that air at a high pressure is forced through the molten ore at any desired level above the molten metal, and by these means raw copper containing as much as 99 per cent of pure copper is obtained."[454]

Electric power was also used to separate minerals, not only to give power to equipment at the mines. The use of electrolysis in metallurgy has its origin from James Elkington, an English plater. He invented a process for refining copper electrically around 1850.[455] The first electrolytic refinery was established in 1869 at Pembrey, near Swansea, in the copper-smelting plant of Mason & Elkington. In Swansea, blister copper was largely imported from Spain and South America and further refined with the use of electrolysis.[456] Magnetic separation was also used:

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452 W. H. Dennis, *Metallurgy 1863-1963* (London, 1963), p. 28
453 "The Copper Industry", *Colonist*, Volume XXVIII, Issue 4163 (12 June 1885), p. 4
454 "The Copper Industry", *Colonist*, Volume XXVIII, Issue 4163 (12 June 1885), p. 4
455 W. H. Dennis, *Metallurgy 1863-1963* (London, 1963), p. 10
456 R. Chadwick, "New Extraction Processes for Metals", in *A History of Technoloy, volume V The Late Nineteenth Century 1850 to 1900,* Singer, C. et al. (eds.) (Oxford, 1958), p. 85

> "The finely crushed ore was carried on a belt between the poles of a powerful electromagnet. This method was first used to separate ferrous from non-ferrous constituents, but by the end of the century it was being used to separate minerals differing only slightly in magnetic susceptibility."[457]

These technological changes, and others, characterised technologically advanced, profitable and successful mining in this period.

8.2 Tacit and practical knowledge

Geological settings and structures, size of ore deposits, composition of minerals and other factors made conditions at each mine, or extraction site, different. For example, open pit mining was different from underground mining, coal was a softer material than copper and silver, minerals and metals reacted differently in chemical processes and horizontal and vertical mining required different structures and working methods. The specific nature of mining made detailed and in-depth knowledge of local geological settings, grounds and ores crucial to initiate production. The mining engineer Ignacio Domeyko, principal of the University of Chile from 1867, pointed out that mining operations varied so greatly from one place to another that each country's mining sector represented a new science.[458]

The uniqueness of each working plant and the practice of finding out about which techniques worked better, implied a large degree of trying and failing. Mining operations were based on hands-on use of equipment and measurement tools, drawing and making of mines, removing, transporting and processing of ores etc. Thus, mining operations were largely based on practical and hands-on activities. In general, Hirsch-Kreisen and colleagues argue that natural resource industries have often developed based on "learning by doing" and trial and error. This is used as part of the explanation for

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[457] R. Chadwick, "New Extraction Processes for Metals", in *A History of Technoloy, volume V The Late Nineteenth Century 1850 to 1900,* Singer, C. et al. (eds.) (Oxford, 1958), p. 74
[458] *Anales de la Universidad de Chile* (Santiago, 1859), p. 185

the little use of R & D in such sectors compared to manufacturing industries.[459] This extensive use of practical knowledge and learning by doing indicate a large degree of tacit knowledge. Nelson and Winter emphasise the tacitness in a working setting. According to them, "…the knowledge that underlies a skillful performance is in a large measure tacit knowledge."[460] In particular, the tacit dimenstion has been pointed out by Joel Mokyr to be particularly important in the case of mining. He stresses that the "…centrality of tacit knowledge…[…]… was especially true for the metal and coal industries...".[461] Although Mokyr refers to the British metal and coal industry in the eighteenth century and onwards, the basic principles for mining operations maintained.

The fact that much of the knowledge on which mining was based was tacit, or knowledge which is hard to explain, led to some challenges in terms of learning. How did miners and engineers understand and acquire tacit knowledge? Observation and experience were pointed out by Domeyko to be particularly important learning methods.[462] Since it is "silent", tacit knowledge is difficult to detect, measure and classify. Yet, a couple of examples of the use of hands-on practical knowledge, gives an impression of its functions. The Dean of the Faculty of Mathematics of the University of Chile, Ricardo Fernandez, gave specific examples of the knowledge that had to be learned outside the classroom in the field or by through practical work. How to distinguish materials, build and manage a construction or plant, understand their defects, how to use tools, machinery etc. were part of this knowledge, he argued.[463] Additionally, in order to select the proper technique for a mining plant, the use of hands-on practice was essential. When selecting techniques, mining companies made sure to acquire specific hands-on knowledge of different alternative methods. This hands-on experience with

[459] H. Hirsch-Kreinsen et al., "Low-Tech Industries and the Knowledge Economy: State of the Art and Research Challenges", *PILOT Policy and Innovation in Low-Tech, STEP – Centre for Innovation Research* (Oslo, 2003), p. 9
[460] R. R. Nelson and S. G. Winter, *An Evolutionary Theory of Economic Change* (Cambridge, 1982),p. 73
[461] J. Mokyr, "Knowledge, Enlightenment, and the Industrial Revolution: Reflections on *Gifts of Athena", History of Science*, vol. 45, part 2, (June 2006), pp. 1-2
[462] *Anales de la Universidad de Chile* (Santiago,1859), p. 185
[463] *Anales de la Universidad de Chile* (Santiago,1883), p. 418

new technology was often acquired through travelling to a working site where the technology was actually used. One among many examples is mining engineer Emil Knudsen, who went to the United States to learn about drilling machines on behalf of Røros Copper Works.[464] In the United States Knudsen observed different drills in action and saw how one particular percussion-drilling machine called Marwin, which drilled 15 feet drill holes per hour in hard limestone. After his return he recommended the Marwin drills and argued that these machines were "the best" to be used at the King and Mugg Mines.[465] Without the practical experience of how these drills operated, knowledge of their strengths and weaknesses and the possibility to evaluate how they worked in comparison with other machines, it would have been hard, maybe impossible, to select the best ones for the mines at Røros (see appendix 22 and 23 for lists of study travels). This case, and others, indicates that observation and practical hands-on knowledge were crucial for the understanding of how techniques worked and whether they would be possible to adopt.

8.3 Scientific knowledge domains

Tasks and practical assignments changed continuously and mining operations in all main activities in both Chile and Norway, as well as in other countries, became increasingly challenging and complex. Each country and mine had their uniqueness, but there were some common traits. The following list includes a simplified classification of the operational activities in mining:[466]

1) Geological surveys and prospecting of ores:
    a. Ore deposits were first searched for. Different types of analyses were carried out to find valuable minerals and determine their economic use.
2) Removal of ores from the ground:

[464] F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005), p. 114
[465] *Teknisk Ukeblad* (Kristiania, 2nd of mai 1895), p. 164
[466] This overview is based on Carstens, H. Carstens, …*Bygger i Berge* (Trondheim, 2000), pp. 24-25

   a. Constructions underground, such as shafts, tunnels, adits, pillars etc. and supporting constructions were made, in addition to supporting constructions, water works, power plants and buildings above ground.[467]
   b. Ore was removed and transported from the mine using human, animal, mechanical or electric power.

3) Processing of ores. After the ore is removed and transported from the mine the mineral was normally crushed and processed to obtain a pure product:
   a. Ore dressing and smelting plants were built and equipped to process the ore. In addition, other types of infrastructure, such as roads, railway etc. was often constructed.[468]
   b. Big pieces of material were crushed into smaller chunks or powder through ore dressing processes to separate the useful mineral from the worthless rock mass. As much gangue as possible was removed before further processing. This was often done through crushing and milling.
   c. Minerals were then separated from each other through a variety of methods depending of their physical and chemical characteristics.
   d. Finally, pure metals were produced using a range of smelting and refining methods.

Historically, the tasks and responsibilities within these three operational activities have varied a great deal. Traditionally, mineral deposits were found through testing the ore in the ground and analysing its composition. Metals and minerals, and how they behaved, were explored to understand their characteristics and composition as far as possible.[469] In the early days, miners had little knowledge of

[467] A. K. Børresen, *Bergtatt: Johan H. L. Vogt – professor, rådgiver og familiemann.* (Trondheim, 2011), pp. 280-281

[468] *Tidsskrift for kemi og bergvæsen* (Oslo, 1932), p. 133

[469] B. I. Berg, *Gruveteknikk ved Kongsberg Sølvverk 1623-1914* (Trondheim, 1998), p. 432

mineralogical features and geological formations.[470] However, a further examination of the operational activities indicates that mining was based on an in-depth understanding of a number of knowledge domains, or sciences, from early on. Gradually, new knowledge gave room for two of the first scientific disciplines: mineralogy and geology.[471] Geologists, mineralogist and chemists increasingly wrote down their analysis results and published books and articles about topics within mining. In the sixteenth century, the German Georgius Agricola discovered many new minerals and created a mineral classification according to their colour, transparency, lustre, brilliance, odour, and taste.[472] He published several books about mineralogy and geology, the most famous being *De Natura Fossilium* from 1546 and *De re metallica* from 1556.[473] *Probierbüchlein*, published in 1524, was an introduction to ore analysis.[474] Other books about mining were also published early. Lazarus Ercker published the book *Mineralischen Ertz- und Berckwerks Arten* in 1574, a technical text with special emphasis on ore testing, also traduced to English and Dutch.[475] Because chemists worked largely with minerals, mineralogy and chemistry, the two knowledge fields were traditionally closely linked. Throughout the eighteenth century new minerals were recognised, described, and classified, and resulted in the discovery of many new elements, such as cobalt, nickel, manganese, tungsten, molybdenum, uranium and others.[476] The Swedish chemist Axel Fredrik Cronstedt collected more than 5000 specimens of minerals based on their chemical composition. He published the book *An Essay Towards a new System of Mineralogy* in 1758, traduced to English in 1770.[477] In 1819, the Swedish chemist Jöns Jacob Berzelius discovered that minerals containing no metal had the same chemical properties. He made a new system for the classification of minerals into metal, sulphides, carbonates, sulphates, etc. As chemistry evolved from being a purely descriptive, qualitative science

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470 F. Habashi, *Schools of Mines* (Quebec, 2003), p. 61
471 B. I. Berg, *Gruveteknikk ved Kongsberg Sølvverk 1623-1914* (Trondheim, 1998), p. 235
472 F. Habashi, *Schools of Mines* (Quebec, 2003), p. 18
473 B. I. Berg, *Gruveteknikk ved Kongsberg Sølvverk 1623-1914* (Trondheim, 1998), p. 235
474 F. Habashi, *Schools of Mines* (Quebec, 2003), p. 80
475 F. Habashi, *Schools of Mines* (Quebec, 2003), p. 82
476 F. Habashi, *Schools of Mines* (Quebec, 2003), p. 64
477 F. Habashi, *Schools of Mines* (Quebec, 2003), p. 62

to a more exact science based on scientific methods and laboratory analyses, the chemical classification of minerals was gradually accepted as an important tool for geologists.[478]

In Norway during the nineteenth century geological surveys, finding ores and mine measurements were gradually carried out in a more systematic and organised way. This involved first and foremost making of more precise and more detailed maps.[479] Chemical analyses, microscopes and separation processes were increasingly used in analyses of geological materials. The use of chemical processes made it possible to determine the composition of rocks and minerals and, to a greater extent than before, reveal their inner structure. Equipment and laboratories became increasingly used in geological research.[480] Norwegian Geological Survey used optical mineralogy from the 1870s, which involved thin pieces of mineral or rock placed under the new polarisation microscopes.[481] Scientifically based geological surveys and the making of geological maps involved extensive knowledge in the field of geology, mineralogy, chemistry and subsequently electro-engineering and magnetism. Development in the fields of chemistry, geology and physics allowed for detailed geophysical and chemical analyses. From the 1920s, magnetic and electrical methods became common. By 1935, new methods consisting of systematic mapping of ore blocks were used.[482] In Chile the use of geophysical methods were also used from the early 1930s.[483]

At any mining company, detailed planning of future production was crucial. Part of the planning and future organising of production included extensive use of knowledge in mathematics, economics and economic geology. At the same time, mining laws and commercial-, civil-, social- and criminal laws of

[478] A. K. Børresen, *Bergtatt: Johan H. L. Vogt – professor, rådgiver og familiemann.* (Trondheim, 2011), p. 70
[479] B. I. Berg, *Gruveteknikk ved Kongsberg Sølvverk 1623-1914* (Trondheim, 1998), p. 432
[480] A. K. Børresen and A. Wale, *Kartleggerne* (Trondheim, 2008), p. 29
[481] A. K. Børresen and A. Wale, *Kartleggerne* (Trondheim, 2008), p. 74
[482] A. K. Børresen and A. Wale, *Kartleggerne* (Trondheim, 2008), p. 131-132
[483] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1931), p. 361

the country, was vital in this work.[484] The mining engineer Jorge Muñoz Cristi underlined the importance of an in-depth knowledge of economic geology. He found that this was perhaps particularly important at small and medium size mines to plan future operation. This was because high-grade ore normally gave the best profit. Indeed, the engineers' greatest enemy was to exhaust the mine. The aim was of course to produce minerals that gave the maximum yield at the lowest cost and to develop mines with minimum expenditure.[485] Cristi's observations with regard to economic geology were particularly important in Chile, since mines were being abandoned and the country had large unutilised mineral ores. However, traditionally, estimations and future planning were not implemented extensively. It was during the nineteenth century that estimations of future productions and profit became more common. For instance, in 1872 the mining engineers Jacob Pavel Friis presented a plan to the Directory of Røros Copper Works, which showed production of two mines, Storwarts and Mugg, for respectively 70 and 30 years.[486] Another example is Orkla Mining Company, which took over operation of Løkken Works in 1904. Before this time, there was little knowledge of the extension of the ore deposits, even though Løkken Works had existed for 250 years. Production depended on the extraction of the highest copper-containing ore and old mining operations were supposedly implemented "from hand to mouth."[487] Mining engineer Holm Holmsen became technical director at the company and had the main responsibility for Løkken mine. He made a report in 1904 of the ores in which "ore in sight" and the percentage of copper and sulphur were accounted for.[488]

After analysing the ore and evaluating the economic profit of operation, one of the biggest challenges was to plan the structure of mines, i.e. map tunnels, adits, shafts, ventilation shafts etc. and organise where they should go relative to each other. Making tunnels and adits meet underground required

[484] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1928), p. 56
[485] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1935), p. 403
[486] J. P. Friis, *Direktør Jacob Pavel Friis' erindringer* (Oslo, 1944), p. 169
[487] Orkla Grube-Aktiebolag, *Løkken Verk En Norsk Grube Gjennom 300 År* (Trondhjem, 1954), pp. 353-355
[488] Orkla Grube-Aktiebolag, *Løkken Verk En Norsk Grube Gjennom 300 År* (Trondhjem, 1954), pp. 353-355

accuracy and detailed measuring. This work became increasingly challenging from the late nineteenth century as mines became deeper and bigger. Specific knowledge in natural sciences was perhaps particularly important in mining operations. The use of principles from scientific methods and detailed and careful examinations of the geological ground were crucial for this type of work. From early on, physical and mathematical principles were perhaps some of the basic knowledge on which mining was based. As mining developed, the mathematics used in operation became more advanced. It is easy to imagine that intricate mathematical calculations were necessary to make deep large sustainable mines. Constructions and structures beneath the earth was particularly difficult, since the mines could easily collapse. Additionally, knowledge of geometry, geology, physics, construction engineering and skills in precision were used to design and make mining constructions beneath the earth and in the making of tunnels, adits, shafts etc. The work of the mining engineer Harald Hansteen is a good example of how mathematics combined with detailed work including mine measuring, calculation and planning was used from early on. Hansteen started as a surveyor at Kongsberg Silver Works in 1852. He began trigonometric measuring and levelling of the mining field of the company and in 1855 he carried out measurements between the King's mine and Gottes Hulfe mine, a task that had started years earlier. Mining superintendent Holmsen completed Hansteen's work with new measurements in 1864.[489] According to the mining engineer Jacob Pavel Friis the work of Hansteen included detailed and precise measuring and maps. One of his accomplishments was to make so that Christian adit and Gottes Hulfe's adit met perfectly underground.[490] Another example of the use of a combination of natural sciences is the work by engineer and sous-director Emil Knudsen at Vigsnes Copper Works in the 1880s. He combined knowledge in mathematics, mineralogy, geology and physics to organise and plan future work at the mining company. The old maps and observations at the firm were not accurate, and so Knudsen made new and more precise ones.[491] The oldest mine

[489] B. I. Berg, *Gruveteknikk ved Kongsberg Sølvverk 1623-1914* (Trondheim, 1998), pp. 431-432
[490] J. P. Friis, *Direktør Jacob Pavel Friis' erindringer* (Oslo, 1944), pp. 120-121
[491] F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005), p. 99

at the company was operated from a shaft of 450 meters. For every 100 meters, main levels of up to 600 meters were built for transport of ore. Drops of 12 to 20 meters were made between the main levels.[492] Knudsen explained that he started during the summer 1883 to make an accurate geological map of the mine with a new theodolite (measuring device).[493] After systematic analyses of the mineral composition, he found out where the mineral ore developed underground:

> On the basis of my geological maps of mine, I did surveys and found vein number 1 again at 360 meters' depth, whereas vein number 3 in my theory was to not to be found that deep since the cavity with ore formation had been removed from the transversal plateau […] at 347 meters the ore appeared…[…] However, I found two new smaller ore veins at 260 and 286 meters…[…]… and when we got down to 460 meters I found vein number 2A, vein number 5…[…]… and vein number 1. At 160 meters I found an unknown ore vein number 1B, which I also rediscovered at 360 meters depth. [494]

As a result of his work "…measurements matched so accurately that there were only five millimetres difference in the lateral direction and 10 centimetres vertically…"[495] Knudsen explained that in the use of room and pillar techniques it is was important to choose the optimal size for the pillars. Too big pillars would potentially mean loss of ore and too small pillars could give too little support and involve the risk of the mine collapsing.[496] It is evident that in order to be able to do these measurements and constructions it is clear that in-depth knowledge of geology, mineralogy as well as mathematics and physics were vital.

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[492] F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005), p. 8
[493] F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005), pp. 88-89 and 99
[494] F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005), pp. 88-89
[495] F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005), p. 99
[496] F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005), p. 8

After the ore was crushed and milled a number of separation- converting- and smelting processes were used to obtain a desirable product. Processing of ores happened in a variety of ways, depending on the composition of ores. Knowledge of the knowledge fields of geology, mechanical engineering, chemistry and metallurgy was extensively used to separate and process ores. The Manhés process and the flotation method to produce copper, the amalgamation process and the use of sodium cyanide to produce silver, magnetic separation in the production of iron, electric smelting and electrolysis in the production of aluminium, nickel and steel are some examples of common processing techniques. In-depth knowledge of each mineral and metal and their characteristics and treatment was crucial in the use of techniques. It was also vital in the testing and experimentation of new methods. New smelting methods permitted the mining of lower grade ores and the making of purer products. The creation and use of an increasing number of metal and mineral productions, and constantly more, better and more efficient techniques to process them, were based on knowledge in geology, chemistry, electro-metallurgy, magnetism and other specialisations. The making of the Orkla process, which led to the successful method for separating pure sulphur and copper from pyrite, illustrates the use of in-depth knowledge of such natural science disciplines. The very common flotation process, used from the early twentieth century, was not adopted at Løkken Mine due to very fine pyrite and high crushing and grinding costs. Instead, in 1918 chemist and metallurgist Harald Pedersen experimented with the possibility of utilising the sulphur content in pyrite without losing a lot of its components in his laboratory. The experiments constituted of mixing crushed pyrite with coke and blowing air through the mixture after heating. The roasting and reduction process was to be performed at a low temperature so that the liquid did not agglomerate.[497] However, problems occurred and the research project was transferred first to Portugal and later to Oskarshamn Copper Works in Sweden where further experiments in separation and smelting were carried out. In 1927,

[497] Orkla Grube-Aktiebolag, *Løkken Verk En Norsk Grube Gjennom 300 År* (Trondhjem, 1954), pp. 441-448

the laboratory work was transferred to Løkken Mine with the necessary equipment, including a water-jacket furnace, electro filter for dust and sulphur, steam boiler and other devices. In the beginning, sixty to sixty-five per cent of the sulphur content of the pyrite was utilised. After a number of modifications, such as installation of a catalyst chamber and an exhaust system to further benefit the sulphur content of the gas, it was possible to utilise up to seventy per cent and later eighty-five per cent of the mineral.[498]

A simple overview sums up some of the knowledge domains that were used to carry out mining in the late nineteenth and early twentieth centuries (see table below):

Simple overview of knowledge domains used in mining

Activity	Knowledge domains (sciences)
Geological surveys/prospecting	Geology Economics Mineralogy Chemistry Electro-engineering
Removing ores	Physics Mathematics Construction engineering Mechanical engineering Electro-engineering
Processing of ores	Geology Mechanical engineering Chemistry Mineralogy Metallurgy (electro-engineering, magnetism etc.)

8.4 Mining education and the indispensable work of mining engineers and technicians

The codification of knowledge within the natural sciences and increased complexity of mining activities were accompanied by the establishment of formal mining education. The gradual

[498] Orkla Grube-Aktiebolag, *Løkken Verk En Norsk Grube Gjennom 300 År* (Trondhjem, 1954), pp. 441-448

mechanisation and adoption of complex machinery and equipment led to an increased use of technical manuals, user's guides and instructions. As mechanics constantly had to read plans, in English and German iron industries during the nineteenth century, although the work of most operatives demanded little more than sheer physical strength, literacy and calculation were essential.[499] Mining education was one of the first technical training programs aimed to form engineers and technicians to a specific industry. The first mining school in Europe was created in Freiberg, Germany in 1702, but schools of mining and metallurgy were also established in Austria, Russia, France, Italy, Norway and Sweden in the eighteenth century. Other mining schools were founded all over Europe in the nineteenth century, such as Saarbrücken School of Mines in 1816, Schools of Mines in Zwickau in 1862, the School of Bridges and Highways, Mines and Architecture in Bucharest in 1864 and the School of Mines in Tarnowitz, Poland, in 1803.[500] The first School of Mines in the United States was the School of Mines of New York, established in 1864.[501] Other mining schools opened in the country in the late nineteenth, such as Columbia School of Mines of 1864, and a number of schools and universities began to offer courses in mining and metallurgy.[502] The first mining school in Latin America was the Mining School of Copiapó in Chile, founded in 1857, and other mining schools were opened in Colombia, Bolivia and Brazil in the late nineteenth and early twentieth centuries. In China the Mining and Engineering College was established in Wuchang in 1892 and in Japan the Imperial College of Engineering, founded in 1875, offered courses in geology, mining and metallurgy.[503] Formal mining engineering education, in particular, has been pointed out to be crucial for mining development. But, how is the role of mining engineers understood? Mining engineers had a crucial role in mining and were meant to lead operational activities at research institutions and mining companies. In Norway, formal education was even mandatory for certain leading positions. In 1818, Røros Copper Works decided by law that the director of the company had to have formal

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[499] P. Musgrave, *Technical Change the Labour Force and Education* (Oxford, New York, 1967), p. 27
[500] F. Habashi, *Schools of Mines* (Quebec, 2003), pp. 115-422
[501] F. Habashi, *Schools of Mines* (Quebec, 2003), p. 450
[502] F. Habashi, *Schools of Mines* (Quebec, 2003), pp. 469-476
[503] F. Habashi, *Schools of Mines* (Quebec, 2003), pp. 516 and 521

training in mining:[504]

> "As Managing Director at Røros Copper Works must in the future no one be selected, who have not fully studied mining, and passed exams in his theoretical as well as practical skills in mining engineering…"[505]

The other foremen, mine leaders and leaders at smelting plants at this company were required to have practical knowledge of mining construction, ore surveying and mineralogy, ore dressing and metallurgy.[506] Later, in the early twentieth century formal training became mandatory also for other working positions. For intermediate technical positions, such as head of mines, the final exam from the Mining School was necessary.[507] It is relevant to mention here that David and Wright give mining schools in the United States a crucial function in their explanation for the exceptional development of the mining sector in this country.[508] Moreover, Duncan and Fogarty find that:

> "…geological knowledge and mining expertise became part of the Australian heritage enriched by schools of mines of world class and the industry has been in the forefront in the development and application of mining and treatment technology."[509]

What kind of working tasks and positions were typical for mining engineers and mining technicians? In general, mining engineers were meant to obtain intermediate and higher engineering and

[504] My translation: *Lov, ang. Røraas Kobberværk* (Trondhjem, 12 September 1818), p. 17
[505] *Lov, ang. Røraas Kobberværk* (Trondhjem, 12 September 1818), p. 17
[506] *Lov, ang. Røraas Kobberværk* (Trondhjem, 12 September 1818), p. 17
[507] *Tidsskrift for kemi og bergvæsen* (Oslo, 1935), p. 154
[508] P. David, G. and Wright, "Increasing Returns and the Genesis of American Resource Abundance", *Oxford Journals*, vol. 6, issue 2 (1997)
[509] Quote taken from D. De Ferranti et al. *From Natural Resources to the Knowledge Economy* (Washington D. C., 2002), pp. 58-59

managing positions. Mining technicians were normally not meant for administrating companies, but rather assisting the engineers in their work. They normally acquired intermediate and lower technical positions, i.e. foremen or assistant engineers.[510] Mining engineers in Norway were to either work in the industry or acquire academic positions at the University and research centres. The latter was motivated by a wish to develop research in chemistry, physics and mineralogy and to increase knowledge about the country's geological structure.[511] Thus, the mining engineering education was directed towards the mining industry, although not uniquely pointed towards a specific profession.[512] In Chile, mining engineers had a similar role. Santiago Macchiavello Varas described them as being responsible for the overall operations and divisions within mining.[513] Felix Cremer confirmed that normal positions for a mining engineer were being in charge of a mine or a concentration plant as administrator, manager, consultant or similar positions.[514] Mining engineers were also meant to fill scientific positions at universities and research centres. In particular, they were seen as crucial for positions responsible for geological mapping and ore surveying.[515] The director of the Mining and Saltpetre School in Antofagasta explained that engineers had overall two purposes. On one hand, the engineer should search for new methods and proceedings of elaboration in order to improve the product or make production cheaper.[516] On the other hand, he should be able to operate the current elaboration system in the field.[517] Mining technicians or "practitioners", on the other hand, were the engineers' assistants and leaders of workshops, supervisors or foremen of the mining work inside the mines or at the foundries.[518] In the bulletin of the Saltpetre and Mining School of Antofagasta

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[510] Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966), pp. 8-10 and 20

[511] G. A. Blom, *Fra bergseminar til teknisk høyskole* (Oslo, 1958), p. 132

[512] J. R. Kyllingstad and T. I Rørvik, *1870-1911 Vitenskapens universitet* (Oslo, 2011), p. 270

[513] S. Macchiavello Varas, *El problema de la industria del cobre en Chile y sus proyecciones económicas y sociales* (Santiago, 2010), p. 123

[514] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1928), p. 57

[515] See reports and articles about the role of mining engineers in the making of geological maps of mineral deposits in the country in the Mining Journal: *Boletín de la Sociedad Nacional de Minería* (Santiago, 1890-1940), for example *Boletín de la Sociedad Nacional de Minería* (Santiago, 1890), p. 419

[516] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1926), pp. 644-646

[517] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1926), pp. 644-646

[518] S. Macchiavello Varas, *El problema de la industria del cobre en Chile y sus proyecciones económicas y sociales* (Santiago, 2010), p. 123

technicians were described as the "engineer's indispensable collaborator" in the management of mining operations. They assisted the engineers in the field, with machinery, in chemical laboratories, with geological mapping, in the technical drawing offices etc.[519]

A revision of the leading positions at mining companies gives an image of some of the tasks that were assigned to the mining engineers and technicians. Mining companies often had a strong organisation of workers. The working system was highly hierarchical. Fritz Hodne points out that in the early nineteenth century, the mining sector in Norway had stronger organisation than in other sectors.[520] Each division had a leader and normally an assistant, while miners, hewers and day labourers carried out the physical work of building, excavating, removing and transporting the ore.[521] Mining companies were sometimes large, with several hundred workers, although the number of workers at each company tended to vary from year to year. In 1940, the largest mining companies in Norway were Sulithjelma Mines Ltd. with around 800 workers, Sydvaranger Ltd. with around 950 workers and Sydvaranger Ltd. with 1 441.[522] Other companies varied between a couple of workers to around 300 workers.[523] The head engineer, or mine leader, planned and organised the work at the mine and was in charge of the miners who worked with removing the ore from the rocks or other geological grounds.[524] This meant having the responsibility for the daily operation concerning removal and transport of ore and ensuring that the work was performed successfully. Mine leader was the kind of position that the mining technicians normally obtained.[525] The work at the mines also required

[519] Ministerio de Educación, *Escuela de salitre y minas de Antofagasta* (Antofagasta, 1920), p. 5
[520] F. Hodne and O. H. Grytten, *Norsk økonomi i det nittende århundre* (Bergen, 2000)
[521] http://bergverkshistorie.no/Artikkel/Kobbersmelteren [accessed 29 March 2015]
[522] Other large companies in Norway were for instance Kongsberg Silver Works with around 330 workers, Evje Nickel Works (Falconbridge) with around 320 workers, Falconbridge Nickel Works with around 580 workers, Knaben Molybden Mines Ltd. with around 350 workers, Stordø Pyrite Mines Ltd. with around 330 workers, the Norwegian Zink Company Ltd. With around 560 workers, Folldal Works with around 350 workers, Orkla Mining Company with around 285 workers and Bjørkåsen Mines Ltd. with around 310 workers: Norges offisielle statistikk, *Norges Bergverksdrift* (Oslo, 1940)
[523] Norges offisielle statistikk, *Norges Bergverksdrift* (Oslo, 1940)
[524] K. Hunstadbråten, *Blaafarveværket* (Drammen, 1997), p. 38
[525] Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966), pp. 8-10 and 20

writing reports, sometimes every week. At some companies, for instance Røros Copper Works, the mine leader was required to send reports about the production, working methods and operations directly to the directory of the company.[526] Mining engineer Emil Knudsen explained that he had to write reports about every operational task to the general director.[527] The mine leader normally had an assistant, or several, who helped him in his work and replaced him when he was away.[528] Leaders of the crushing plants led the work at the quarries, including the washing of the ore.[529] Leaders at the processing and smelting plants were smelting masters, smelting accountants and metallurgists. The smelting master was the leader of the ore smelting processes.[530] He was in charge of the workers who operated the smelting ovens and furnaces and answered to the smelting accountant. Leading the smelting operation meant having the responsibility for the whole set of furnaces and smelting techniques and involved leading the physical work of carrying, loading, separating the ores, as well as maintaining and repairing machinery. The smelting accountant was the upper chief of the smelting plant and worked as an accountant and bookkeeper for the smelting operations. He was usually the office manager and chief bookkeeper at a mining company and answered to the mining accountant.[531] At Røros Copper Works, the mining accountant was the accountant and bookkeeper of the whole company. He was the administrating director at plant and was in charge of operations, salaries for the workers and keeping records of proceedings of the company. He was also in charge of the lists of inputs and outputs, keeping records of orders and all the monthly accounts.[532] The mining superintendent was another important position in Norwegian mining. He supervised mining operations and made sure surveying, mining and ore dressing were carried out properly.[533] At the same time, the mining superintendent position was a civil servant appointed by the King who granted

[526] The archive of Røros Copper Works includes continuous reports from the “mine leaders” to the directory about the production and daily work at the mine.
[527] F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005), p. 99
[528] S. Imsen and H. Winge, *Norsk historisk leksikon*, 2. edition (Oslo, 1999), p. 38
[529] FINN SIDE: S. Imsen and H. Winge, *Norsk historisk leksikon*, 2. edition (Oslo, 1999),
[530] www.bergstaden.org [accessed 28th March 2015]
[531] www.bergstaden.org [accessed 28th March 2015]
[532] Lov, ang. Røraas Kobberværk, 1818 p. 17-18
[533] K. Hunstadbråten, *Blaafarveværket* (Drammen, 1997), p. 38

metal and mineral licenses.[534] In 1812, Norway was divided into three mining superintendent districts and each district had a mining superintendent and a mining superintendent assistant.[535] In the early nineteenth century, the Director of Kongsberg Silver Works saw this position as Norway's highest mining engineering position.[536] On the other hand, mining engineers also led whole companies. Managers normally led the operations while the director (or the directory) had the overall responsibility. Managing and directing positions involved administrating the operation and having the overall responsibility for decision-making and delegation of work.[537]

A revision of the organisation of some of the mining companies in Chile indicates that leading positions at mining companies were characterised in a similar way as in Norway. The mining administrator at the mining company Descubridoras de Caracoles was described the following way in 1872:

> "(T)he responsibilities of each mine administrator are in particular to execute orders from the general administration, both with regard to inside operations and economic order…[…] … (T)he mine administrator, besides the mechanism of each plant, and the distribution and arrangement of work subsequent to it, is in charge of managing the storeroom, booking and warehouse…"[538]

He was also responsible for salaries, consumption, metal materials etc. [539] The general administrator at this company was in charge of:

[534] K. Hunstadbråten, *Blaafarveværket* (Drammen, 1997), p. 38
[535] S. Imsen and H. Winge, *Norsk historisk leksikon*, 2. edition (Oslo, 1999)
[536] B. I. Berg, *Gruveteknikk ved Kongsberg Sølvverk 1623-1914* (Trondheim, 1998), p. 432
[537] Finn side: S. Imsen and H. Winge, *Norsk historisk leksikon*, 2. edition (Oslo, 1999),
[538] Descubridoras de Caracoles, *Memoria* (Santiago, 1872), pp. 32-34
[539] Descubridoras de Caracoles, *Memoria* (Santiago, 1872), pp. 32-34

> "…everything that relates to the work at the mines, metal divisions and references, the mechanism in detail of the various mines, as the movement of employees and workers, organisation of labour and everything related to the discipline and good order." [540]

Some of the largest mining companies in the world operated in Chile and had up to 10 000 workers. In the beginning of the twentieth century the administrator at the Potrerillos plant of Andes Copper Company delegated responsibility and operation tasks to leaders of the different plants at the company. The plant had a leader for each mine and section. The superintendent collaborated with the chief of mines, the chief engineer of the railway systems and water reservoirs and the chief of accounting.[541] Coal companies were administrated similarly. In the beginning of the twentieth century, the management of The Coal Company of Lota was located in Valparaíso, near Santiago. In this division, the administrative and technical staff worked with the planning and organisation of operation. They were also in charge of the commercial activities, purchase of materials, sale of coal etc. The general administration was located in Lota and was responsible for the local divisions. Each division had a number of departments, including mines, transport, electricity, mechanical workshop, architecture, ceramics, timber, accounting and social welfare departments.[542] Saltpetre companies also had a number of divisions and often a leader of each division. Normally leader positions were divided in five: the administrator, the chief of caliche, the chief of elaboration, the chief of plant and machinery and the chemist. These leaders had assistants helping them in their work and leading the workers.[543] The table below shows a simple overview of the hierarchical structure and the most common divisions and positions at mining companies:

[540] Descubridoras de Caracoles, *Memoria* (Santiago, 1872), pp. 32-34
[541] F. Solano Vega, *El Mineral de Potrerillos 1916-1918* (Copiapó, 1918), pp. 12-14
[542] O. Astorquiza, *Compania Carbonifera e industrial de Lota 1852-1942* (Valparaíso, 1942), p. 135
[543] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1926), p. 644-646

Simple overview of the hierarchical structure of mining companies

Board of Directors

Manager

In charge of accounting and bookkeeping:
mining and smelting accountants
(mining superintendents)

In charge of divisions and daily work:

Mine leaders (head leaders at the mines)	**Leaders of ore dressing (head leaders at ore dressing plants)**	**Smelting masters (head of smelting plants)**	**Leaders of laboratories**	**Leaders of power stations**	**Leaders of transport systems**
Assistants	**Assistants**	**Assistants**	**Assistants**	**Assistants**	**Assistants**
Miners	**Crushers**	**Smelters**	**Chemists**	**Electricians**	**Drivers**

What kind of knowledge was used to carry out these operational activities successfully? We have already seen that knowledge from natural science disciplines, such as mathematics, geology, physics, mechanics, chemistry and metallurgy were important to carry out mining. It is argued, however, that in earlier times, around the time of the Kongsberg Mining Seminar in the eighteenth century, theoretical sciences were not much used in mining.[544] The historian Bjørn Ivar Berg base this assumption on the point that:

> "…the mining sciences' low stage of development prevented yet a thorough application of theory to practical mining techniques, and the institution had limited impact on technical innovation in this period…[…] The mining technique was still largely dominated by traditions and craft skills."[545]

However, at a later stage scientific knowledge became more important. From the mid-nineteenth century, "a broad general academic education with some basic science was essential" when working

[544] B. I. Berg, *Gruveteknikk ved Kongsberg Sølvverk 1623-1914* (Trondheim, 1998), p. 314
[545] My translation: B. I. Berg, *Gruveteknikk ved Kongsberg Sølvverk 1623-1914* (Trondheim, 1998), p. 314

in the German and English iron industry.[546] Especially managers in these industries needed a "…sound basic education which included science."[547] Engineers, professors and industrialists in Chile and Norway also confirmed this. As early as 1833 Jacob Aall, Member of Parliament and owner of Næs Iron Works, argued that the metal works were the country's most important factories, and thus proper management demanded "numerous kinds of knowledge and a long preparation."[548] The mining engineer Ignacio Domeyko criticised workers in Chile, who some of them believed that mining was easy. He argued that many did not know that theoretic as well as practical knowledge of chemistry and physics was vital in order to understand how mining was carried out.[549] The National Mining Society also stated in one of its reports in the year 1891 that the nature of the mining engineer's work "requires deep theoretical knowledge."[550] Francisco Encina confirmed in 1912 that "from the point of view of capital and of technical and administrative aptitude, the copper industry is as demanding as the most complicated manufacturing industries."[551] From the turn of the century, formal mining education became more and more complex and specialised. The increased diversity within the mining industry was used as an important argument for formal mining education. In 1910 it was stated in the study programs that "(a) large modern mining enterprise is a technically very complicated business and requires among engineers and managers a significant insight in numerous and extensive areas."[552] Ignacio Diaz Ossa, mining engineer and director of the Mining School in La Serena, argued much in the same way that mining engineers and technicians would need "sound scientific knowledge" and an excellent instruction.[553] In relation to the development of copper mines in Naltagua in the beginning of the twentieth century, transport, power plant, different constructions and making of mines involved big challenges and highly qualified engineers were seen as a highly

[546] P. Musgrave, *Technical Change the Labour Force and Education* (Oxford, New York, 1967), p. 27
[547] P. Musgrave, *Technical Change the Labour Force and Education* (Oxford, New York, 1967), p. 74
[548] *Tidsskrift for kemi og bergvæsen* (1932), p. 133
[549] C. C de bon Urrutia, *La Escuela de Minas de La Serena Derroto de sus Orígenes* (La Serena, 1992), p. 27
[550] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1891), p. 159
[551] F. A. Encina, *Nuestra inferioridad Económica Sus Causas, sus Consecuencias* (Santiago, 1912), pp. 45-46
[552] Norges Tekniske Høiskole, *Beretning om virksomheten 1910-1920* (Trondhjem, 1920), p. 56
[553] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1912), p. 556

useful:

> "The time it has taken to prepare the mines indicates the innumerable difficulties that any modern company has to overcome, being able to say that more than any other, [mining] needs the competition of the most skilled and experienced engineers to carry it out to success."[554]

The argument that education was crucial for mining strengthened. In 1935, the mining engineer Jorge Muñoz Cristi found that the administrators at the metallurgical plants should have a broad theoretical base, which allowed them to handle the many problems in practical working.[555] In fact, the director of the Mining and Saltpetre School in Antofagasta actually claimed that without theoretically prepared technicians mining operations would fail due to "lack of a conscious, rational and scientific direction."[556]

The diversity within the mining sector allowed for workers with different scientific backgrounds. Chilean engineers repeatedly expressed in the Mining Bulletin that experience and knowledge of many sciences, such as mathematics, physics, mechanics, mineralogy and geology were essential in the work at mining companies.[557] At Braden Copper Company, for instance, there were managers in charge of the personnel, a superintendent in charge of the mines, subordinate leaders and supervisors in charge of the welfare department, the survey division, the ore dressing and mill section, the preparation and extraction plant, laboratories, the construction division, the railway section, two electric power plants, lifts, the material department and so on.[558] The initial construction

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[554] My translation: J. Gandarillas Matta, *Estado actual de la industrial minera del cobre en el extranjero y en Chile* (Santiago, 1915), pp. 93-94

[555] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1935), p. 404

[556] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1926), pp. 644-646

[557] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1928), p. 56

[558] L. Hiliart, *Braden Historia de una mina* (Chile, 1964), p. 67; A. Fuenzalida Grandón, *El trabajo y la vida en El Teniente* (Santiago, 1918), p. 403; *Boletín de la Sociedad Nacional de Minería* (Santiago, 1940); A. Concha,

phase of Andes Copper Company at the Potrerillos plant between 1916 and 1925 demonstrates a number of knowledge domains. The company constructed a railway from the Potrerillos mines to the port in Chañaral, 168 drilling holes to start the mining process, excavation work, construction of an electric power plant with 3000 kW capacity and electric transmission, installation of tubes for water supply, establishment of a town site in Potrerillos with 237 houses, hospital, schools, shops and public buildings, and construction and of mechanic workshops of different types.[559] In addition, large concentration and metallurgical plants for processing were built.[560] The mechanical engineer Wilbur Jurden, wrote to the metallurgical manager Fredrick Laist in July 1925 about the recruitment of skilled workers at the Potrerillos plant. A long list of workers were argued as necessary for the many departments; superintendents, office engineers, foremen, field engineers, different types of construction foremen, clerks, construction mechanics, carpenters, electricians, electric constructers, draftsmen, erectors, supervisors, machinists, tank erectors, steel erectors, brick masons, pipers and others.[561] With regard to the machinist department, in addition to one general machinist foreman, Jurden stated that "…we should have at least six experienced machinists to install the great number of machines which go into the complete plant."[562] In the saltpetre industry too, a great variety of skilled workers were used. The director of the Mining and Saltpetre School in Antofagasta in Chile, for instance, wrote to the General Director of Industrial Education in 1926 about the demands of the saltpetre industry. He argued that the saltpetre industry, as any other mining industry, acquired many types of technicians, such as mechanics, electricians, chemists etc.[563]

"Informe presentado al directorio del servicio de minas y geologia del ministerio de Industria y obras publicas sobre la "planta beneficiadora" de minerales de cobre "El Teniente" de propiedad de la Braden Copper Company" (Santiago, 1920)

[559] M. C. Baros Mansilla, *Una historia de pioneros* (Santiago, 2006), pp. 57-58

[560] S. Collier and W. F. Sater, *A History of Chile, 1808-2002* (Cambridge, 2004)

[561] Montana Historical Society Archives, Collection No. 169, *Anaconda Copper Mining Company Records*, subj. file 6.4c, folder no. 78-6, 1925-1928 staff

[562] Montana Historical Society Archives, Collection No. 169, *Anaconda Copper Mining Company Records,* subj. file 6.4c, folder no. 78-6, 1925-1928 staff

[563] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1926), pp. 644-646

8.5 New knowledge specialisations at the mines: mechanical-, construction- and electro-engineering

Adoption of mechanised equipment occurred early in some countries. The economic historian Margaret C. Jacob analyses England in the eighteenth century and emphasises in particular the use of mechanical science in mining and other industries. This science:

> "… permitted engineers and entrepreneurs to have a conversation while standing at a coal mine that kept flooding, or when figuring out the best size steam engine to attach to a previously horse-driven battery of textile machines, or when dredging a harbor or laying a canal over hilly terrain."[564]

During the nineteenth and twentieth centuries, new techniques were gradually adopted in mining in both Chile and Norway. The industry statistics from the National Insurance Institution and the National Statistics Bureau in Norway from the late nineteenth century give an indication of the gradual mechanisation of mining operations in this country (see appendix 8 of use of power at mining companies). In 1895, 26 out of 90 companies used engines and a total of 31 water engines, 32 steam engines, 18 electrical engines and 1 gas engine.[565] The increased mechanisation with the use of steam engines, turbines and other mechanic equipment modified daily tasks and duties at the companies. These changes were based on increasingly diverse and specialised knowledge. The creation, transfer, installation and repair of these new devices were based on knowledge in mechanics, construction engineering, and other knowledge fields, which had not previously been used in mining. In 1926, the Norwegian mining engineer Wolmer Marlow stressed the importance of having knowledge of how to operate and repair new machinery:

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[564] M. C. Jacob, *Scientific culture and the making of the industrial west* (Oxford, 1997), p. 8

[565] Norges Officielle Statistik, *Rigsforsikringsanstaltens Industristatistik for årene 1895-1899* (Kristiania, 1904)

> "In order to master the increasingly applied mechanical operations at a modern mine and the often necessary large building projects, it must be required of the leader, that he fully knows this very important side of a mining operation. The daily and constant work at a mine is often purely mechanical and structural."[566]

11 years later, in 1937, Professor Harald Dahl stressed that the increasing mechanisation of the mining industry influenced the work of the engineer. The faster the mechanisation the more important it was for the engineer to become acquainted with the machinery they were operating. He referred to an English mining engineer who argued that "…the more machinery that gain access to the mines, the higher the requirements of expertise."[567]

From the late nineteenth century, mining companies started to adopt electricity as a source of power and electro engineering then became a new widely used knowledge field. Large power plants were built and used to provide electric power to equipment at the mines and processing plants. In 1918, 1 654 electric engines were registered at mining companies in Norway. The applied mechanical power was 36 947 horsepower.[568] In 1938, 146 companies used a total of 6 592 electric engines. The total primary power in ore, metal and mineral extraction and processing companies had increased to 98 078 horsepower in addition to the electricity for smelting, electrolysis etc. which totalled 294 210 kW (around 400 000 horsepower).[569]

The mining engineer Emil Knudsen explained in his memoires how a power plant at Røros Copper Works was installed. In the early 1890s, Knudsen first studied the geological conditions at the Arv Lake, near the King's Mine, to find out whether it was actually possible to install an electric power

[566] My translation: *Tidsskrift for kemi og bergvæsen* (Oslo, 1926), p. 31
[567] *Tidsskrift for kemi og bergvæsen* (Oslo, 1937), p. 158
[568] Norges Officielle Statistik, *Industristatistikk for året 1918* (Kristiania, 1921)
[569] Norges Offisielle Statistikk, *Norges Industri Produksjonsstatistikk 1939* (Kristiania, 1941)

plant. Knudsen explained that the first step of the process involved reading about electro engineering.[570] After several geological analyses and measurements, he found that the waterfall Arv Lake was too small compared to the size of the company. He continued to analyse the waterfall conditions other places.[571] The next step was to learn how electric power plants worked at other mining companies and to consult with electric companies. In Västerås, Sweden, he consulted the General Electrical Company about cost estimates. He travelled to Norberg, among other places, to see how new electric plants operated in practise.[572] Finally, Knudsen decided to establish the plant at the Kuraas waterfall in Glommen, near Røros. In 1895 the plans of installing a power plant was initiated.[573] The power station constituting three-phase electric power with transformers and cables between the mines and the primary station of around 4000 volts was to provide electricity to engines for transport, drilling, ore dressing, lifting and lightening at Storvarts and King's Mines.[574] The waterfall was relatively close to the mines, around seven-eight kilometers, and was able to provide "significant power".[575]

From the turn of the century, hydroelectricity became crucial also in Chile. At some of the companies, electricity was used to provide power to machinery, such as lifts, drainage engines, transport, mills and other equipment for more efficient mining operations. With the large North American copper companies, electric power became increasingly used. Braden Copper Company provides an illustrative example. Two hydroelectric plants supplied the electric force that was used at the mines. The Cachapoal plant at Coya, built in 1910, consisted of five reaction turbines that were connected

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[570] F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005), pp. 112-113
[571] F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005), pp. 112-113
[572] F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005), p. 116
[573] F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005), p. 117
[574] *Teknisk Ukeblad* (Kristiania, 2nd of mai 1895), p. 163
[575] *Teknisk Ukeblad* (Kristiania, 2nd of mai 1895), p. 163

directly to generators, operated with a waterfall of 125 meters and a capacity of about 22 000 kW. The Pangal plant was completed in 1919 and had three pelton turbines directly connected to generators, with a waterfall of 460 meters, and a capacity of 20 000 kW.[576] An electric railway, which transported mineral to the crushers, was built in 1911.[577] The total electric power that was used at copper smelting plants went up from 13 050 horsepower in 1912 to 130 532 horsepower in 1925 (see appendix 9 for use of power in copper production).[578] In 1925, there were 55 electric engines in use. In 1939, the number of engines and energy level had increased dramatically. In this year, there were a total of 35 generators, 345 generator engines and 5792 electric engines.[579] Hydraulic turbines, steam piston engines, steam turbines and diesel engines provided respectively 68 025 horsepower, 1 110 horsepower, 89 000 horsepower and 130 horsepower, in addition to generators and generator engines which provided 286 483 horsepower in total. The 5 181 electric engines in use provided 225 102 horsepower.[580]

The saltpetre production and iron industry also went through a mechanisation. In 1912, 15 450 horses and mules were used in operation and 642 800 tons of coal and 206 362 tons petroleum were consumed in the operation of engines. In 1925, the number of horses and mules had decreased to 10 999 and cars, trucks, locomotives and other vehicles summed 2 301. In 1939 13 piston steam engines and 69 combustion engines were used, in addition to 212 electric and steam generators and 2 389 motor engines.[581] Betlehem Steel Corporation invested in the Tofo iron mine in central Chile in 1913. Iron was excavated through separated tunnels with compressed air drills, which were fully loaded with gunpowder and other explosives. The broken ore was carried out with automotive

[576] La Braden Copper Company Mineral de “El Teniente” (Rancagua, 1942)
[577] S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), pp. 175-176
[578] Oficina Central de Estadística, *Anuario Estadístico Minería y Metalurgia 1912* (Santiago, 1913); Oficina Central de Estadística, *Anuario Estadístico Minería y Metalurgia 1925* (Santiago, 1926)
[579] Oficina Central de Estadística, *Anuario Estadístico Minería y Metalurgia 1939* (Santiago, 1940)
[580] Oficina Central de Estadística, *Anuario Estadístico Minería y Metalurgia 1939* (Santiago, 1940)
[581] Oficina Central de Estadística, *Anuario Estadístico Minería y Metalurgia 1912* (Santiago, 1913); Oficina Central de Estadística, *Anuario Estadístico Minería y Metalurgia 1925* (Santiago, 1926); Oficina Central de Estadística, *Anuario Estadístico Minería y Metalurgia 1939* (Santiago, 1940)

mechanical shovels. Steam locomotives were used for transport and were later replaced by electric locomotives. A thermoelectric plant driven by petroleum provided the electric energy.[582]

8.6 New knowledge specialisations in mineral processing: chemistry

New techniques within the processing of ores were based on a number of specialisations. In 1925, the Norwegian mining engineer Fredrik Sebastian Nannestad confirmed that it was important to be aware that, in practice, there were no minerals which were treated equal. Therefore, the knowledge of ore dressing methods, mineral characteristics and processing techniques represented very extensive knowledge.[583] The broad knowledge base indicated that innovation processes took time, sometimes decades. Edquist even suggests that innovation processes often are path-dependent over time and that the actors involved sometimes do not know what the end-result will be or which path will be taken.[584] The Söderberg process, used in aluminium production, is a good example of how the making of techniques are based on and depended on previous decisions and work. The combination of different capabilities, knowledge from a number of fields and three engineers with different theoretic training and work experiences ensured a successful product. The idea started with the Swedish-Norwegian Carl Wilhelm Söderberg, electro-engineer from the Technical School in Hannover in Germany. He believed that it was possible to develop a continuous, self-determining electrode for electrical ovens, instead of the current one, which needed to be replaced after 5-10 days.[585] Söderberg experimented with his idea at Jøssingfjord Manufacturing Company in 1910. His attempts were, however, not successful.[586] As Söderberg lost faith, the electro-chemist Mathias Sem, with a doctoral degree from the Technical School in Darmstadt, continued the process. After many experiments and failures it was Jens Westly, a technician and chemist from the Technical School in

[582] S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), pp. 180-192
[583] *Tidsskrift for kemi og bergvæsen* (Oslo, 1925), pp. 215-17
[584] Edquist, " The Systems of Innovation Approach and Innovation Policy: An account of the state of the art", 2001, pp. 15-16
[585] A. K. Børresen and A. Wale (red.), *Vitenskap og teknologi for samfunnet? Bergfagene som kunnskapsfelt* (Trondheim, 2005), p. 15
[586] K. Sogner, *Elkem gjennom 100 år Skaperkraft 1904-2004* (Oslo, 2003), pp. 59-61

Bergen, who managed to solve the problem. He was able to make a useful fastener, which was vital for the use of the electrode. His solution enabled the continuous self-burning electrode to be put into practice.[587]

The broad knowledge base was also emphasised in Latin America. At a conference in Bolivia in 1928, the engineer Félix Cremer argued much in the same way as Nannestad. He underlined that mining was such a vast sector and included so much knowledge that "no human brain can adequately meet its demands".[588] Subdivisions and specialties were a natural consequence of this broad knowledge base and essential, he argued, to be able to absorb the "infinite details" which formed each of these branches. He argued that differences were actually so big that sometimes the mining engineer's capacity to lead operations at a tin or lead mining works was questioned if he, for instance, only had practical experience with silver and zinc. For this reason, he found that it was normal among mining engineers to dedicate their whole life to one branch, for instance coal, metal mining or petroleum etc.[589]

8.7 New knowledge specialisations in the organisation of mining: economics and administration

With large-scale and more diversified productions, an increased emphasis was given on administration, long term planning and leadership. Perhaps knowledge in administration and economics seems unnecessary for mining at first sight. The business historian Alfred D. Chandler argued that administrative challenges in mining companies in the early twentieth century were minor compared to those of many other industries due to fewer technological changes.[590] However, this argument is unconvincing. Actually, it seems like it was very much important to know how to

[587] K. Sogner, *Elkem gjennom 100 år Skaperkraft 1904-2004* (Oslo, 2003), p. 62
[588] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1928), p. 55
[589] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1928), p. 55
[590] A. Chandler, *Scale and Scope: the dynamics of industrial capitalism* (The United States, 1990)

administrate and manage mining companies property. As companies started to increase productions knowledge about how to administrate large institutions in a rational way became gradually even more important. In the case of iron industries in England and Germany, Musgrave found that the growth of production and the increased complexity opened for the use of accountants and men trained in management and commerce.[591] In 1939 in Britain:

> "…the techniques of the industry demanded a broad academic education backed by some professional further education for most of the new entrants to management. A level of scientific and business skill higher than in 1900 was needed because of the more complicated nature of products and the larger scale. The growth in size of unit of control and of administrative staff probably changed the needs at this level most; metallurgists and accountants could be expected amongst top managers." [592]

This was also the case in other countries. For instance, the Norwegian Mining Journal wrote in 1925 that the understanding of "…economic, commercial management of a mine" was important, and even required, for the employment in leading positions.[593] The Chilean Mining Bulletin wrote in 1926 that:

> "The administration of a mining business requires, in a larger degree than other engineering firms, these qualities of good management, without which the whole entire technique and mining experience are useless…"[594]

The Chilean mining sector was very large and the companies employed thousands of workers, which

[591] P. Musgrave, *Technical Change the Labour Force and Education* (Oxford, New York, 1967), p. 74
[592] P. Musgrave, *Technical Change the Labour Force and Education* (Oxford, New York, 1967), pp. 134-135
[593] *Tidsskrift for kemi og bergvæsen* (Oslo, 1925), p. 186
[594] My translation: *Boletín de la Sociedad Nacional de Minería* (Santiago, 1925), pp. 663-4

probably meant that knowledge in administration would be even more crucial in this country. After the turn of the century the sector amounted to over 100 000 workers, which was around 10 times more than the Norwegian sector of a total of up to 12 000 workers.[595]

8.8 Essential know-what, know-who, know-how and know-why in technology transfer processes

New technology often had origin in industrial powers, such as Britain, Germany, France and the USA (see overview of technological development in mining). Thus, innovation involved in a large degree transfer of technology from these countries. Innovation in smaller "catching-up economies" of the Industrial Revolution involved in a large degree transfer of technology from abroad, notably these large industrial powers. An important argument here is that small follower countries were usually not able to make the investments, research and development of similar magnitude as large economies.[596] Therefore, the capacity to absorb foreign knowledge has been essential. Bruland stresses that in these cases:

> "(w)hether they undergo industrialisation processes and remain in the forefront in terms of advanced industrial performance depends largely on whether they can develop the ability to apply technologies developed abroad."[597]

Technology transfer involved travelling to places where technology was in use. The textile industry in Norway, and the ability to adapt, use, imitate and copy foreign machines, she argues, developed after Norwegians had travelled and acquired training abroad.[598] Similarly, the development of the

[595] Oficina Central de Estadística, *Anuario Estadístico Minería y Metalurgia* (Santiago, 1909-1940); Norges offisielle statistikk, *Norges Bergverksdrift* (Oslo, 1855-1940)
[596] K. Bruland, "Norsk mekanisk verkstedindustri og teknologioverføring 1840-1900", in *Teknologi i virksomhet: verkstedindustri i Norge etter 1840*, E. Lange (ed.) (Oslo, 1989), p. 34
[597] K. Bruland, "Norsk mekanisk verkstedindustri og teknologioverføring 1840-1900", in *Teknologi i virksomhet: verkstedindustri i Norge etter 1840*, E. Lange (ed.) (Oslo, 1989), p. 34
[598] K. Bruland, "Norsk mekanisk verkstedindustri og teknologioverføring 1840-1900", in *Teknologi i virksomhet: verkstedindustri i Norge etter 1840*, E. Lange (ed.) (Oslo, 1989), pp. 55-60

workshop industry in Norway was a result of "…training and education, access to information on foreign technical advances and the ability to use information."[599]

The introduction of the Pierre Manhés process at Røros Copper Works is an illustrating example of how know-what, know-who, know-how and know-why were acquired from long trips to other countries. During the year 1886, the Board of Directory gathered knowledge, or know-what, about existing techniques. The Bessemer method was considered a good alternative to the old technique and information about it was first acquired from "various sources" through that year.[600] Thereafter the company began to search for people with relevant know-how. In 1886 Anton Sophus Bachke, a member of the Board of Directors, went to a number of European countries on behalf of Røros Copper Works to obtain practical knowledge of the different copper smelting techniques on the market. During such trips, which were very common among mining engineers, information about people with relevant knowledge was acquired (see appendix 22 for list of study travels by mining engineers). The Manhés' process was used in Swansea, England by the "great copper king" sir Hussey Vivian. Bachke managed to make contact with Mr. Vivian, who accompanied him to the section at his company where the Manhés furnace was used. During these trips, the engineers acquired practical and hands-on knowledge of technology, their strength and weaknesses. This experience was essential in processes of selecting new techniques. Sophus Bachke was allowed to stay at Hussey Vivian's smelting plant and observe and try out how the technique worked. Bachke then went to Paris to pay for the patent right and managed to obtain the same conditions as Hussey Vivian.[601] In February 1887, after a long process of acquiring information and learning about different techniques, it was thus decided that the Manhés process was to be put in use at Røros.[602] Yet, in order to be able to use

[599] K. Bruland, "Norsk mekanisk verkstedindustri og teknologioverføring 1840-1900", in *Teknologi i virksomhet: verkstedindustri i Norge etter 1840*, E. Lange (ed.) (Oslo, 1989), p. 73
[600] Røros kobberverk, *årlig rapport 1886* (Trondheim, 1887), p. 9
[601] *Tidsskrift for bergvæsen* (Oslo, 1916), pp. 41-42
[602] Røros kobberverk, *årlig rapport 1887* (Trondheim, 1888), p. 8

this method several changes were necessary.[603] Understanding how long the matte should smelt in the water-jacket ovens, pouring the right amount of matte to the converters, making the air blow correctly into the converters, carrying out the process efficiently and knowing what the concentrated product should look like when it was finished, etc. were complex tasks.[604] Therefore, to assist with the installation of new furnaces and equipment and to use the new technique a foreman (contremaître) was sent from France to Røros in October 1887 to teach the workers how to install and use the technique.[605] Acquiring assistance from a person with the right know-how and in-depth knowledge of the scientific principles on which the technique was based, or know-why, was probably very useful when installing the process at the smelting plant. After some failed attempts and further modifications, the process was in use from October 1888 with good results.[606] Another case, which shows the transfer and use of knowledge from abroad, is the installation process of a new machine at Taltal Mining and Processing Company in Chile in the early twentieth century. The company had decided to adopt a diesel engine machine for ore concentration. The appropriate paraffin diesel machine for the company had to be ordered from Switzerland.[607] The administrator of the mining firm, Adolfo Wegmann, confirmed in the annual report that the engine and additional devices arrived in January and February 1905 at the nearest port.[608] He stated, however, that the engine, representing modern and "not well-known" technology in Chile, was made to operate below 1000 meters. The mines were, however, located at 3000 meters above sea level, which meant that "… a series of experiments and changes to the climate" were carried out.[609] An engineer with useful know-how was sent from Europe to assist with the installation in 1905.[610] The installation and use of the machinery involved a number of challenges. Engineers worked around one month at the mining plant

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[603] *Tidsskrift for bergvæsen* (Oslo, 1916), p. 43
[604] H. Dahle, *Røros Kobberværk 1644-1894* (Trondheim, 1894), p. 447
[605] H. Dahle, *Røros Kobberværk 1644-1894* (Trondheim, 1894), p. 447
[606] *Tidsskrift for bergvæsen* (Oslo, 1916), p. 43
[607] Compañía de Minas Beneficiadora de Taltal, *Memorias* (Valparaíso, 1906, segundo semestre), p. 10
[608] Compañía de Minas Beneficiadora de Taltal, *Memorias* (Valparaíso, 1905), p. 7
[609] Compañía de Minas Beneficiadora de Taltal, *Memorias* (Valparaíso, 1905), p. 8
[610] Compañía de Minas Beneficiadora de Taltal, *Memorias* (Valparaíso, 1905), p. 7

"…to overcome problems" mostly caused by the height.[611] The problems were solved after some time, and the machine was finally used in operation.

In the process of starting up a mining company, a number of things had to be in place. To begin with, the necessary procedures had to be carried out and the people with the right know-how had to be contacted and used. The establishment of Aconcagua Mining Company and Río Blanco Copper Corporation shows the importance of having the right experiences and contacts with relevant expertise, to establish a mining company. Contacts and experience with technology were often acquired from abroad. In 1911, after finishing his engineering studies at the University of Chile, the Chilean civil engineer Félix Federico Corona went on a study trip to Europe. The purpose of the trip was to study mining techniques in France, Sweden and England. During his time in Europe, he studied the last advances in electrometallurgy and the use of electro-thermic processes. He visited companies in Sweden where they became acquainted with induction steel furnaces and in France, he learned about reverberatory ovens heated by electric arcs.[612] At the end of 1917, after his travel around Europe, he studied electric engineering at the University of California in Berkley. After his formal studies, he started to work in the electric power industry in Pittsburgh. During his stay there, he specialised in the construction and installation of hydraulic turbines, electric generators and electric transmission of high voltage over long distances.[613] After his return to Chile, he began preparing for the start-up of a copper mining company. One of Corona's points, emphasised by Muñoz Maluschka, was that the North American companies in Chilean mining based their operations on the efficient use of electric power both outside and inside their mines. The electricity was supplied by power plants, which were situated tens of kilometers away.[614] His idea was to use hydroelectric power, of which Chile had plenty, and make a project similar to Braden Copper Company, initiated by

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[611] Compañía de Minas Beneficiadora de Taltal, *Memorias* (Valparaíso, 1905), p. 8
[612] E. Muñoz Maluschka, *Andina Historia del nacimiento de una mina* (Chile, 1987), pp. 13-15
[613] E. Muñoz Maluschka, *Andina Historia del nacimiento de una mina* (Chile, 1987), pp. 13-16
[614] E. Muñoz Maluschka, *Andina Historia del nacimiento de una mina* (Chile, 1987), p. 14

William Braden.[615] Corona found the right conditions for a large copper production and abundant hydraulic reserves at the mine Americana in the region Los Andes and the rivers Aconcagua, Colorado and Blanco.[616] It is clear that he used the experience and know-how he had learned abroad in this process, which support Bruland's argument that "…foreign trips sometimes gave the original incentive to establish firms."[617] Perhaps the most critical part of the start-up of this firm was to find people who were interested in investing in the project, which involved new trips abroad. To ensure finances he went to the United States.[618] He sought among his contacts, or know-who, about shareholders and obtained the necessary capital for making the investments: "Advised by American experts and Chilean friends in New York, [Corona] managed to organise a prospector mining company which he called "Río Blanco Copper Corporation Limited.""[619] The result was the establishment of the Aconcagua Mining Company in 1921 and Río Blanco Copper Corporation in 1924.[620]

In-depth understanding of scientific principles was useful, if not necessary, in the development of new techniques. This was the case for Elias Anton Cappelen Smith, a Norwegian-American engineer who contributed to the making of the Pierce-Smith copper converter and the Guggenheim process, used in the extraction of saltpetre and low-grade copper. The latter revolutionised smelting practices and was immediately adopted by many large copper producers in the world.[621] Right after he finished studies in 1893, Cappelen Smith went to the United States and started to work at the Chicago Copper Refining Company. At this company, he acquired work experience and learned how to smelt copper.[622] He worked later at the Anaconda Copper Company in Montana and the Baltimore Copper Smelting and Rolling Company. He acquired experience with metallurgical processes and started to

[615] E. Muñoz Maluschka, *Andina Historia del nacimiento de una mina* (Chile, 1987), p. 14
[616] E. Muñoz Maluschka, *Andina Historia del nacimiento de una mina* (Chile, 1987), pp. 16-17
[617] K. Bruland, "Norsk mekanisk verkstedindustri og teknologioverføring 1840-1900", in *Teknologi i virksomhet: verkstedindustri i Norge etter 1840*, E. Lange (ed.) (Oslo, 1989), p. 45
[618] E. Muñoz Maluschka, *Andina Historia del nacimiento de una mina* (Chile, 1987), pp. 55 and 72
[619] E. Muñoz Maluschka, *Andina Historia del nacimiento de una mina* (Chile, 1987), p. 71
[620] E. Muñoz Maluschka, *Andina Historia del nacimiento de una mina* (Chile, 1987), pp. 55 and 72
[621] K. O. Bjork, *Saga in steel and concrete: Norwegian engineers in America* (Minnesota, 1947), pp. 244-260
[622] K. O. Bjork, *Saga in steel and concrete: Norwegian engineers in America* (Minnesota, 1947), pp. 244-260

experiment with electrolytic refinery. One of his tasks, given to him by his superintendent and manager William H. Peirce, was to experiment with copper convertors.[623] His first contribution to the copper production was a modified version of the Manhés converter. The Manhés process was already used at several mines all over the world and Cappelen Smith was probably acquainted with this process at Røros Copper Works, which was near The Technical Training Institution in Trondhjem where he had studied. But, the problem with the Manhés converter was that the lining was consumed relatively quickly. The Pierce-Smith converter, on the other hand, introduced basic lining, which meant that 3000 tons of copper could be produced without relining, instead of the former 10.[624] The Pierce-Smith converter was adopted at the Braden Copper Company at El Teniente and Andes Copper Company.[625] This improvement had probably not been possible without a profound understanding of both *how* the Manhés process worked and *why* the basic lining was more efficient. In 1912 Cappelen Smith was hired as a consultant by the Guggenheim Brothers for the Chile Exploration Company and the Braden Copper Company. His task was then to develop a method to extract low-grade copper, around 2, 5 per cent copper ore, with profit.[626] The Chuquicamata ore deposits in the Atacama Desert had been extracted by miners even before the Spanish conquest, but utilisation of the low-grade ores had later resulted in failure.[627] Cappelen Smith visited the mine to do analyses of the ground. The aim of this trip was to find a solution for how to extract the low-grade copper ore.[628] The process was not developed easily. The low-grade ores contained both chlorides and sulphates and required both leaching and precipitation. A number of experiments were conducted at the Guggenheim laboratories in New Jersey. The chemical process that was developed was regarded as “extremely clever” and involved leaching in dilute sulfuric acid, removing chloride with a treatment with dispersed copper and finally electrolysis.[629]

[623] K. O. Bjork, *Saga in steel and concrete: Norwegian engineers in America* (Minnesota, 1947), pp. 244-260
[624] K. O. Bjork, *Saga in steel and concrete: Norwegian engineers in America* (Minnesota, 1947), pp. 244-260
[625] M. C. Baros Mansilla, *Una historia de pioneros* (Santiago, 2006), p. 98
[626] K. O. Bjork, *Saga in steel and concrete: Norwegian engineers in America* (Minnesota, 1947), pp. 244-260
[627] K. O. Bjork, *Saga in steel and concrete: Norwegian engineers in America* (Minnesota, 1947), pp. 244-260
[628] K. O. Bjork, *Saga in steel and concrete: Norwegian engineers in America* (Minnesota, 1947), pp. 244-260
[629] K. O. Bjork, *Saga in steel and concrete: Norwegian engineers in America* (Minnesota, 1947), pp. 244-260

Another interesting case, the career path of the Norwegian chemist Olav Steen, demonstrates the drawing on a long working experience abroad in a process in which Stavanger Electrical Steel Works selected a new and more efficient smelting technique. His experience and work had large implications for the Norwegian iron and steel industry. Working experiences from foreign mining companies were often very useful when carrying out innovation projects. First of all, training and work provided engineers with relevant know-what of technology, hands-on practice and know-how. Second, specific knowledge of how foreign techniques were used, their functions, advantages and disadvantages was also certainly relevant. Steen graduated from Christiania Technical School and Hochschule in Charlottenburg around 1895 after having studied chemistry. He started a career in mining after his studies. He worked at several iron and steel companies in Germany and Italy. One of his working tasks was to travel around Europe and study different techniques for iron and steel smelting. In 1917, he returned to Norway and started as operation manager at Stavanger Electrical Steel Works. Immediately after he started to work there it was decided to modernise the company. Expansions were carried out, partly according to Olaf Steens' plans. Steen argued that the furnace that was used at the company, a Roechling-Rodenhauser induction furnace of four steps, was not safe. He found that it had low durability, long repair time and was expensive to operate. He recommended electric arc smelting, which he had studied and practiced at a number of companies on the Continent. He suggested an eight-ten ton Heroult furnace, and a gradual reduction of the induction smelting furnace, which would eliminate coal and lead to important cost reductions. This furnace was similar to the furnace he had introduced at an iron works in northern Italy a couple of years before. The oven he recommended was ordered from England and after a couple of years it was installed and used successfully in operation.[630] It is clear that Steen's long working experience abroad and understanding of steel techniques was of great advantage to Stavanger Electrical Steel Works.

[630] *Studentene fra 1890* (Kristiania, 1915), pp. 217-218; Oslo tekniske skole, *Skrift ved 50 årsjubileet for ingeniørene fra KTS 1894* (Oslo, 1944), pp. 92-102

8.9 Concluding remarks

This chapter has provided an overview of some of the knowledges that was used in innovation processes in technologically advanced mining of the time. Knowledge terms, mainly natural scientific disciplines, tacit and codified knowledge and know-who, know-what, know-how and know-why, have been used to detect and identify the different knowledge elements that were used. The tacit dimension was probably high in all mining activities. This argument is based on the fact that building of plants and operational activities depended to a large extent on specific knowledge of the local geological ground. Practical learning, learning by doing and work experience were therefore particularly important. On the other hand, theoretic knowledge in scientific disciplines, such as mathematics, physics, mechanics, geology, mineralogy, metallurgy etc. was equally vital for mining performance. Mapping, surveying, planning, drawing and construction of underground mines involved complex calculations, measurements and constructions, without which an in-depth comprehension of knowledge within these scientific disciplines would have been extremely difficult. The exhaustion of high-grade ores and the making of deeper and bigger mines in more remote areas meant that preparing maps, construction and organisation of workers became even more challenging. Moreover, the processing of minerals became gradually complex and specialised for at least two reasons. First, the extraction of lower grade ores was more challenging than high-grade ores and required the use of new techniques. Second, the development of new productions, such as aluminium and steel, demanded fundamental understanding in new knowledge areas. Extensive knowledge in chemistry and electro-metallurgy became increasingly important.

There was a growing conviction that formal mining education and engineering were needed to carry out certain responsibilities within mining and were understood as very useful for some strategic technical intermediate, leading and positions. This was certainly the case in Norway and Chile, but was also a general trend other places, notably in European and American countries. It was even declared as mandatory for certain managing positions. The organisation of operational activities and workers varied from company to company and depended on the size and type of production. However, companies had in common to be highly hierarchical. Directors had the overall responsibility, managers normally administered daily operations and supervisors, foremen, head engineers and chemists were leaders of working divisions, while intermediate leader assistants of mines and smelting plants were in charge of the daily tasks and workers. Formally educated mining engineers were meant to lead operations at mining companies, notably as managers, mine leaders and leaders of smelting plants. They were also meant to do scientific work positions at universities and at research centres.

The making of deeper mines, the extraction of minerals in rougher terrain and the replacement of man force by mechanic power called for in-depth knowledge in mechanical and construction engineering. The use of electricity in mining operations from the late nineteenth century and new electro-chemical methods required new specialised knowledge within chemistry, metallurgy and electro-engineering. In addition to mining engineers and technicians, mining companies eventually used workers with other theoretical and practical experience, notably chemists, mechanical engineers, electro-engineers, construction engineers and others. As productions increased, companies grew in size and knowledge of management, administration and economics became crucial, especially in Chile where companies extracted and processed some of the largest mineral deposits in world. The large-scale foreign companies had many divisions and demanded a broad spectre of specialised skills. Some companies in this country employed thousands of workers and represented some of the largest mining companies in the world. In sum, technological changes were supported by complex knowledge specialisations and is simplified as follows:

Simple overview of knowledge used and required in mining

<table>
<tr><th>Mining activity</th><th>Knowledge domains (sciences)</th><th>New knowledge areas from the late nineteenth century</th><th>Tacit knowledge</th><th>Relevant knowledge of new technology</th></tr>
<tr><td>Geological surveys/prospecting</td><td>Geology
Mineralogy
Chemistry
Economics</td><td rowspan="3">Electro-engineering

Economics

Administration</td><td rowspan="3">High degree</td><td rowspan="3">Continuous acquisiton of:

know-how

know-what

know-who

know-why</td></tr>
<tr><td>Removal of ores</td><td>Physics
Mathematics
Construction engineering
Mechanics</td></tr>
<tr><td>Processing of ores</td><td>Geology
Mechanics
Chemistry
Mineralogy
Metallurgy (electro-engineering, electro-chemistry etc.)</td></tr>
</table>

From where was knowledge transferred? Which institutions and organisations enabled knowledge transfers? Knowledge was attained from many places and in a variety of ways, which makes it difficult to make clear models for learning and innovation processes. However, some institutions were used repeatedly. First of all, universities, technical schools and research institutions were clearly the organisations which dominated the development of natural scientific knowledge. Second, the tacit dimension was considerably large in mining, although it is hard to determine it. It was probably transferred from and learned at all places where mining was carried out, notably through practical tasks, observation and work experience. Third, relevant and useful know-how, know-who and know-what were often acquired from different types of institutions all over the world. New machinery, equipment and furnaces were in a large degree developed in England, France, Germany and the United States, which meant that organisations looked abroad and collaborated with foreign actors when transferring technology. In these processes, it was crucial for workers, engineers and technicians to travel to places where new technology was in use. From such travels, engineers and technicians acquired experience with new technology, contacts and practical knowledge of how to select, transfer and adopt techniques.

A whole set of institutions and organisations was used to start-up and advance mining projects. A whole collection of domestic and foreign institutions and organisations, notably companies, universities, laboratories, industrial exhibitions, professors, consultants and engineers interacted with each other to learn, accumulate knowledge, develop technological capabilities and innovate. Establishments of new mining projects and technological advance are here summarised in the following steps:

Simplified model of the start-up and advancement of efficient mining projects

Step	Steps in the process	Institution/organisation	Purpose
1	Geological mapping, ore surveys and measurement of economic profit	Geological Surveys	Find out whether mining is profitable and prepare mining projects
2	Establishment of mining projects and companies	Private or public actors	Produce metals and minerals and sell them for profit.
3	Acquisition of technological knowledge (notably from abroad)	Magazines Industrial exhibitions Travelling engineers Consultants (domestic or foreign)	Be updated continuously on new technology to increase profit and be competitive.
4	Installation and use of new technology*	Workers Engineers, technicians and professionals External companies (workshops) Research institutions (laboratories, universities) External experts (professors, consultants)	Create, transfer, modify and use new working techniques for a continuous and profitable production.

*The last step is a continuous process

It should be stressed that other factors were required to develop profitable mining companies. Capital, investments, markets, prices etc. of course influenced productions and the industrial development of sectors. However, I argue that the knowledges outlined here, and the institutional and organisations which supported the development of these, formed a setting that was indispensable to successful and profitable mining.

9 An overview of the mining sectors in Chile and Norway: a gap in development

This overview only covers the period until 1940, the period leading up to the economic divergence between Chile and Norway. A much longer period should be analysed to acquire a complete picture of the developments of the two sectors, and the two countries as a whole. Yet, in a global context, this was a critical period and companies were required to catch up with the global developments in order to continue to be profitable.

From the late nineteenth century, mining industries worldwide were met with new challenges in terms of finding, removing and processing of ores. Many of the world's high-grade mineral deposits were exhausted and mining companies began to extract ores of lower grade. This required large changes in operational techniques. Mining worldwide gradually went through a mechanisation process from the latter half of the nineteenth century. From the turn of the century, mining companies started large-scale production with the use of electricity, new machinery and new processing methods. The new challenges that emerged, and the technological transformation of the industry makes the late nineteenth century and early twentieth century a period of transformation, in which companies underwent significant changes to continue carrying out profitable mining.

The aim of this chapter is to provide a framework for the analysis of knowledge institutions and organisations which aimed to develop knowledge for mining in Chile and Norway. The factors which are analysed are (1) productions and natural resource potentials, (2) technological levels, (3) multinationals and (4) linkages to the capital goods industries. As seen in one of the previous chapters, the two mining sectors differed considerably in size. In Chile, it represented one of the main economic sectors and the absolute largest for exportation, up to ninety per cent. In Norway, in contrast, although the numbers are unclear, it is obvious that the mining sector was considerably smaller in terms of GDP and accounted for up to around five per cent of exports until the turn of the century. With the new electro-metallurgical industries from the early twentieth century, the sector's share of exports increased gradually to around thirty per cent at the end of the 1930s. How were the development of the two sectors linked to the economic gap between Chile and Norway? I argue that a describtion of how natural resources were utilised will shed light on some repeating patterns within the sectors, which in turn were linked to the gap between the two countries. To find patterns, I examine the most important mineral and metal productions within the sectors separately and subsequently discuss them in the summarising part. In Chile, although productions varied, the largest industries in both tonnage and value were normally copper and saltpetre. Saltpetre stood for the largest share of the mineral and metal production from the late nineteenth century until the late 1920s. In 1919, its proportion of total mineral production was fifty-three percent.[631] The same year copper stood for around twenty-three percent and coal nineteen percent.[632] In 1939, copper had taken over for saltpetre and become the largest industry accounting for fifty-nine percent of the total mining production, while saltpetre had decreased to nineteen percent. Expect for coal, other mineral and metal productions were relatively insignificant (see table below):[633]

Chilean mining products in percentage (value)

Mining products	Percentage	
	1919	1939
Metals		
Gold	0,6	8,5
Silver	0,8	0,3
Copper	***22,8***	***59,2***
Manganese	0,001	0,09
Lead	0,005	0,009
Iron	0,005	1,8
Molybdenum	0,001	-
Samples	0,001	-
Mercury	0,023	-
Tin	-	0,002
Antimony	-	0,0001
Fuels		
Coal	***19,8***	***5,1***
Natural salts		
Saltpetre	***53,2***	***19***
Common salt	0,3	0,4
Iodine	1	2,8
Perchlorate	0,002	-
Borate	0,5	-

[631] Oficina Central de Estadística, *Anuario Estadístico Minería y Metalurgia 1919* (Santiago, 1921), pp. 14-15
[632] Oficina Central de Estadística, *Anuario Estadístico Minería y Metalurgia 1919* (Santiago, 1921), pp. 14-15
[633] Dirección General de Estadística Chile, *Minería e Industria 1939* (Santiago, 1940), p. 18

Sodium sulphate	-	0,4
Non-metallic		
Sulphur	0,5	0,8
Calcium	0,07	0,08
Plaster	0,05	0,2
Guano	0,3	0,4
Apatite	0,02	-
Kaolin	0,005	-
Clay and coal	-	0,06
Carbonate of calcium	-	0,7
Calcium phosphate	-	0,05
Diatomite	-	0,009
Total	**100**	**100**

Calculations based on statistics from Oficina Central de Estadística, *Anuario Estadístico Minería y Metalurgia 1919* (Santiago, 1921), pp. 14-15 and Dirección General de Estadística Chile, *Minería e Industria 1939* (Santiago, 1940), p. 18

In Norway, important traditional productions were copper, silver, gold and iron. From the late nineteenth century, pyrite became a large production, which in 1919 together with copper stood for almost eighty percent of total mining production. By 1939, new electro-metallurgical products had increased significantly; notably nickel, aluminium and iron (see table below):

Norwegian mining products in percentage (value)

Mining products*	Percentage	
	1919	1939
Mining ore products		
Silver ore	***6***	***0,2***
Copper ore	1,5	2,2
Pyrite (partly with copper)	***76,5***	***7,9***
Nickel ore	0,8	0,5
Iron ore	8,6	10,3
Zinc and lead ore	0,03	0,2
Molybdenite	4,7	1,1
Rutile	0,05	0,04
Chrome ore	0,2	-
Manganese ore	0,01	-
Titaniferous	0,9	-
Arsenopyrite	0,009	-
Apatite	0,5	-
Fluorspar	0,1	-
Other products	-	0,04
Electro-metallurgical products		
Silver	-	0,2
Copper	-	3,9
Nickel	***-***	***11,6***
Aluminium	***-***	***19,3***
Ferroalloys	***-***	***19,4***
Pig iron	-	2,5
Zink	-	6,5
Lead and tin	-	0,4
Sulphur	-	13,6

*The value of coal is excluded from the statistics
Calculations based on statistics from Norges offisielle statistikk, Norges bergverksdrift 1919 og 1920 (Kristiania,

1922) and Statistisk sentralbyrå, *Norges bergverksdrift 1939* (Oslo, 1941)

In spite of long mining traditions, the two mining sectors developed in very different ways. The mining sector in Chile was huge, but developed slowly. The sector went through a number of crises, did not fully take advantage of the resource potential, developed enclave tendencies, had large technological gaps between domestic and foreign companies and developed few linkages to other industries.[634] The Norwegian mining sector, on the other hand, increased linkages to the capital goods sector, ensured local participation of engineers and other professionals, began new large-scale productions, and in the late nineteenth century branched out a large electro-metallurgical sector based on the utilisation of hydroelectric power.[635] In short, Norway made more out of its mineral resources than Chile did.

9.1 Utilisation of natural resources

Mining has long traditions in Chile. Indigenous people used copper long before the Spaniards arrived to Latin America. After independence from Spain in 1810, the mining industry in Chile included mainly the extraction of copper, gold, silver and some mercury.[636] Production of copper and silver was concentrated around the Atacama Desert and Coquimbo in the northern part of the country. These productions increased in the mid-nineteenth century and until 1880s, Chile was the world's largest copper producer. Thereafter, the copper production fell dramatically (see appendix 1 for copper production). In 1878, Chile's share of the world's copper production was 43, 6 per cent, but fell to 25, 3 per cent in 1880 (see table below):

[634] See F. A. Encina, *Nuestra inferioridad Económica Sus Causas, sus Consecuencias* (Santiago, 1912); A. Pinto Santa Cruz, *Chile, un caso de desarrollo frustrado* (Santiago,1959); J. Pinto Vallejos and L. Ortega Martínez, *Expansión minera y desarrollo industrial: un caso de crecimiento asociado (Chile 1950-1914)* (Santiago, 2004)
[635] For a description of general development of the mining sector see H. Carstens, *…Bygger i Berge* (Trondheim, 2000)
[636] S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 95

Chile's share of world copper production, selected years

Year	Copper production corresponding to Chile in percentage
1879	30,07
1880	25,30
1885	17,37
1890	9,73
1895	6,59
1900	5,61
1905	4,11
1910	4,40

Source: Oficina Central de Estadística, *Anuario Estadístico Minería y Metalurgia* (Santiago, 1911).

While copper decreased, silver production increased radically from the 1880s, before a dramatic decrease from the early twentieth century (see appendix 1). From the early twentieth century, copper production increased once again with large North American companies operating in low-grade copper mines. However, it did not result in a large increase in the share of total world copper production. In 1910 Chile's share of the world's total copper production decreased to 4, 4 per cent and in 1918 it represented 7, 54 per cent.[637]

Part of the problem of was that Chile had large unutilised mineral deposits. By the 1880s and towards the turn of the century high-grade ore deposits containing twenty, twenty-five and thirty per cent copper and silver were exhausted. Low-grade ores were still in the ground, only deeper and in less available areas.[638] As the high-grade ore deposits were utilised, Chilean engineers and investors started to abandon mines.[639] Francisco M. Aracena, a miner and scientist of the time, stressed the precarious situation in 1884. Ten or fifteen years earlier the Chilean copper industry had been prosperous, but by this time, large and modern copper foundries had stopped production.[640] The mining engineer Alberto Herrmann explained the situation much in the same way. He argued that the

[637] M. J. Mamalakis, *The growth and structure of the Chilean economy* (London and New Haven, 1976), p. 40

[638] A. Sutulov, "Antecedentes históricos de la producción de cobre en Chile", in *El cobre chileno,* A. Zauschquevich, A. and A. Sutulov (Santiago, 1975), pp. 27-29

[639] S. Macchiavello Varas, *El problema de la industria del cobre en Chile y sus proyecciones económicas y sociales* (Santiago, 2010), p. 90

[640] F. M. Aracena and R. Sagredo Baeza, *Apuntes de viaje: la industria del cobre en las provincias de Atacama y Coquimbo, los grandes y valiosos despósitos carboníferos de Lota y Coronel en la Provincia de Concepción* (Santiago, 2011), pp. 28-29

"(t)he abundance of copper production in the period of 1860-1888 initiated the creation of many foundries." These were found in the most productive mining areas, such as Tocopilla, Gatica, Chañaral, Copiapó, Coquimbo, Lota etc. However, almost all of them had disappeared by 1900.[641] For instance, the copper foundry in Lota was affected by the recession and exhaustion of the high-grade mines and finally closed down in 1915.[642] Large unexploited mineral deposits and abandoned mines were described in the national statistics of the time. In 1913 there were 12 403 reported inactive copper mines. The number was higher if mines with silver and copper and gold and copper were included.[643] The copper mining production found itself in crisis. In 1915 Javier Gandarillos Matta, an engineer and industrialist of the time, made two observations. He argued that the large copper, gold, silver, cobalt and sulphate deposits in the northern part of the country were unexploited first of all because the mining industry did not utilise low-grade ores and extracted only minerals which could be smelted directly. Second, ore processing, in form of converting and smelting, which would give higher profits, was not taken advantage of in Chile.[644] According to him, companies would profit from a transformation of the operational techniques:

> "[The] conditions under which extraction is done are, except for rare exceptions, deficient…[…] (I)f we could transform methods work multiplying railways and making them cheaper, supply cheap electric power…[…]…, make this production converge with processing plants near the coast etc. we would have achieved a remarkable improvement compared to the current status, which would allow us to develop a large and rational production, extracting truly low grade ores."[645]

Chile had much to learn from other mining countries, he argued, "…especially in the sense of

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[641] *Boletin de la Sociedad Nacional de Minería* (Santiago, 1900), pp. 108-109
[642] O. Astorquiza, *Compania Carbonifera e industrial de Lota 1852-1942* (Valparaíso, 1942), p. 81
[643] J. Gandarillas Matta, *Estado actual de la industrial minera del cobre en el extranjero y en Chile* (Santiago, 1915), p. 75
[644] J. Gandarillas Matta, *Estado actual de la industrial minera del cobre en el extranjero y en Chile* (Santiago, 1915), pp. 78-80
[645] J. Gandarillas Matta, *Estado actual de la industrial minera del cobre en el extranjero y en Chile* (Santiago, 1915), p. 75

organising tasks and merge [plants] under a single technical administration."[646] He summed up the situation in three points. First, the industry needed to be concentrated into a reduced number of plants. Second, companies should adapt to new processing methods to benefit low-grade ores. Finally, the use of cheap electric power was required to extract the mines "…in accordance with modern systems."[647] With short transport distances, short distance to the sea, abundance of hydraulic power, mineral deposits of copper, silver, gold etc. the country were in general in good conditions for developing a competitive mining sector:

> "In short, we can say that there have never been more favorable expectations than now for the development of the copper mining industry. If, as we believe, and engineers who have travelled around the world have repeated this, our country is one of the most copper rich in the world, we must look at the future with confidence and now prepare to exploit our mineral wealth."[648]

Santiago Macchiavello Varas also emphasised the country's water supply and found that it was very useful for the extraction of copper, especially in the northern part of the country. The use of this power at the mines, in processing, transport etc. would be highly useful, and key, to increase copper production, according to him.[649] He explained that Chile was privileged with the Andes mountains, which had "…countless waterfalls".[650]

Nevertheless, in spite of reports showing good prospects for the mining industry, large mineral deposits and mines remained unexploited. Large unutilised mineral deposits of metallic and non-

[646] J. Gandarillas Matta, *Estado actual de la industrial minera del cobre en el extranjero y en Chile* (Santiago, 1915), p. 125
[647] J. Gandarillas Matta, *Estado actual de la industrial minera del cobre en el extranjero y en Chile* (Santiago, 1915), p. 128
[648] J. Gandarillas Matta, *Estado actual de la industrial minera del cobre en el extranjero y en Chile* (Santiago, 1915), p. 129
[649] S. Macchiavello Varas, *El problema de la industria del cobre en Chile y sus proyecciones económicas y sociales* (Santiago, 2010), p. 186
[650] S. Macchiavello Varas, *El problema de la industria del cobre en Chile y sus proyecciones económicas y sociales* (Santiago, 2010), p. 186

metallic ores were referred to in the Mining Bulletin almost every year.[651] One of the publications from 1934, for instance, referred to "… huge deposits of non-metallic substances, which would give rise to new productive industries." [652] The Credit Bank of Mining explained in 1939 that: "in our country numerous mines of lead, silver and zinc exist without any study or preparation".[653] There were also large unutilised manganese deposits. Chile had one of the largest manganese deposits in the world, which made it hard to explain the little export of this mineral. The Mining Bulletin stated that "we have not only high-grade ores, but also plenty of low-grade, easy to concentrate because the gangue is very light."[654] Many of these ores remain unexploited today. In 1989, many decades later, Chile still held approximately 40 per cent of the world's copper reserves, both as vein and porphyry copper.[655]

Iron production started with the French company Hauts Fourneaux Forges et Aciers du Chili in 1906 and the North American company Bethlehem Chile Iron Mines in 1913.[656] Yet, Chile had huge iron ores, which were not being exploited. In a monograph of Bethlehem Chile Iron Mines, the lack of activities in this industry was pointed out:

> "As of the year 1903, there was no interest in the country to acquire iron minerals, owners of deposits of this nature were dedicated solely to protect its mining claims, by paying the respective patents, hoping that they soon be utilised."[657]

The situation did not change considerably. Iron stood for 0,005 percent of mining production in 1919

[651] Mineral deposits of metallic and non-metallic ores of copper, silver, cobalt, iron, feldspar, aluminium, borax, sodium, sulphur, talc, zinc, lead, manganese, and others, were referred to almost every year in *Boletin de la Sociedad Nacional de Minería*.
[652] *Boletin de la Sociedad Nacional de Minería* (Santiago, 1934), p. 122
[653] *Boletin de la Sociedad Nacional de Minería* (Santiago, 1939), p. 302
[654] *Boletin de la Sociedad Nacional de Minería* (Santiago, 1939), pp. 303-304
[655] W. W. Culver and C. J. Reinhart "Capital dreams: Chile's Response to Nineteenth-Century World Copper Competition", *Comparative Studies in Society and History*, vol. 31, No. 4 (October 1989), p. 725
[656] S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), 181
[657] My translation: O. Peña i Lillo, *Monografia sobre el mineral de fierro de "El Tofo" que explota la Bethlehem Chile Iron Mines Company en la provincia de Coquimbo* (Santiago, 1928), p. 9

and in 1939 the share had increased to 1,8 per cent. In 1939 the share had increased to 1,8 per cent.[658] It should be stressed, however, that production increased in the 1920s (see appendix 1 for production of iron). Decades later, high-grade iron mines were exhausted in the United States and small mines started iron production in Atacama and Coquimbo. These companies started operations in 1952, but used manual operations and had a low degree of mechanisation.[659]

In Norway, mining became an important sector in the sixteenth century. Traditional metals, such as copper, silver, gold and iron, represented key productions.[660] Central mining companies developed from the seventeenth century, such as the state-owned company Kongsberg Silver Works, established in 1623, Røros Copper Works, founded in 1644, and Løkken Works, established in 1654. Norway was a country with a much smaller mining sector than Chile in terms of production and share of GDP. Productions were volatile and experienced challenges from the late nineteenth century. From the late 1870s, productions started to decline due to a recession period with low prices and many of the old iron and copper works disappeared.[661] Between 1873 and 1876 Norway, produced one third of the world's total supply of nickel. However, from the late 1870s nickel mines were closed down.[662]

On the other hand, production of silver and copper were renewed. Silver production was mainly carried out by the Kongsberg Silver Works, while new copper companies were established, such as the Swedish Sulithjelma Copper Works and Porsa Copper Mines. In 1917, there were a total of 169 mining companies, of which 20 were copper companies.[663] A decline in copper prices resulted in a recession period during the 1920s, but production increased gradually from the 1930s (see appendix 2).

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[658] Oficina Central de Estadística, *Anuario Estadístico Minería y Metalurgia 1919* (Santiago, 1921), pp. 14-15; Dirección General de Estadística Chile, *Minería e Industria 1939* (Santiago, 1940), p. 18
[659] S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 309
[660] H. Carstens, *…Bygger i Berge* (Trondheim, 2000), p. 32
[661] H. Carstens, *…Bygger i Berge* (Trondheim, 2000), p. 108
[662] O. Wicken, "The Norwegian Path Creating and Building Enabling Sectors" (Oslo, 2010), p. 15
[663] Some pyrite mining companies also produced copper.

The sector diverged with new mineral productions from the late nineteenth century. From the 1860s, industrial operations of pyrite was first initiated at Ytterøy Copper Works and later at the French Vigsnes Copper Works. Røros Copper Works began pyrite production around 1900. Large foreign companies, such as the Sulithjelma Copper Works, the British Bede Metal and Chemical Co. Ltd. at Killingdal mines, Løkken Works (taken over by the Swedish Orkla Mining Company in 1904), the Belgian Stordø Pyrite Mines Ltd., and Folldal Works (purchased by British interests in 1904) also started production of pyrite.[664] Pyrite became a large-scale industry and production increased dramatically from the early twentieth century (see appendix 2).

In contrast to Chile, the mining sector in Norway renewed itself by branching out a large-scale electro-metallurgical industry at the turn of the century. The old iron and nickel industries were renewed and large-scale iron, steel and nickel production was initiated. One of the cornerstones of the Norwegian economies in the twentieth century was the large-scale electro-metallurgical productions. In addition, production of new minerals started, such as aluminium, silicon, ferrosilicon, magnesium, nickel, ferromanganese, silicon carbide and others (see appendix 3).[665]

9.2 Technological level

Coal mining in Chile became a large industry from the mid-nineteenth century (see appendix 1 for production). The coal industry was perhaps the most successful of the mineral industries. Production of coal with the use of advanced English technology started in the mid-nineteenth century. Matías Cousiño was a famous coal mining industrialist.[666] He invested, together with other industrialists, in

[664] H. Carstens, *…Bygger i Berge* (Trondheim, 2000), p. 110; A. Stonehill, *Foreign Ownership in Norwegian Enterprises* (Oslo, 1965), pp. 20-38

[665] H. Carstens, *…Bygger i Berge* (Trondheim, 2000), p. 32

[666] A. Millán Urzúa, *La minería metalica en Chile en el siglo XIX* (Chile, 2004), pp. 80-81

coal mines and established the Lota Company in 1852 near Concepción in Southern Chile.[667] Federico Schwager, another Chilean industrialist, founded the Schwager Coal Company and invested in other coal mines in Coronel, next to Lota.[668] These companies dominated coal mining. Steam engines gave power to mines from the 1850s and used for ventilation and to transport coal. Steam locomotives were used in some areas.[669] The hydroelectric plant Chivilingo was built in 1897, and was the first installation of high-voltage electric power in Chile and South America. The power plant provided electric energy to equipment used at the mines.[670] Coal mining continued to change. From 1904, the English "long wall" system was adopted to extract the coal and replaced the old "board and pillar" method.[671] Electric bombs were used from 1901, safer explosives with electric triggers replaced the use of black powder in 1908 and electric drilling machines were used from 1913.[672] Mechanical choppers and mechanical disc diggers, which cut the coal by the "teeth" of the disc, were also adopted. The chain stripper represented a mechanised outbreak and a more efficient technique with the concept of "continuous mining". Railways were constructed for transport inside the mines and outside and conveyors were introduced in 1915. Electric locomotives replaced horses.[673] Production increased gradually, despite some fluctuations from the 1920s.

The saltpetre production also adopted new and more efficient techniques. In 1852, the Chilean chemical engineer Pedro Gamboni made a modified nitrate processing technique consisting of replacing direct fire on the boilers by direct injection of hot steam and water on the crushed caliche. With this system, heat was better benefitted processed and caliche of 40 to 50 per cent could be

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[667] This company changed names many times. Later in the thesis the company will be be referred to as Coal Company of Lota: O. Astorquiza, *Compania Carbonifera e industrial de Lota 1852-1942* (Valparaíso, 1942), pp. 33-34

[668] O. Astorquiza, *Compania Carbonifera e industrial de Lota 1852-1942* (Valparaíso, 1942), p. 26

[669] O. Astorquiza, *Compania Carbonifera e industrial de Lota 1852-1942* (Valparaíso, 1942), p. 40

[670] L. Mazzei de Grazia, *Los británicos y el carbon en Chile* (Concepción, 1924), p. 155

[671] O. Astorquiza, *Compania Carbonifera e industrial de Lota 1852-1942* (Valparaíso, 1942), p. 62

[672] O. Astorquiza and O. Galleguillos, *Cien años del carbon de Lota 1852-1952*, 1952, p. 189

[673] O. Astorquiza and O. Galleguillos, *Cien años del carbon de Lota 1852-1952*, 1952, p. 189

processed.[674] Gamboni also managed to separate the iodine from the salted waters, which remained after the saltpetre extraction.[675] From the 1870s, the British engineer James Thomas Humberstone introduced the "Shanks System". With this mechanised method, indirect heating through the circulation of steam inside tanks was carried out to process the nitrate-rich mineral. This resulted in five to eight per cent waste of saltpetre compared to twenty to thirty per cent waste with the old system.[676]

Large multinationals with origin from industrialised countries, mainly British, German, and later North American, grew significantly from the nineteenth century and began to invest in natural resource sectors. Mining was one of the first economic sectors in which multinationals invested.[677] The saltpetre production increased gradually from the 1870s with British investments and became one of the most important industries of the Chilean economy. However, after synthetic fertiliser entered the market in the early twentieth century, this production also faced huge challenges. From the turn of the century problems emerged. In the 1910s, the Chilean saltpetre industry started to fluctuate and from the 1930s, production stagnated (see appendix 1 for the saltpetre production). The industry continued to develop during the 1940s and 50s, but the number of works declined and did not manage to compete against the new artificial product. Functionaries from the Foreign Office wrote in 1927 that the "…Chilean saltpetre industry was a sinking ship." Chile's share of production decreased from fifty-two per cent in 1928 to eighteen per cent in 1933 before losing completely to synthetic fertilisers.[678]

Production at both Chilean and British companies was expensive due to the elaboration of merely

674 J. Pinto Vallejos and L. Ortega Martínez, *Expansión minera y desarrollo industrial: un caso de crecimiento asociado (Chile 1950-1914)* (Santiago, 2004), p. 39
675 S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 184
676 J. Pinto Vallejos and L. Ortega Martínez, *Expansión minera y desarrollo industrial: un caso de crecimiento asociado (Chile 1950-1914)* (Santiago, 2004), p. 39
677 G. Jones, *Multinationals and Global Capitalism* (Oxford, 2005), p. 10
678 A. Soto Cardenas, *Influencia británica en el salitre: origen, naturaleza y decadencia* (Santiago, 1998), p. 328

high-grade caliche and the lack of modern machines and production methods.[679] The Shanks system could arguably be used only as long as Chile had a near monopoly on saltpetre production and the price remained high.[680] The saltpetre works often did not use engineers and the managers were warehousemen and merchants from the ports who had no knowledge of engineering or commerce. According to a Memorandum from the 1920s, "…the main technical advisor of the entire industry was a man who had no professional training except the one he had acquired in the prairie (pampa) or elsewhere in Chile." The Laurato Nitrate Company, the most important producer, had only one qualified engineer and his office was in Valparaíso, miles away from the saltpetre production.[681] Another report, made by the Section for External Trade of the Department of Commerce of the United States, concluded that the regions, which were rich in caliche, were spread around. There was little knowledge of their location, concentration, grade and depth because of the scarcity of available information and a lack of systematic scientific and technological knowledge. The use of traditional methods in the saltpetre production was considered very risky.[682] In order to continue profitable saltpetre production, especially with synthetic fertiliser on the market, the industry had to renew itself.

North American companies changed the way saltpetre was produced by adopting new operational techniques and organisation methods. From the late 1920s, companies with origin from the United States implemented a centralisation of management, a mechanisation of operations and new techniques in ore processing.[683] They adopted the Guggenheim process, also used in copper production, which entailed lixiviation with a lower temperature than earlier, and crystallisation of the

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[679] A. Soto Cardenas, *Influencia británica en el salitre: origen, naturaleza y decadencia* (Santiago, 1998), p. 343
[680] P. Marr,"Ghosts of the Atacama: The abandonment of nitrate mining in the Tarapacá region of Chile", *Middle States Geographer*, 40 (2007), pp. 22-31
[681] A. Soto Cardenas, *Influencia británica en el salitre: origen, naturaleza y decadencia* (Santiago, 1998), p. 328-329
[682] A. Soto Cardenas, *Influencia británica en el salitre: origen, naturaleza y decadencia* (Santiago, 1998), p. 163
[683] M. Wilkins, *The Maturing of Multinational Enterprise: American business abroad from 1914 to 1970* (Cambridge, 1974), p. 104

nitrate with artificial refrigeration.[684] These technological changes enabled the industry to continue profitable productions for a while, but was apparently not enough to compete against synthetic fertilisers in the end.

The copper industry in the mid-nineteenth century was considered advanced of the time. Perhaps the most famous Chilean industrialist in copper mining was José Tomás Urmeneta. He invested in a copper mine in Tamaya near Coquimbo in the Central part of Chile.[685] The copper produced at this company was known worldwide as “Chilean bars” and was 99, 5 per cent pure.[686] Urmeneta’s company experimented with new horizontal mining to make deeper structures, employed over 7000 workers and had thirty-nine mines in 1861, some of which used steam engines for drainage and transport.[687] In the beginning of the 1880s, the Rosario mine was 650 meters deep with an adit of 300 meters.[688] Later, mines were made with more than 10 000 meters of gallery.[689] In an article in Mining Review in Chicago in 1883, the Danish engineer Folger Birkedale compared one of Urmeneta’s mines, the Tamaya mine, with Freiberg in Germany and called José Tomás Urmeneta “the Chilean mining genius”.[690] Copper was also processed to fine copper in Lota. A processing plant was established there in 1857 and had easy access to coal for the furnaces.[691]

Then, after the turn of the century, a technological gap became apparent within the large copper industry. North American companies started operating some of the largest mines in the world with thousands of workers and used new complex and up-to-date equipment.[692] A number of new

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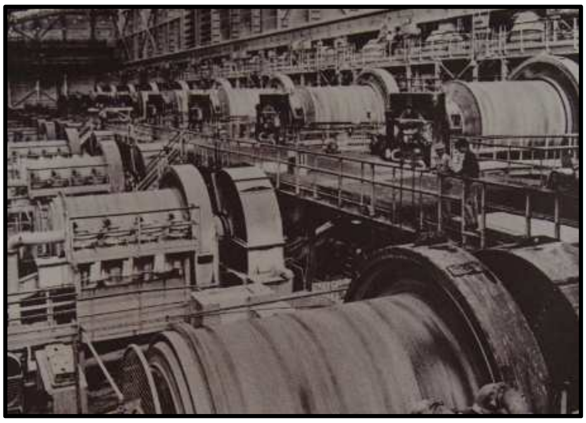
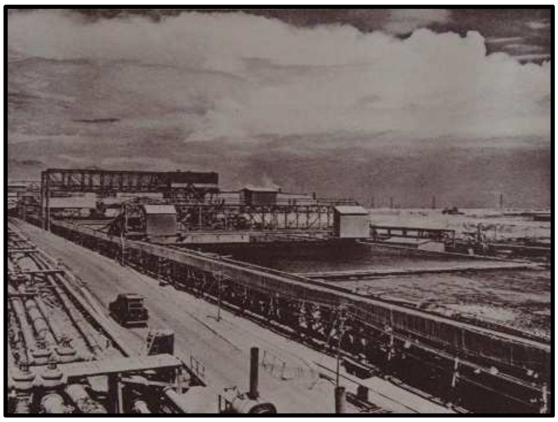
684 A. Sutulov, “Antecedentes históricos de la producción de cobre en Chile”, in *El cobre chileno,* A. Zauschquevich, A. and A. Sutulov (Santiago, 1975), p. 33
685 A. Millán Urzúa, *La minería metalica en Chile en el siglo XIX* (Chile, 2004), pp. 80-81
686 S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 107
687 R. Nazer Ahumada, *José Tomás Urmeneta. Un empresario del siglo XIX*, (Chile, 1993), p. 74
688 R. Nazer Ahumada, *José Tomás Urmeneta. Un empresario del siglo XIX*, (Chile, 1993), p. 74
689 S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 103
690 Quote taken from S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 103
691 O. Astorquiza, *Compania Carbonifera e industrial de Lota 1852-1942* (Valparaíso, 1942), p. 80
692 S. Macchiavello Varas, *El problema de la industria del cobre en Chile y sus proyecciones económicas y sociales* (Santiago, 2010), pp. 184-185

techniques, such as the block caving method, the flotation process, the Guggenheim process, electrolysis and other methods were adopted and enabled a profitable large-scale production of low-grade copper mines. The block-caving method was developed for the first time in the world in Potrerillos and later in El Teniente. This method allowed for extraction of low-grade copper deposits of one to two per cent and, when used successfully, costs were lower than open pit mining. [693] The flotation process was introduced at El Teniente in 1916. This meant an increase from sixty per cent recovery of the mineral to eighty-five to ninety per cent. Minerals were further smelted and refined to acquire as fine copper as possible.[694] The three North American companies produced blister copper of 99,7 per cent, refined copper of 99,2 per cent and electrolytic copper of 99,99 per cent copper. The latter was made from a refining of blister copper. [695]





Ballmills at the Chuquicamata concentration plant Leaching tanks at Chuquicamata
Source: Chuquicamata Esfuerzo Industrial de Chile, Chile Exploration Company

On the other hand, small and medium sized companies, mainly domestic firms, used simple and old technology. They were characterised as very rudimentary and were highly labour intensive.[696] Ore analyses, which were vital for continuous profitable operations, were not used in small and medium

693 S. Villalobos et al., *Historia de la ingenieria en Chile* (Santiago, 1990), p. 297
694 A. Sutulov, "Antecedentes históricos de la producción de cobre en Chile", in *El cobre chileno,* A. Zauschquevich, A. and A. Sutulov (Santiago, 1975), p. 31
695 S. Villalobos et al., *Historia de la ingenieria en Chile* (Santiago, 1990), p. 298
696 P. Meller, "Chilean Economic Development 1880-1990", in *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development,* M. Blomström and P. Meller (eds.) (Washington, 1991), p. 42

sized companies until the 1960s.[697] Disorganised and inefficient working methods without technical and economic order led to disorderly developed mines, which were often torn down. This resulted in huge mineral losses.[698] The problem, as seen by Chilean historians and economists, was that domestic investments continued to extract small mines and did not use "modern large-scale technology."[699] Disorganised and inefficient operational techniques became apparent in different ways. First, domestic companies continued to exploit high-grade mines. A foreign engineer, A. Von G, wrote in the Mining Bulletin in 1904 that: "(s)mall works which are called mines are found everywhere; but are not, in fact, what is called a mine in other countries. Here rich minerals are looked for. Poor minerals are not touched."[700] In the United States, on the other hand, copper ores of two to three per cent were being extracted by 1883.[701] Second, the domestic industry constituted in low and medium sized companies, often of one to fifty employees.[702] A. Von G. explained that:

> "(e)veryone wants to have a mine and exploit it by themselves, instead of making joint venture with the neighbours. With partnership they could obtain many facilities and earn plenty of money. Working separately they do not achieve anything."[703]

The third point, which explains the disorganised and inefficient operational techniques, was the little use of mechanised power. Instead, man and animal power was extensively used.[704] Manual drilling was common and gunpowder was used to remove ores instead of more efficient and safer explosives.[705] Miners carried the loads of minerals and selected them by hand. Mules normally did the lifting and transportation of rocks. A common way of organising mining operations was to have

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[697] S. Villalobos et al., *Historia de la ingenieria en Chile* (Santiago, 1990), p. 307
[698] S. Villalobos et al., *Historia de la ingenieria en Chile* (Santiago, 1990), pp. 97-101
[699] P. Meller, "Chilean Economic Development 1880-1990", in *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development,* M. Blomström and P. Meller (eds.), (Washington, 1991), p. 42
[700] My translation: *Boletín de la Sociedad Nacional de Minería* (Santiago, 1904), p. 340
[701] S. Villalobos et al., *Historia de la ingenieria en Chile* (Santiago, 1990), p. 110
[702] S. Villalobos et al., *Historia de la ingenieria en Chile* (Santiago, 1990), 174
[703] My translation: *Boletín de la Sociedad Nacional de Minería* (Santiago, 1904), p. 340
[704] S. Villalobos et al., *Historia de la ingenieria en Chile* (Santiago, 1990), p. 100
[705] S. Villalobos et al., *Historia de la ingenieria en Chile* (Santiago, 1990), p. 96

workers who were not hired in a regular sense to do the work. This system was called "pirquen" and involved miners collecting minerals and paying a fixed price or parts of the outcome to the owner. Pirquineros miners dominated especially the small mines.[706] Drilling and other preparation work were not used at these mines and the companies normally did not have mills or processing plants.[707] Mining engineer Ignacio Díaz Ossa argued in 1920 that the "…backwardness that copper mining in Chile has been suffering is especially due to the lack of modern processing methods."[708] In the copper mines in the Atacama Desert in the northern part of the country, mining operations were particularly primitive. Pirquen work predominated and technical advances that were adopted other places did not exist there. The depth of the mines was on average fifty meters extracting copper ores of eighteen per cent.[709] A. von G. concluded that these small works without adequate "…machinery, transport and organisation" was not really an industry.[710]

Domestic capital continued to invest in small and medium size companies. In the 1920s the small copper and gold mining companies consisted of mines of no more than 30 meters deep and only in some cases did they have motorised winches at the mines.[711] In 1940, companies still used "artisanal" working methods with pirquineros and without any mechanisation.[712]

There were, however, some exceptions. A couple of domestic companies developed and adopted techniques in line with the technological changes that were happening at the time. The Mining Company of Gatico, established in 1905, had 700 employees and was seen as the most successful and

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[706] S. Villalobos et al., *Historia de la ingenieria en Chile* (Santiago, 1990), pp. 105-106
[707] S. Villalobos et al., *Historia de la ingenieria en Chile* (Santiago, 1990), pp. 105-106
[708] Quote taken from S. Macchiavello Varas, *El problema de la industria del cobre en Chile y sus proyecciones económicas y sociales* (Santiago, 2010), p. 41
[709] S. Villalobos et al., *Historia de la ingenieria en Chile* (Santiago, 1990), p. 105
[710] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1904), p. 340
[711] H. D. Vásquez, "Fomento minero desde la cacremi hasta la enami", in *Chile minero, ENAMI en la historia de la pequeña y mediana minería chilena*, ENAMI (Santiago, 2009), p. 103
[712] H. D. Vásquez, "Fomento minero desde la cacremi hasta la enami", in *Chile minero, ENAMI en la historia de la pequeña y mediana minería chilena*, ENAMI (Santiago, 2009), pp. 103-104; *Boletín de la Sociedad Nacional de Minería* (Santiago, 1940), p. 744

modern Chilean company.[713] The mine "Toldo" was 404 meters deep in 1909 and the company used drills.[714] A furnace was installed with the capacity to smelt twelve to fifteen tons fine copper and the annual report of the company affirmed that the foundry "…melts cheaper than any other in Chile." [715] Another success story was a Chilean miner who, after a number of drawbacks, had achieved with the Manhés method "very beautiful results."[716] There were other medium-sized companies, which were considered advanced of the time, such as French Company La Societe de Mines de Cuivre, Copiapó Mining Company, Mining Company Los Bronces and Mining Company Sali Hochschild. [717] However, such examples were few. The production of small and medium mining was 27 000 tons fine copper in 1939, corresponding to only eight per cent of the national production.[718]

In Norway, in contrast, there was no apparent technological gap between foreign and domestic companies. From the early twentieth century, the mining and metallurgical industry was characterised as technologically up-to-date. Companies, such as Orkla Mining Company and Sulithjelma Copper Works were technologically advanced corporations with large-scale productions of copper and pyrite. By the 1920s, Orkla Mining Company was viewed as "…an extremely well managed enterprise, the mine was one of the best in Europe and the mechanical equipment was excellent."[719] The company was called "Europe's most modern and well-equipped and leading pyrite works."[720] Sulithjelma Copper Works became Norway's second largest company at the beginning of the twentieth century. With the first railway in the northern Norway and one of the first electric smelting ovens, the company was considered "Europe's most modern mining works."[721]

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[713] S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 173
[714] J. Gandarillas Matta, *Estado actual de la industrial minera del cobre en el extranjero y en Chile* (Santiago, 1915), p. 83
[715] Compania de Gatico, *Memoria* (Santiago, 1905), pp. 2-3
[716] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1900), p. 69
[717] One particular advance of medium-sized mining was the public company Paipote, created later by CORFO in 1947. However, the machinery and engineering team at this company was also imported from the United States: S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), pp. 303-304
[718] S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 305
[719] T. Bergh et al. *Brytningstider: Orklas historie 1654-2004,* (Oslo, 2004), p. 57
[720] *Tidsskrift for kemi og bergvæsen* (Oslo, 1933), p. 49
[721] A. K. Børresen and A. Wale, *Kartleggerne* (Trondheim, 2008), p. 107

Technological changes, renewal and the branching out of metallurgical productions started after a recession period in the late nineteenth century. In the 1880s Professor Johan Herman Lie Vogt argued, after having visited German and Swedish mining works, that Norwegian mining was in a large degree based on “rules of thumbs” and “rather vague and not very accurate” techniques. Operations at smelting plants were based on observations, rather than structured and planned ways of working, which were not suitable for efficient operations, according to him.[722] In other countries innovative companies, solid organisations and mining traditions were far ahead of the firms he knew in Norway.[723] Yet, the changes that were happening in the sector contributed to a rationalisation and efficient organisation of production. According to Halfdan Carstens, the electro-metallurgical industry was particularly successful: “More than anything else it was this industry which transformed Norway from a rather poor farmland into a prosperous industrialised country.”[724]

Domestic companies also renewed themselves and adopted continuously new working techniques. The state owned company Kongsberg Silver Mines became a “fully modern mining works” in 1914 with the installation of a full electric operation of pumps and lifts.[725] In the beginning of the twentieth century, coal production started in the archipelago Svalbard. In 1925, the year Svalbard was officially acquired by Norway, there were eight active coal companies, the most important being Big Norwegian Spitsbergen Coal Company Ltd., established in 1916 and Kings Bay Kullkompani Ltd., founded in 1917, both owned by Norwegians. Of the remaining companies were two Norwegian-owned, two British-owned, one was Dutch and one was Swedish.[726] In 1932, Norwegian Spitsbergen Coal Company operated with different extraction methods, depending on the hardness of the

[722] A. K. Børresen, *Bergtatt: Johan H. L. Vogt – professor, rådgiver og familiemann.* (Trondheim, 2011), p. 205
[723] A. K. Børresen, *Bergtatt: Johan H. L. Vogt – professor, rådgiver og familiemann.* (Trondheim, 2011), p. 205
[724] H. Carstens, *…Bygger i Berge* (Trondheim, 2000), p. 32
[725] O. A. Helleberg, *Kongsberg sølvverk 1623-1958: kongenes øyesten – rikenes pryd,* (Kongsberg, 2000), p. 292; B. I. Berg, *Gruveteknikk ved Kongsberg Sølvverk 1623-1914* (Trondheim, 1998), p. 421
[726] A. Stonehill, *Foreign Ownership in Norwegian Enterprises* (Oslo, 1965), p. 52

mineral, long wall machines and electric drilling machines in the mines. Electric trolley locomotives and a lift transported the coal to a "modern American storage- and cargo arrangement". The company used a power plant to provide power to the around ninety electric machines.[727]

Røros Copper Works and Kongsberg Silver Works, both domestic companies, were often the first to experiment with new techniques. The first big electric power plant for mining in Norway was installed and used at Røros Copper Works in 1896 and included a high voltage network which provided power to lifts, pumps, locomotives, crushing machines and other equipment.[728] A couple of examples illustrate how these companies continuously adopted new techniques to extract new types of ore and rationalise operations to maintain a profitable production. Fall in copper prices in the 1870s-80s led Røros Copper Works to make changes to save operational costs. One way to reduce expenses was to use other types of fuel. Members of the Board of Directors discussed the possibility of using coke instead of charcoal in the smelting process. The use of coke was much cheaper and easier to obtain. Jacob Pavel Friis, the administrative director of the company, went to Åtvidaberg Copper Works in Sweden in 1876 to acquire information about coke.[729] He learned how smelting processes worked there and convinced the Board of Directors after his return that: "(a)fter what I saw and heard about the use of coke in the smelting of matte, it was quite clear that coke might also be used in smelting at Røros."[730] The company started to use coke, first mixed with charcoal, but later with more coke than charcoal and finally with coke alone.[731] Another way to reduce costs was to adopt new processing techniques. A special shaft furnace was installed with slag pots, which meant that more ore was smelted with reduced consumption of coke and charcoal. The process expanded from around eight to nine days to around forty to fifty days.[732] In spite of this radical change, the Board of Directors

[727] *Tidsskrift for kemi og bergvæsen* (Oslo, 1932), p. 183
[728] B. I. Berg, *Gruveteknikk ved Kongsberg Sølvverk 1623-1914* (Trondheim, 1998), p. 421; G. B. Nissen, *Røros Kobberverk 1644-1974* (Trondheim, 1976), pp. 195-96
[729] J. P. Friis, *Direktør Jacob Pavel Friis' erindringer* (Oslo, 1944), p. 172
[730] J. P. Friis, *Direktør Jacob Pavel Friis' erindringer* (Oslo, 1944), pp. 173-174
[731] J. P. Friis, *Direktør Jacob Pavel Friis' erindringer* (Oslo, 1944), pp. 173-174
[732] G. B. Nissen, *Røros Kobberverk 1644-1974* (Trondheim, 1976), p. 191

considered the expenses to be too high. In the annual report of the company from 1886, it was affirmed that the deficit was 160 NOK per ton.[733] The next step was to upgrade and improve the quality of copper. The possibility of replacing the current refining of copper with another process "…applicable to mechanical processing" was considered.[734] In February 1887, after a long process of collecting information, travels abroad and evaluations the company decided to use the Manhés process.[735] The process was put to use from October 1888, gave ninety-nine per copper and "worked excellently", according to one of the Board members, Anton Sophus Bachke.[736] Around fifteen years later, a Committee was organised to evaluate Røros Copper Work and the use of this technique was pointed out as particularly cost effective. Around 150 NOK per ton copper was saved with the use of the Bessemer process, according to the Committee.[737] The metallurg Johan Herman Lie Vogt explained in a presentation in 1904 that:

> (w)hile the smelting expenses in the period 1833-1867 (under the five-step process) showed an average of 440 NOK per ton, they were reduced around the turn of the century 1900 decreased to approximately 270 NOK, or 39 %. This reduction was compensated for the fall in prices of copper.[738]

Severe economic problems were solved with these changes. However, the company faced new economic problems in the early 1920s. The challenge involved the utilisation of low-grade ores. A significant portion of the known ore was removed at Storvarts Mine, the main mine at Røros Copper Works, and only a relatively low-grade pyrite ore remained. The company had to suspend the operation for a couple of years due financial problems. A royal commission was appointed with experts in different areas to discuss possible solutions. For a long time it had been discussed whether

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[733] Røros kobberverk, *årlig rapport 1886* (Trondheim, 1887), p. 7
[734] Røros kobberverk, *årlig rapport 1886* (Trondheim, 1887), p. 8
[735] Røros kobberverk, *årlig rapport 1887* (Trondheim, 1888), p. 8
[736] *Tidsskrift for bergvæsen* (Oslo, 1916), p. 43
[737] *Beretning angående Røros Verks tilstand fra den i generalforsamling i verket den 29. april 1902 Nedsatte komité* (Trondhjem, 1902), pp. 49-50
[738] J. H. L. Vogt, *Bergværksdriften i det Trondhjemske: Foredrag afholdt paa det 3die norske landsmøde for teknik* (Trondhjem, 1904)

the ore at Storvarts Mine could be processed by more modern ore dressing processes.[739] Flotation was seen as a suitable technique to process this ore, which allowed for processing of ore containing 1, 5 per cent copper (see appendix 6 for a description of the technique).[740] Mining engineers Kraft Johanssen and Magne Mortenson carried out experiments with good results at Professor Harald Pedersen's laboratory in Trondheim. A test plant was built at Storvarts in 1927.[741] Another flotation plant was created in 1932 for the King's Mine.[742] Pedersen explained in 1929 that "…ore that was considered to be worthless before" was being utilised.[743] The new process was crucial for the company to continue profitable production.

Smelting plant Røros Copper Works (1887 to 1900)
Source: Digitalt museum

Smelting furnace Røros Copper Works (1901)

9.3 Multinationals and linkages to the capital goods industry

As seen in a previous chapter, foreign companies dominated both mining sectors. However, the foreign companies played out differently in Chile and Norway and did not benefit the two countries to the same degree. In terms of linkages, local participation and technology transfers Norway

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[739] H. Pedersen, «Samarbeidet mellem teknisk-videnskapelig forskning og industrien, foredrag i Polyteknisk Forening den 29. oktober 1929, *Teknisk Ukeblad,* 2nd January (1930), p. 6
[740] M. Mortenson, Utviklingslinjer i norsk oppredningsteknikk, *Særtrykk av Tiddskrift for kjemi, bergvesen og metallurgi* 2 (1949), p. 4
[741] H. Pedersen, «Samarbeidet mellem teknisk-videnskapelig forskning og industrien, foredrag i Polyteknisk Forening den 29. oktober 1929, *Teknisk Ukeblad,* (2nd January, 1930), p. 6
[742] M. Mortenson, Utviklingslinjer i norsk oppredningsteknikk, *Særtrykk av Tiddskrift for kjemi, bergvesen og metallurgi* 2 (1949), p. 6
[743] H. Pedersen, «Den tekniske høiskole er i kontakt med storindustrien», *Bergens Tidende* (9 of April 1929)

benefitted much more from foreign companies than Chile did. The following review of foreign companies in the two countries discuss these issues in more detail.

Sometimes large multinational companies have been the only opportunity when it comes to industrial projects. Geoffrey Jones points out several reasons. First, multinationals have often had large amounts of capital and been willing to take high risks.[744] They are normally large corporations and the size of the firm increases the possibility for large-scale production. This has also been the case in natural resource industries. Mining, in particular, has been a high-risk industry and have often required large investments. There have been many unpredictabilities related to such productions. The extension and composition of ores have often been difficult to know in advance and operation techniques have changed along the way. This, in turn, have involved uncertainties regarding costs, completion time and operation performance. As ore deposits are located anywhere, and sometimes in rough terrain, challenges concerning infrastructure have been common. In addition, fluctuation of prices represents another risk factor.[745] Second, multinationals have sometimes possessed a specific type of knowledge or technology that other companies have not had access to or not been able to use. These advantages have included "…access to superior technology, information, knowledge, and know-how".[746] Compared to smaller companies, multinationals have sometimes had superior organisational structures, "superior management techniques" or "better trained or educated managers".[747] Irving Gershenberg stresses that experience in managerial know-how and knowledge of how to train and motivate managers have been, in particular, one of the technological advantages which have enabled such firms to successfully compete in other countries:

> "Multinational enterprises…[…]… possess an appreciable supply of managerial expertise which they utilize in their overseas operations. The organization theory of foreign direct investment emphasizes

[744] G. Jones, *Multinationals and Global Capitalism* (Oxford, 2005), p. 8
[745] G. Jones, *Multinationals and Global Capitalism* (Oxford, 2005), p. 52
[746] G. Jones, *Multinationals and Global Capitalism* (Oxford, 2005), p. 8
[747] G. Jones, *Multinationals and Global Capitalism* (Oxford, 2005), p. 8

> that, in order to be able to compete against indigenous entrepreneurs, foreign direct investors must possess some special attribute or factor of production which is sufficient to tip the competitive scale in their favour."[748]

The question here, however, is wether the multinational companies benefitted and contributed to growth in Chile and Norway.

Historians have found that British and North American saltpetre companies in Chile in the late nineteenth and early twentieth centuries were more linked to their country of origin than the Chilean economy. Although they contributed with taxes and employment, the expression that was used of the foreign saltpetre companies was that "here remained nothing" ("aquí no quedó nada").[749] The lack of integration in the Chilean economy became apparent in different ways. First, Encina found that for every hundred dollars of produced saltpetre remained only between forty and fifty per cents in Chile. The rest was taken out of the country.[750] Second, the foreign companies purchased the majority of inputs from abroad. Alejandro Soto Cárdenas examines the British influence in the Chilean saltpetre industry and confirms that the majority of machinery, replacements, spare parts, tools and chemical products used at British saltpetre companies was supplied by Great Britain.[751] The use of foreign suppliers prevented important learning processes through linkages to the domestic capital goods industry. Third, although workers were employed at a lower level, Chileans were excluded from strategic and leading positions. Foreign engineers and managers possessed nearly all these positions and administrated and led operations at these companies. This reduced the chance of diffusion of technical and managerial knowledge in Chile.[752] The British and North American saltpetre companies

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[748] I. Gershenberg, "The Training and Spread of Managerial Know-How, A Comparative Analysis of Multinational and Other Firms in Kenya", *World Development*, Vol. 15, No. 7 (1987), p. 932
[749] P. Meller, "El cobre chileno y la política chilena" (2003), pp. 21-22
[750] F. A. Encina, *Nuestra inferioridad Económica Sus Causas, sus Consecuencias* (Santiago, 1912), pp. 228-231
[751] A. Soto Cardenas, *Influencia británica en el salitre: origen, naturaleza y decadencia* (Santiago, 1998), pp. 379-380
[752] A. Soto Cardenas, *Influencia británica en el salitre: origen, naturaleza y decadencia* (Santiago, 1998), p. 73

possessed the "technical knowledge and administrative capacity" that Chileans lacked, according to Alejandro Soto Cárdenas.[753]

On the other hand, some scholars find that the claimed enclave tendencies in the saltpetre industry were exaggerated. Foreign investments contributed instead positively to industrial and economic growth in Chile. Marco Mamalakis finds that the share of earnings of saltpetre that fled the country is overstated:

> "In my more recent estimate, the distributions of nitrate revenues between 1880 and 1924 amounted to 6.9 billion gold pesos of 18 pence. One-third accrued to government (and Chile's Center), one-third involved the cost of production, and one-third was earned by capitalists, Chilean and foreign. The amount of nitrate revenues leaking abroad – foreign profits, amortization, and so forth – was also 33 per cent or 7 per cent of GDP if offsetting capital inflows are ignored. However, it was only a small or negligible amount if these induced inflows are considered."[754]

The taxes on saltpetre accounted for around fifty per cent of total income from taxes for the government between 1895 and 1920.[755] Patricio Meller shows that the state's revenues increased drastically due to export taxes, from less than one million USD in 1880 to more than twenty million USD in the first part of the twentieth century.[756] In 1905, the earnings reached over twenty millions and in 1910 nearly thirty millions. During a boom in 1917 and 1918, income tax on saltpetre reached about forty million USD annually. In the period between 1880 and 1930 total fees paid by the saltpetre and iodine reached almost a billion USD.[757]

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[753] A. Soto Cardenas, *Influencia británica en el salitre: origen, naturaleza y decadencia* (Santiago, 1998), p. 85
[754] M. J. Mamalakis, *The growth and structure of the Chilean economy* (London and New Haven, 1976), p. 55
[755] P. Meller, "Chilean Economic Development 1880-1990", in *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development,* M. Blomström and P. Meller (eds.) (Washington, 1991), p. 39
[756] P. Meller, "Chilean Economic Development 1880-1990", in *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development,* M. Blomström and P. Meller (eds.) (Washington, 1991), p. 39
[757] C. C. Sutter and O. Sunkel, *Un siglo de historia economica de Chile* (Santiago, 1990), p. 89

Julio Pinto Vallejos and Luis Ortega Martínez actually argue against the enclave hypothesis when it came to the saltpetre industry. They focus on linked industries between the mining sector and the capital goods- and consumer goods industries and show that linkages were created, especially in northern saltpetre industry.[758] In the mid-nineteenth century, evidence indicates that linkages were created between some of the the mining companies and workshops. In 1871-72 the National Foundry, for instance, delivered twenty-four tanks to saltpetre companies.[759] Workshops, foundries and armories appeared in Santiago, Valparaíso and other places. They produced a variety of metallic products for mining companies, such as transport materials, engines, locomotives, lifts, gold and silver amalgamators, converters etc.[760] The Foundry of Balfour Lyon in Valparaíso, for instance, established in 1846, produced steel cables, wagons, turbines, hydraulic presses, steam pumps, hand centrifuges, machines for the processing of gold, silver and copper, furnaces, ventilators etc.[761] Another example is the Victoria Foundry in Valparaíso, established in 1884. This foundry offered a number of devices, such as machinery for saltpetre, silver amalgamation, extraction and smelting of copper, gunpowder etc. La Union Foundry also offered gold amalgamation furnaces and other types of furnaces, copper converters etc.[762] Other workshops were created especially to produce firebricks and explosives for mining.[763] Luis Ortega Martínez mentions in particular two workshops of this kind. They were Puchuco, established in 1865 in Coquimbo, and the Firebrick Factory in Lota, founded in

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[758] J. Pinto Vallejos and L. Ortega Martínez, *Expansión minera y desarrollo industrial: un caso de crecimiento asociado (Chile 1950-1914)* (Santiago, 2004)

[759] L. Ortega Martínez, "Acerca de los origenes de la industrialización chilena 1860-1879" in *Nueva Historia* año 1 no. 2 (London, 1981), p. 41

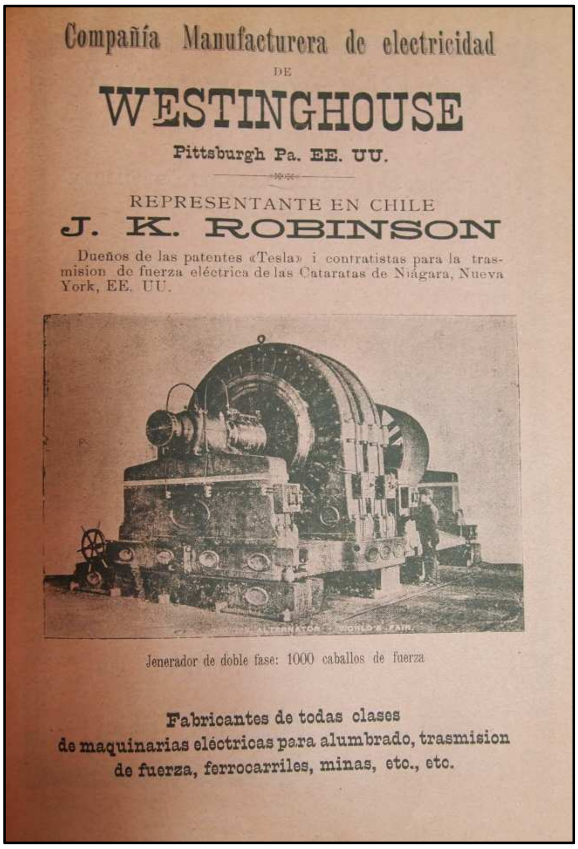
[760] See L. Ortega Martínez, "Acerca de los origenes de la industrialización chilena 1860-1879" in *Nueva Historia* año 1 no. 2 (London, 1981), pp. 33-35; S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 226

[761] J. P. Canto, *La Industria Nacional Estudios i Descripciones de Algunas Fabricas de Chile Publicadas en el Boletin de sociedad de fomento fabril 1889-1890* (Santiago, 1891), p. 15

[762] J. Pinto Vallejos and L. Ortega Martínez, *Expansión minera y desarrollo industrial: un caso de crecimiento asociado (Chile 1950-1914)* (Santiago, 2004), pp.100-101

[763] L. Ortega Martínez, "Acerca de los origenes de la industrialización chilena 1860-1879" in *Nueva Historia* año 1 no. 2 (London, 1981), pp. 27-30

1864, and part of the Coal Company of Lota and Coronel.[764] A decade later, the National Gunpowder Factory was established in Valparaíso to produce gunpowder for mining operations.[765] In addition to domestic workshops, a number of foreign companies opened subsidiaries in Chile for sale of European and North American equipment. In the official bulletin of the National Exposition of Mining and Metallurgy in Chile of 1894, a number of foreign subsidiary workshops promoted their products. They were for instance Julio Müller, representing a German machine factory in Santiago and J. K. Robinson, representing a North American electricity company in Chile (see publicities below):



Source: *Revista de la Exposicion de minería y metalurjía*, publicación oficial 1894, nr. 1 (Santiago, 1894).

Mining company records from the late nineteenth century and early twentieth centuries show that mining companies used local workshops to some degree. For instance, in the mining company Buena

[764] L. Ortega Martínez, "Acerca de los origenes de la industrialización chilena 1860-1879" in *Nueva Historia* año 1 no. 2 (London, 1981), p. 30
[765] L. Ortega Martínez, "Acerca de los origenes de la industrialización chilena 1860-1879" in *Nueva Historia* año 1 no. 2 (London, 1981), p. 27

Esperanza de Tres Puntas' cash book from 1869-71 a series of orders were made from a workshop in Caldera, such as spare parts for steam engines and crushers as well as shafts, muffles, valves, keys, iron covers and screws.[766] Arturo Prat Mining Company, Las Vacas Mining Company and Taltal Mining and Processing Company purchased machinery and equipment from local workshops (see appendix 4 for purchase of equipment by Chilean companies). In 1889 the Arturo Prat Mining Company received two cauldrons from Santiago,[767] Las Vacas Mining Company had a broken engine repaired in Valparaíso 1921[768] and in 1878 the Descubridoras de Caracoles Company had the keys of a steam engine changed and introduced a gear device made in Valparaíso.[769]

Julio Pinto Vallejos and Luis Ortega Martínez show that linkages between the capital goods and mining sectors were most evident in the northern provinces, where workshops specialised in supplying saltpetre and railway companies with useful equipment.[770] The mining production was here linked to multiple financial, technological and commercial channels and the demands of the mining industry "…could be met, at least partially, from within the country."[771] They conclude that: "(a)ll evidence seemed to indicate that it was not valid to continue qualifying mining as a mere "enclave" economy without any influence on its immediate environment."[772] Sunkel and colleagues follow in the same line of argument. They affirm that: "…during the period between 1880 and 1930, and indeed long before, the Chilean economy experienced a boom from its export sector, mainly on the basis of saltpetre."[773] Revenues from saltpetre, at least a large share of them, were accordingly used to build infrastructure and to promote agricultural and industrial activities. Trade and foreign

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[766] J. Pinto Vallejos and L. Ortega Martínez, *Expansión minera y desarrollo industrial: un caso de crecimiento asociado (Chile 1950-1914)* (Santiago, 2004), p. 81
[767] La Compañía Minera "Las Vacas", *Informe 1889,* (Valparaíso, 1890)
[768] La Compañía Minera "Las Vacas", *Informe 1921, segundo semestre* (Valparaíso, 1922)
[769] Minas Descubridoras de Caracoles, *Memoria 1878, primer semestre* (Valparaíso, 1879), p. 11
[770] J. Pinto Vallejos and L. Ortega Martínez, *Expansión minera y desarrollo industrial: un caso de crecimiento asociado (Chile 1950-1914)* (Santiago, 2004), p.77
[771] J. Pinto Vallejos and L. Ortega Martínez, *Expansión minera y desarrollo industrial: un caso de crecimiento asociado (Chile 1950-1914)* (Santiago, 2004), p.vi
[772] J. Pinto Vallejos and L. Ortega Martínez, *Expansión minera y desarrollo industrial: un caso de crecimiento asociado (Chile 1950-1914)* (Santiago, 2004), p.vi
[773] C. C. Sutter and O. Sunkel, *Un siglo de historia economica de Chile* (Santiago, 1990), p. 67

investments contributed to the development of transport, institutional and communication infrastructure in the central and northern regions, industrial activities and the incorporation of the southern agricultural sector to the national economy.[774] They argue, therefore, that:

> "…the expansion of saltpetre export activity, even if it was largely controlled by foreign capital, far from being an isolated enclave that inhibited the development of capitalism in Chile, would have been on the contrary an essential factor for its expansion and development."[775]

Patricio Meller agrees that "nitrate provided a big push to the Chilean external sector and nitrate became the engine of growth."[776]

Yet, even though saltpetre companies contributed to industrial growth and remunerations for the state, the saltpetre industry has been characterised by Chilean analysts as the "missed opportunity". The argument is that Chileans "let" foreigners discover, carry out and develop mining operations and "lived of the rents" of the industry.[777] This argument was related to the fact that few Chilean engineers and industrialists were involved in the development of the industry. The British companies were given "carte blanche in the saltpetre industry" and dominated the production trade.[778] From the 1920s, the saltpetre industry "…fell into the hands of the North Americans", represented by the Guggenheim Brothers, and the industry continued to be under foreign control, as it always had been.[779] Thus, although saltpetre benefited the Chilean economy to some degree, in terms of investments, state earnings, some linkages and employment, the country was not able to ensure

[774] C. C. Sutter and O. Sunkel, *Un siglo de historia economica de Chile* (Santiago, 1990), pp. 67-68
[775] My translation: C. C. Sutter and O. Sunkel, *Un siglo de historia economica de Chile* (Santiago, 1990), pp. 68-69
[776] P. Meller, "Chilean Economic Development 1880-1990", in *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development,* M. Blomström and P. Meller (eds.) (Washington, 1991), p. 41
[777] A. Pinto Santa Cruz, *Chile, un caso de desarrollo frustrado* (Santiago,1959), p. 56
[778] A. Soto Cardenas, *Influencia británica en el salitre: origen, naturaleza y decadencia* (Santiago, 1998), pp. 211-212
[779] A. Soto Cardenas, *Influencia británica en el salitre: origen, naturaleza y decadencia* (Santiago, 1998), pp. 362

long-term development of the industry based on domestic control and participation.

A similar, but more extreme, story is told of the copper industry from the early twentieth century. Large North American copper companies started to invest in some of the largest copper mines in the world with up-to-date technology. These companies, as was the case with the foreign saltpetre companies, contributed first of all with taxes. Taxes gradually increased on copper and other minerals from the 1870s. In 1872, the tax on copper was set to a fixed rate of sixty cents per quintal (around 46 kilos).[780] In 1920, the tax on the foreign copper companies was set to twelve per cent on taxable income. An additional tax of six per cent was established in 1925 and a special charge in favour of the newly created public institution for the encouragement of industries CORFO (Corporation for Promotion of Production) was added in 1939.[781] From 1932, the Commission of International Exchange required for the first time a share of the value of export on saltpetre, iodine, iron and copper.[782] In 1942, a new special tax of fifty per cent was added on the highest taxable income of the companies producing copper bars.[783] The companies certainly contributed to employment of workers. Andes Copper Mining Company employed 9840 workers in 1926.[784] In 1942, workers at El Teniente reached 5700 workers and total workers at the Braden Copper Company were more than 9000.[785]

However, in spite of paying taxes and employing local workers, the North American copper companies were heavily criticised. First, mining production declined in relative terms. Although

[780] A. Sutulov, “Antecedentes históricos de la producción de cobre en Chile”, in *El cobre chileno,* A. Zauschquevich, A. and A. Sutulov (Santiago, 1975), p. 67

[781] A. Sutulov, “Antecedentes históricos de la producción de cobre en Chile”, in *El cobre chileno,* A. Zauschquevich, A. and A. Sutulov (Santiago, 1975), p. 69

[782] A. Sutulov, “Antecedentes históricos de la producción de cobre en Chile”, in *El cobre chileno,* A. Zauschquevich, A. and A. Sutulov (Santiago, 1975), p. 70

[783] A. Sutulov, “Antecedentes históricos de la producción de cobre en Chile”, in *El cobre chileno,* A. Zauschquevich, A. and A. Sutulov (Santiago, 1975), p. 70

[784] “Monografia Andes copper mining company”, in *Boletín de la Sociedad Nacional de Minería* (Santiago, 1927), p. 103

[785] La Braden Copper Company Mineral de “El Teniente” (Rancagua, 1942), p. 13

production of copper increased in terms of tons, the country's share of world copper production reduced dramatically from the early twentieth century (see previous section). Markos Mamalakis shows how the loss of Chilean share of total world copper production correlated with the entry of the large North American copper companies. Chile was the world's largest copper producer until 1880s, but the share of the world's copper production fell dramatically after this time. In 1878, Chile's share of the world's copper production was 43, 6 per cent. In 1918, when Chile's share of total copper production was 7, 54 of world production, Chilean investors were responsible for only 4, 5 per cent of the production, while 86, 72 per cent were produced by North American companies. The rest corresponded to other foreigners. The relative loss to Chile as a copper producer more than matched with the "…almost complete loss of ownership in domestic copper production through the rapid process of denationalization."[786] Enclave tendencies became more apparent with these large copper companies. They were practically not linked to Chilean industries and were even more isolated and excluded from the domestic economy than the saltpetre companies. Markos Mamalakis confirms that "…a true enclave sector with maximum links to the metropolis was established for the first time" in Chile.[787]

Several points supports this argument. First, enclaves played out as closed towns which supplied everything for the foreign companies' own need, such as machine shops, warehouses, repair shops and small foundries, as described by Mira Wilkins. Some companies had cattle ranches, diaries and vegetable farms to meet their own necessities. These towns often had a company-owned commissary and were normally closed for outsiders. There was control at the gates and no unauthorised person could enter or live in such towns, much less do business there.[788] Second, large machinery and

[786] M. J. Mamalakis, *The growth and structure of the Chilean economy* (London and New Haven, 1976), p. 40
[787] M. J. Mamalakis, *The growth and structure of the Chilean economy* (London and New Haven, 1976), p. 34
[788] M. Wilkins, *The Maturing of Multinational Enterprise: American business abroad from 1914 to 1970* (Cambridge, 1974), p. 125

technical services were purchased from abroad, normally Europe and the United States.[789] Braden Copper Company, operating at El Teniente mine in the central part of Chile, installed for instance an electric power plant in 1911 with equipment imported from the Westinghouse Factory from Pittsburgh and Boith, Germany.[790] In 1912, a new concentration plant was established. This was built by Mineral Separation Ltd, a British firm.[791] A new smelting plant was constructed in 1922 with equipment and installations ordered from the United States.[792] Andes Copper Company even imported wood, in addition to explosives, materials, goods and machinery for the creation of the Potrerillo plant.[793]

The isolation of multinationals have been particularly damaging because it has prevented linkages to the wider domestic economy. Multinationals can create linkages to domestic industries, but without any interaction between these companies and domestic firms, organisations and suppliers, vital learning and innovation processes can hardly take place. A recent report by the United Nations affirms that the:

> "…key factor determining the benefits host countries can derive from FDI [foreign direct investments] are the linkages that foreign affiliates strike with domestically owned firms. Backward linkages from foreign affiliates to domestic firms are important channels through which intangible and tangible assets can be passed on from the former to the latter. They can contribute to the upgrading of domestic enterprises and embed foreign affiliates more firmly in host economies."[794]

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[789] M. Wilkins, *The Emergence of Multinational Enterprise: American business abroad from the colonial era to 1914* (Cambridge, 1970), p. 181
[790] L. Hiliart, *Braden Historia de una mina* (Chile, 1964), p. 158
[791] L. Hiliart, *Braden Historia de una mina* (Chile, 1964)
[792] L. Hiliart, *Braden Historia de una mina* (Chile, 1964)
[793] M. C. Baros Mansilla, *Una historia de pioneros* (Santiago, 2006), p. 61
The dominant role of the multinationals in Chile was the motivation for a nationalisation policy, which began in the 1960s, called the "Chilenisation process". The process sought to integrate the foreign companies more in the domestic economy. In the early 1970s, a unanimous parliament voted in favour of a complete acquisition. The big copper companies were then completely nationalised and taken over by the state for a fee: P. Meller, "Chilean Economic Development 1880-1990", in *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development,* M. Blomström and P. Meller (eds.) (Washington, 1991), p. 42
[794] UNCTAD, "World Investment Report 2001 Promoting Linkages" (New York and Geneva, 2001), p. xxi

According to Jones, such linkages between foreign and domestic companies have provided one of the most important ways in which firms act as "engines of growth".[795]

One reason why foreign companies may have favoured foreign sources of supply have been control.[796] Recent reports by the United Nations reveal that multinationals have often chosen foreign suppliers because they have established international supply chains and preferred suppliers who know their technical foundation, quality, scale and cost needs. Companies have also chosen to produce inputs locally, i.e. produce them in-house to save cost, instead of using established local producers.[797]

However, the lack of linkages in Chile is probably explained by a declining and uncompetitive domestic capital goods industry. The workshop industry in Chile was marginal. The "metal-mechanic sector" stood for five per cent of the "industrial and artisanal" production between 1895 and 1918.[798] According to statistics, the metal-mechanic sector represented 3, 8 per cent of total manufacturing output in 1917 and 7, 7 per cent in 1927[799], while the whole Chilean manufacturing sector stood for around twelve per cent of GDP between 1860 and 1940.[800] Although the capital goods industry had an annual rate of 9, 1 per cent between 1917 and 1927, the productivity was lower than the industrial sector as a whole.[801] Markos Mamalakis also finds that the Chilean manufacture sector increased before 1930 and developed from "artisan work" to "manufacturing processes". Nevertheless:

[795] G. Jones, *Multinationals and Global Capitalism* (Oxford, 2005), p. 262
[796] G. Jones, *Multinationals and Global Capitalism* (Oxford, 2005), p. 272
[797] UNCTAD, "World Investment Report 2001 Promoting Linkages" (New York and Geneva, 2001), p. 133
[798] M. Carmagnani, *El desarollo industrial y subdesarrollo económico* (Santiago, 1998), p. 65
[799] S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 229,
[800] J. Braun et al. *Economía chilena 1810-1995 Estadísticas históricas* (Santiago, 2000), pp. 31-32
[801] S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 229; see also M. J. Mamalakis, *The growth and structure of the Chilean economy* (London and New Haven, 1976) for an explanation of imbalances in the capital goods from the 1840s.

> "…it did not become a source of technical progress and only partially improved the quality of inputs and outputs. Although Chile was a major producer of capital goods, tools and instruments before 1900, it largely lost this function when industry failed to acquire the internal capacity to modernize or transform production to the degree necessary for self-sustained growth, in either its own or other sectors. As a source of modernization and transformation it was neither dynamic nor leading."[802]

Badia-Miró and Ducoing find that the industrial sector in Chile did not develop into a leading sector. They argue that:

> "Chilean industry was not the leading sector during nitrate cycle, and it was not able to transform the country into a modern economy country. In that sense, expansion of demand in some regions and weak linkages of mining activity to other sectors of economy, specifically in the industry, were not enough to push economy to converge with the high-income countries. In that sense, the decline of nitrate cycle and the emergence of copper cycle could not change this pattern."[803]

They continue by explaining that:

> "Copper industry was an important sector for economy but it lacked linkages, especially in the demand sector. To confirm this assumption, we state that the boom of bar production, transforming 50% more tons than axis and 80% than minerals, did not push the rest of the economy nor did it impulse machinery production…[…] At the same time, it had no impact on the demand due to fact that it was an extremely concentrated activity."[804]

The historian Sergio Villalobos affirms that even though the foundries, factories and shipyards

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[802] M. J. Mamalakis, *The growth and structure of the Chilean economy* (London and New Haven, 1976), p. 14
[803] M. Badia-Miró and C. Ducoing, "The long run development of Chile and the Natural Resources curse. Linkages, policy and growth, 1850-1950", UB Economics working papers, 2014/318 (2014), p. 11
[804] M. Badia-Miró and C. Ducoing, "The long run development of Chile and the Natural Resources curse. Linkages, policy and growth, 1850-1950", *UB Economics working papers*, 2014/318 (2014), pp. 12-13

produced durable and finished goods, by the end of the 1920s, the capital goods sector had not developed capital goods for the agricultural sector, the mining sector nor the manufacturing sector. The sector had not managed to generate a dynamic, which would allow it to start a self-sustaining expansion process with high levels of productivity and modernisation, with an impact on other productive sectors and the economy as a whole.[805] The situation worsened from the 1920s. By the end of the 1920s, the capital goods industry did not supply capital goods to mining companies.[806] Metal-mechanical companies went through rough difficulties and a number of companies were liquidated or reduced their operations.[807]

To innovate, mining companies instead imported machinery and equipment from other countries. Import of mining machinery and equipment increased gradually in quantity, according to official statistics, and correlates with the declining capital goods industry. In 1860, only one foundry machine was imported, while a total of 444 956 kilos of "mining machines" were registered in 1900. In 1940, imports had increased to 441 743 kilos of equipment and machines for mining as well as 910 550 kilos of spare parts and tools for machinery (see appendix 7 for import of mining equipment). The import statistics indicate that the mining industry purchased a variety of machinery and equipment both in the extraction and processing of metals and minerals. Moreover, the imported technology became increasingly diverse. In the early period fuses (for explosions) and pumps (for drainage) were important equipment for mining extraction, but also complex machinery, such as milling machines, saltpetre processing machines and other mining machines. After 1900 drilling devices, air pumps, winches, steam generators, picks, excavators, crushers and grinding machines, pans, lamps and ventilators became common, in addition to electric ventilators, perforators and mechanical shovels. Technology was imported from a number of countries, such as Belgium, Italy, Austria, Denmark, Sweden, Switzerland, Norway and Holland, and American countries such as Canada Argentina, Peru,

[805] S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 229
[806] S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 229
[807] S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 228

Panama and Bolivia. However, goods from the industrial powers Britain, Germany, France and the United States dominated during the whole period until 1940. The large share of import of machinery and equipment prevented vital learning processes. Nathan Rosenberg elaborates that:

> "(t)he experience of successful industrializing countries in the nineteenth century indicates that learning experiences in the design and use of machinery were vital sources of technological dynamism, flexibility and vitality. Countries which rely upon the importation of a foreign technology are thereby largely cut off from this experience."[808]

Villalobos gives an explanation for the decline of the capital goods industry in Chile. He finds that this was related to the fact that workshops continued to offer steam locomotives and equipment for small and medium sized mining operations rather than combined machines.[809] Mining companies used complex machinery, power plants and furnaces from the turn of the century, and did not use the equipment supplied by domestic capital goods workshops. Marcello Carmagnani gives a similar explanation and finds that the metal-mechanic sector was "…in the process of becoming a marginal sector, instead of assuming the role of as…[…]… vanguard of industrial development."[810] The industry did not keep up with these requirements. Villalobos understands its resistance to innovate was seen as the "seeds of its failure".[811] Geoffrey Jones explains that foreign affiliates have sometimes switched to domestic goods and services after a while.[812] In Chile, however, the capital goods industry was declining and did not supply relevant equipment, which meant that the only alternative for mining companies, notably large North American copper corporations, was to purchase technology from other countries.

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[808] N. Rosenberg, *Perspectives on Technology* (London, 1977), p. 157
[809] S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 229
[810] My translation: M. Carmagnani, *El desarollo industrial y subdesarrollo económico* (Santiago, 1998), p. 88
[811] S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 229
[812] G. Jones, *Multinationals and Global Capitalism* (Oxford, 2005), p. 272

The third point which support the enclave tendency theory is that Chilean skilled workers were altogether excluded from engineering, strategic technical and managing positions at these foreign mining companies. Workers were hired, but Chileans "…provide[d] none of the managerial elite".[813] It was not until the 1960s that Chilean engineers and managers filled strategic technical and managerial positions.[814] This had several negative effects. The first obvious problem was related to communication challenges between foreign managers and local workers. Few of the foreign managers and engineers learned Spanish.[815] Another negative outcome of the exclusion of Chilean engineers, which influenced the whole sector, was the limited knowledge spillover effects. Domestic engineers could potentially transfer valuable managerial knowledge and operational skills to other parts of the sector. However, their absence indicates that such knowledge transfers did not occur. According to Irving Gershenberg: "(i)t is this "spread" effect which is generally assumed to constitute the most significant contribution of multinational firms to the development of an indigenous cadre of managers."[816] Farmer and Ricman explain that:

> "(i)n all economic systems, management is a primary active ingredient in the productive process. A country can have endless resources of all sorts but unless management is applied to the factors, production will be close to zero. Moreover, the better the management, the greater will output be. Managerial effectiveness is the critical factor in the economic system."[817]

The North American companies could potentially have contributed to a spread of crucial managerial knowledge in Chile, but they did not. Actually, in spite of being so crucial for economic systems, there

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813 M. J. Mamalakis, *The growth and structure of the Chilean economy* (London and New Haven, 1976), p. 42
814 P. Meller, "Chilean Economic Development 1880-1990", in *Diverging Paths Comparing a Century of Scandinavian and Latin American Economic Development,* M. Blomström and P. Meller (eds.) (Washington, 1991), p. 45
815 M. Wilkins, *The Maturing of Multinational Enterprise: American business abroad from 1914 to 1970* (Cambridge, 1974), p. 126
816 I. Gershenberg, "The Training and Spread of Managerial Know-How, A Comparative Analysis of Multinational and Other Firms in Kenya", *World Development*, Vol. 15, No. 7 (1987), pp. 931-939
817 Quote taken from I. Gershenberg, «The Training and Spread of Managerial Know-How, A Comparative Analysis of Multinational and Other Firms in Kenya», *World Development*, Vol. 15, No. 7 (1987), pp. 931-939

are few examples of diffusion of managerial knowledge. Multinationals have in general had a tendency to hire expatriates to strategic and leading positions and only used local workers for lower positions and unskilled and semiskilled jobs. Multinational companies investing in mining have historically offered particularly few opportunities for the upgrading of human skills and used expatriates to handle the newest technologies and install and manage complex systems.[818] Why have the spread of managerial knowledge been so scarce? Why have multinational companies often not hired skilled workers from the host country? It seems clear that in order to be hired by a technologically advanced company in the first place, specific education and experience are often required. High illiteracy rates and low technical education levels are viewed as a hinder to employment of local workers at multinational companies, but we still do not know much about the specific role education plays and its interaction with the foreign companies. If the answer lies in the local basic education and technical education system, then the instruction and knowledge development at these institution and employment requirements and specific training procedures at multinational companies should be explored further.

Foreign investments started early in Norway, as it did in Chile. The engineer H. H. Smith showed that English capital played a crucial role from the early nineteenth century in the copper production. He mentioned Altens or Kaafjord Copper Works from 1830, Åmdals Copper Works from 1860, Ytterøen Mine from 1860-61, Bøilestad from 1860, Skattemyr Copper Mines, Varaldsø Pyrite Mines and others.[819] Foreign owned corporations were characterised by being large, capital intensive and large-scale production. Arthur Stonehill described the large foreign investments in the pyrite production in the early twentieth century:

[818] G. Jones, *Multinationals and Global Capitalism* (Oxford, 2005), p. 267
[819] *Tidsskrift for kemi og bergvæsen* (Oslo, 1930), p. 60

> "The three largest foreign investments were concentrated with the mining and export of pyrites, which were valuable for their sulphur and copper content. In 1909, Swedish-owned Sulitjelma Aktiegruber, Fauske, employed 1688 persons. This made it the second largest corporate employer. Capital stock was kr. 7 021 000. A second pyrite mining company, The Foldal Copper Sulphur Co. Ltd., Lillelevdedalen, employed 530 persons, making it the seventeenth largest corporate employer. It began originally as a small copper mine, but went over to pyrite export in 1907. In 1904, British interests had purchased the company…[…] In 1909, its capital stock was kr. 5 580 000, mostly in British hands. A third pyrite mining company, Orkla-Grube Aktiebolag, Løkken Verk, was founded in 1904 with Swedish capital supplied by the Wallenberg group. In 1909, employment was 285 persons and capital stock kr. 4 500 000, mostly in Swedish hands."[820]

Other foreign companies were Killingdal Mines (The Bede Metal and Chemical Co. Ltd.), Dunderland Iron Ore Co. Ltd (British), Stordø Pyrite Mines Ltd. (Belgian), Sydvaranger Ltd. (German and Norwegian) and Bjørkaasen Mines (German).[821] Large foreign companies operated in the production of aluminium from the late nineteenth century. The key to these productions was the abundant supply of electric power, of which Norway had plenty.[822] Stangfjorden Electrochemical Factories Ltd., Norway's first aluminium works, was originally founded in 1897 by Norwegian capital, but its capital stock was later purchased by The British Aluminium Company. Most of the stock of Vigeland Works Ltd. was purchased by British Aluminium Company in 1912.[823] Norwegian Nitride Company Ltd. was founded in 1912 with seventy-seven per cent French capital.[824] The only Norwegian-owned company Høyangfaldene Norwegian Aluminium Company Ltd., founded in 1915, formed a fifty-fifty partnership with the North American company ALCOA in 1923.[825]

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[820] A. Stonehill, *Foreign Ownership in Norwegian Enterprises* (Oslo, 1965), p. 38
[821] Norges officielle statistikk, *Fabriktællingen I Kongeriket Norge 1909* (Kristiania, 1911), p. 152
[822] http://snl.no/.nbl_biografi/Harald_Pedersen/utdypning; [accessed 29 March 2015]; A. K. Børresen and J. T. Kobberrød (red.), *Bergingeniørutdanning i Norge gjennom 250 år* (Trondheim, 2007), p. 109
[823] A. Stonehill, *Foreign Ownership in Norwegian Enterprises* (Oslo, 1965), pp. 37-38
[824] A. Stonehill, *Foreign Ownership in Norwegian Enterprises* (Oslo, 1965), p. 37
[825] A. Stonehill, *Foreign Ownership in Norwegian Enterprises* (Oslo, 1965), p. 50

Even though foreign companies dominated several industries in Norway there was apparently no strong criticism against their economic activities as there was in Chile. In contrast, there is an agreement among scholars that foreign investments contributed to industrial development and fostered economic growth in the country.[826] Arthur Stonehill refers to a case analysis from 1952 to 1962 from which it is concluded that capital owners, employers and government actually received bigger income from foreign companies than from domestic firms in industry and mining (in average). He also finds that foreign corporations paid more taxes in relative terms than domestic companies.[827]

Moreover, foreign companies contributed to transfer of technical and managerial knowledge. Norway was, perhaps, one of the few places in which transfer of such valuable knowledge from multinational companies occurred. Such knowledge transfers could happen in two ways, as pointed out by Irving Gershenberg.[828] First, managers could be trained and promoted into more responsible positions in the foreign companies. Norwegian engineers were often the motivators, or initiators, of large foreign-financed mining projects. For instance, the Norwegian engineer Christian Thams was heavily involved in the establishment of Orkla Mining Company, the Norwegian industrialist Sam Eyde was the initiator of Elektrokemisk and mining engineer Anton Grønningsæter contributed to the establishment of Falconbridge Nickel Works (see the last chapter for further discussion).[829] A revision of the student graduate reports shows that Norwegian engineers worked at all foreign mining companies (see appendix 14 for Norwegian engineers employed at mining companies). For instance, thirty ex-students of technical schools in Norway confirmed to have worked at the Canadian Falconbridge Nickel Works between 1929 and 1940. They were employed as “administrating director”, “business assistant”, “chemists”, “chief chemists”, “engineers”, “metallurgists” or similar engineering

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[826] See for example E. Lange (ed.), *Teknologi i virksomhet: verkstedindustri i Norge etter 1840*, (Oslo, 1989); A. Stonehill, *Foreign Ownership in Norwegian Enterprises* (Oslo, 1965)
[827] A. Stonehill, *Foreign Ownership in Norwegian Enterprises* (Oslo, 1965), p. 212
[828] I. Gershenberg, “The Training and Spread of Managerial Know-How, A Comparative Analysis of Multinational and Other Firms in Kenya”, *World Development*, Vol. 15, No. 7 (1987), pp. 931-939
[829] T. Bergh et al. *Brytningstider: Orklas historie 1654-2004,* (Oslo, 2004); *Elektrokemisk 1904-54*; P. Thonstad Sandvik, *Multinationals, Subsidiaries and National Business Systems* (London, 2012), pp. 35-36

positions.[830] Second, Gershenberg explains that there is also the possibility of spread of management knowledge. In these cases, individuals would be trained at a foreign company and subsequently transfer their managerial know-how to other firms. There are several examples of such knowledge transfers between companies in Norway. A couple of examples demonstrate how knowledge transfers occurred. Holm Egeberg Holmsen, a Norwegian mining engineer, switched work a number of times between domestic and foreign companies in the Norwegian mining sector. After graduation in 1891 he was located a short while at Freiberg before he became a trainee, ore analyst and smelting accountant at Kongsberg Silver Works from 1891 to 1892. From 1892 to 1902, he was mining assistant and head engineer at Røros Copper Works before becoming a director at Orkedal Mining Company (part of Orkla Grube Aktiebolag). In 1907, he became assistant director at Sulitjelma Aktiegruber and director at the same company in 1908. After this long experience in the mining industry he started functioning as a consultant engineer for "…almost all the copper mines in Norway", among other Løkken Mines, Meldalen, Meraker Mines, Alten Copper Works, Birtavarre Mines etc.[831]

The work of mining engineer Jacob Pavel Friis shows in detail how transfer of knowledge between companies happened. Around 1859 the leaders at Kongsberg Silver Works started to evaluate the

[830] O. Alstad (red.) *Trondhjemsteknikernes Matrikel Biologiske meddelelser om samtlige faste og hospiterende elever av Trondhjems Tekniske Læreanstalt 1870-1915*, (Trondhjem, 1916); *Artiummatrikler studentene* [student yearbooks] (Kristiania/Oslo, 1855-1940); H. O. Christiansen et al. *25-års jubileumsberetning 1912-1937 Bergen Tekniske Skole Oslo Tekniske Skole Trondheim Tekniske Skole* (Norway, 1937); *Festskrift i anledning af Kristiania Tekniske Skoles 25 aars jubilæum* (Kristiania, 1898); R. Baggethun, *Horten Ingeniørhøgskole Horten tekniske skole En beretning om landets eldste tekniske skole gjennom 125 år* (Horten, 1980); S. Heier, *100 års biografisk Jubileums-festskrift, Horten Tekniske Skole 1855-1955* (Horten, 1955); KTS, *50 årsberetning om ingeniørkullet fra Kristiania Tekniske Skole 1896* (Oslo, 1946); Kristiania tekniske skole, *Ingeniørene fra KTS 1897-1947* (Oslo, 1947); *Ingeniører fra Kr.a Tekniske Skole 1897* (Kristiania, 1922); *K.T.S. ingeniørene av 1909: matrikkel utarbeidet til 25-års jubileet 1934* (Oslo, 1934); Oslo Tekniske Skole, *Skrift ved 50 års jubileet for ingeniørene fra K.T.S. 1894,* (Oslo, 1894), *KTS til Ingeniørkullet av 1910: 20 årsjubileum år 1910-1930* (Oslo, 1930); *Trondhjems Tekniske Mellomskoles virksomhet i de 3 første læseaar 1912-1915* (Trondhjem, 1916); *Skrift ved 50 års jubileet for ingeniørene fra K.T.S. 1894* (Oslo, 1944); L. Eskedal, *BTS-matrikkelen Ingeniører uteksaminert ved Bergen Tekniske Skole 1875-1975* (Bergen, 1975); TTL, *1897-1922* (Kristiania, 1922); Trondhjem tekniske læreanstalt, *Festskrift ved Afslutningen av Trondhjems Tekniske Læreanstalts 25de Læseaar* (Trondhjem, 1895); B. Bassøe, *Ingeniørmatrikkelen Norske Sivilingeniører 1901-55 med tillegg* (Oslo, 1961)
[831] *Studentene fra 1886* (Kristiania, 1911), p. 177

possibility of changing the drills that were used at the mines. The ones in use were iron drills, but steel drills were a better alternative due to better quality of the material and the possibility for one man drilling.[832] After evaluations, testing and modifications the leadership and workers at the company were all "…pleased with the new drills."[833] Friis demonstrated how the technological changes increased the number of drilled inches and reduced the number of damaged drills. The new drills resulted in a reduction in expenses and a more profitable operation.[834] The year after introducing this change Friis started to work as a mine leader at Røros Copper Works. He then managed to use his experience from Kongsberg Silver Works at Røros. He repeated the success from Kongsberg and replaced the iron drills with steel drills "after much hard work".[835]

Another example of how skills and managerial knowledge were transferred within the Norwegian mining sector is the career path of mining engineer Emil Knudsen. He graduated from the Mining Academy in Freiberg in 1876 and started as trainee at Kongsberg Silver Works. In 1879, he became manager at Svenningsdalen Silver Mines and in 1880 manager at the Norwegian Mining Company in Risør. In 1882, he became engineer and assistant director at the French Vigsnes Copper Works.[836] Knudsen describes his working experiences at Vigsnes in some of his Memoires: "My title was "ingenieur chef de service"…[…] The company was of course French…[…] It was for me a first-class practical school." He explained that he was given a lot of responsibility, but at the same time able to confer with "…talented people with great experience" who encouraged him in his work.[837] Moreover, he argued that:

[832] *Polyteknisk Tidsskrift* (Kristiania, 1864), p. 189
[833] *Polyteknisk Tidsskrift* (Kristiania, 1864), p. 193
[834] *Polyteknisk Tidsskrift* (Kristiania, 1864), pp. 188-191
[835] J. P. Friis, *Direktør Jacob Pavel Friis' erindringer* (Oslo, 1944), p. 155
[836] F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005)
[837] F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005), p. 84

> "(t)he work in this well organised, large modern mining plant was so developed by the varied tasks that I was a completely different man than before, and had acquired practical experience not only in mining techniques, but also in smelting operation, construction techniques and statistics."[838]

His experiences with the operations at the French company were undoubtedly very useful when leading other companies later during his career. After his work at Vigsnes, he started to work at Røros Copper Works. He was first head engineer and became administrating director 1895. In 1897, he became administrating director at Sulitjelma Copper Mines. Moreover, Knudsen referred to other workers and leaders of plants at Vigsnes Copper Works who later started to work at Sulitjelma Mining Company. Foreman Lars Christoffersen, smelting master Braathen and leader of mine Kolben Mjaaseth worked at Sulitjelma Copper Works after having worked at Vigsnes Copper Works. Mine leader Abraham Finne and machinist Johan Finne worked at Sulitjelma Copper Works and Røros Copper Works after having worked at Vigses Copper Works.[839] These switching of jobs opened up for interactions and transfer of knowledge and experiences among companies. The fact that Norwegian engineers were heavily involved in mining companies opened up for sharing of experiences and knowledge transfers between firms.

The capital goods industry in Norway shows another story than in Chile and was closely linked to the mining sector, including foreign companies. Imports of machinery were reduced from the 1860s and the capital goods sector grew gradually during the late nineteenth and twentieth centuries, as demonstrated by Bruland:

[838] My translation: F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005), p. 105
[839] F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005), p. 105

> "As the Norwegian industrial sector continued to grow in this period… [it]… indicates that Norwegian producers increasingly met the needs; thus the Norwegian mechanical workshop industry succeeded in the competition with foreign producers."[840]

Workshops in Norway started gradually to construct complex machinery and devices instead of purchasing them from other countries. An example of this was Nyland Workshop, which in 1892 decided to construct a machine they needed instead of importing it from England. This is used as an indication that "…Norway during the nineteenth century had developed a mechanical workshop industry which standard ultimately was on par with the rest of the industrialised world."[841] Actually, in the late nineteenth century the workshop industry grew faster than all the other industries in Norway and in the 1880s the industry became "a leading sector in the country", while other sectors stagnated from 1875.[842] This trend continued after the turn of the century. "Industry" alone stood for 21, 4 per cent of net domestic product in 1910, 22, 1 per cent in 1930 and 22, 7 per cent in 1935, according of official statistics.[843] It is unclear how many per cent the capital goods industry represented in terms of total GDP, but it is confirmed that it was the industry's largest branch.[844] According to Even Lange, "…the mechanical workshop industry has been a leading branch in Norwegian industry also in qualitative terms."[845]

Pioneers in the capital goods industry were Akers Mechanical Workshop, O. Jacobsen Machine Workshop, Kværner Works, Christiania Nail Works, Thune Mechanical Workshop, Nyland Mechanical

[840] K. Bruland, "Norsk mekanisk verkstedindustri og teknologioverføring 1840-1900", in *Teknologi i virksomhet: verkstedindustri i Norge etter 1840*, E. Lange (ed.) (Oslo, 1989), p. 41
[841] K. Bruland, "Norsk mekanisk verkstedindustri og teknologioverføring 1840-1900", in *Teknologi i virksomhet: verkstedindustri i Norge etter 1840*, E. Lange (ed.) (Oslo, 1989), p. 72
[842] F. Sejersted, *Demokratisk kapitalisme* (Oslo, 1993), p. 94; E. Lange (ed.), *Teknologi i virksomhet: verkstedindustri i Norge etter 1840* (Oslo, 1989), pp. 18-20
[843] Norges Offisielle Statistikk, *Historisk statistikk* (Oslo, 1978), p. 96
[844] E. Lange (ed.), *Teknologi i virksomhet: verkstedindustri i Norge etter 1840* (Oslo, 1989), p. 18-20
[845] E. Lange (ed.), *Teknologi i virksomhet: verkstedindustri i Norge etter 1840* (Oslo, 1989), p. 17; see also F. Sejersted, *Demokratisk kapitalisme* (Oslo, 1993); and Kari Amundsen, "Fra trillebård til Gardemobane", in Strømmen og Strømmens Værksted fra industri til handel, 1996 for development of mechanic workshops

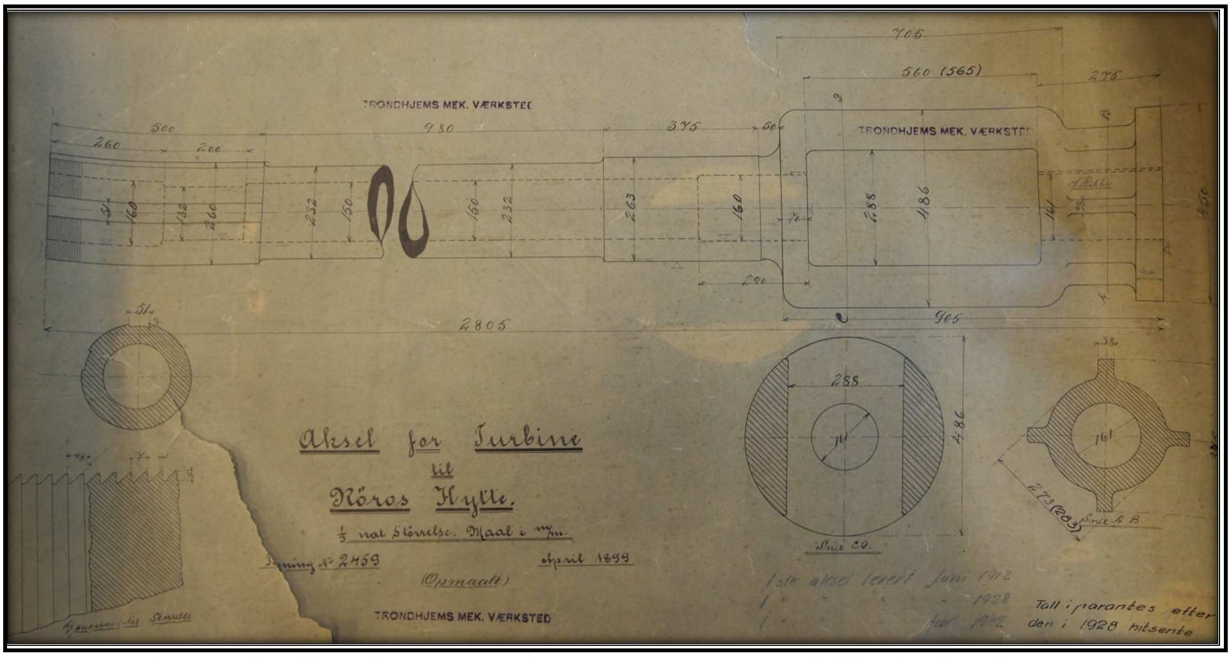
Workshop, Trondheim Mechanical Workshop, Bergen Mechanical Workshop, Kristiansand Mechanical Workshop, Stavanger Foundry & Dok., Trolla Works and Mesna Works.[846] Mining companies purchased gradually more material, equipment and machinery from these workshops. Kongsberg Silver Works provides a good illustration of purchase of machinery and technical services. In the early nineteenth century, the company acquired machinery and equipment, such as steam engines and water column machines, from foreign companies in Sweden, England and Germany. However, from the 1830s explosives and machine parts were purchased from domestic companies.[847] Drammen Iron Works and Mechanical Workshop supplied Kongsberg with five water column machines from 1872 to 1887. Kværner Works, Bærum Iron Works and other workshops were also used for deliveries.[848]

Mechanical workshops became more specialised from the 1890s and supplied increasingly complex machinery.[849] Myren Mechanical Workshops, for instance, made turbines and planning machines and Kværner Workshop constructed water power turbines.[850] Numerous examples of machinery delivered by workshops to mining companies suggest that linkages between the two sectors maintained. In the 1890s, for instance, Kværner made turbines for Røros Copper Works.[851] In 1902, the mining company Løkken Works ordered an electric system from Myhrens Workshop and a pump from Siemens and Haske.[852] Kongsberg Silver Works ordered equipment from Kværner Works, Norwegian Electric Ltd. and Borchgrevink & Company, among others, for the power plant that the company installed in the early twentieth century.[853] Later, in 1926, Ørens Mechanical Workshop in Trondheim supplied the new flotation plant at Røros Copper Works.[854] The engineering firm Fer.dP. Egeberg and engineer

[846] F. Hodne and O. H. Grytten, *Norsk økonomi i det nittende århundre* (Bergen, 2000), pp. 198-199
[847] B. I. Berg, *Gruveteknikk ved Kongsberg Sølvverk 1623-1914* (Trondheim, 1998), pp. 321-355
[848] B. I. Berg, *Gruveteknikk ved Kongsberg Sølvverk 1623-1914* (Trondheim, 1998), p. 450
[849] Famous workshops from that time: Akers mek. Verksted, Bergens Mek. Verksted, Christiania Spigerverk, Kristiansands mek. Verksted, Kværner Brug, Nylands Verksted and Trondhjems mek. Verksted.
[850] F. Hodne and O. H. Grytten, *Norsk økonomi i det nittende århundre* (Bergen, 2000), p. 201
[851] F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005), pp. 117-118
[852] B. I. Berg, *Gruveteknikk ved Kongsberg Sølvverk 1623-1914* (Trondheim, 1998), p. 421
[853] B. I. Berg, *Gruveteknikk ved Kongsberg Sølvverk 1623-1914* (Trondheim, 1998), p. 450
[854] G. B. Nissen, *Røros Kobberverk 1644-1974* (Trondheim, 1976), p. 247

Kraft Johansen Another constructed another flotation plant in 1932.[855]

In the records of the Trondhjem Mechanical Workshop, drawings of machinery for several mining companies were listed from the late nineteenth century and the first half of the twentieth century. The records include a wide range of illustrations of machinery, devices for electric plants and furnaces. Machines for Røros Copper Works were for instance a turbine, washing drum, mining trolley, convertor, dynamo, water jacket, refining furnace, ore dressing device, twin blower machine and cableway (see drawing below).[856] Gunnar Brun Nissen confirms that a double-acting cylinder blowing machine with turbine and pipeline, three convertors with carriages and other equipment were purchased by this company from Trondhjem Mehcanical Workshop and installed at the smelting plant in relation to the introduction of the French Pierre Manhés converting technique in 1886.[857]



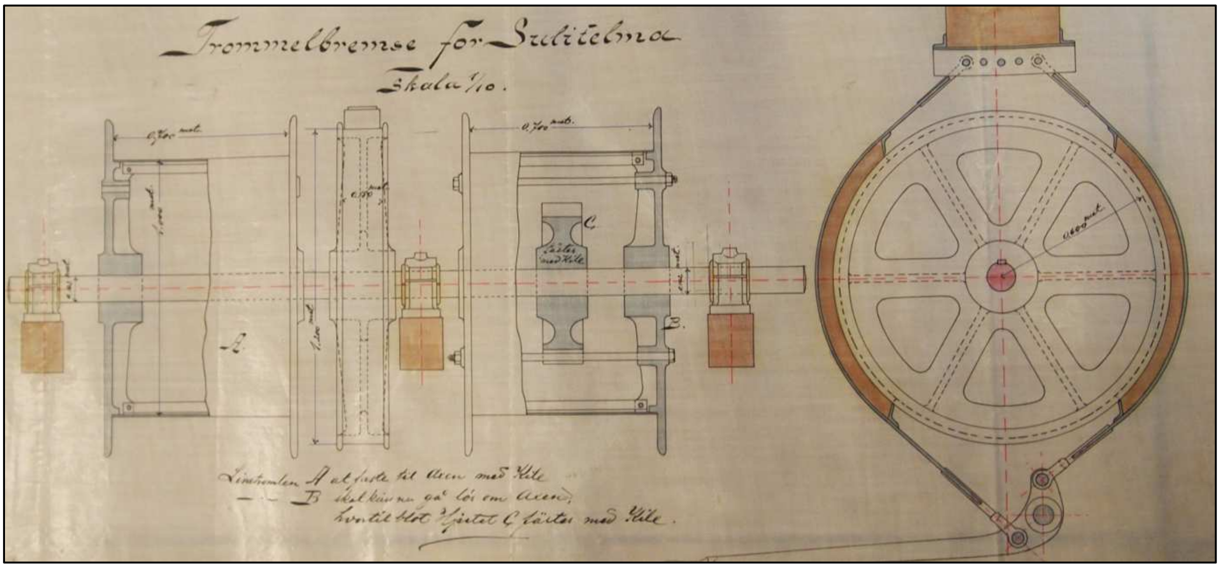
Source: Trondhjem Mekaniske Verksted, Privatarkiv 310, NTNU Universitetsbiblioteket (Dora), Industritegninger, Røros Kobberverk år 1885-1909

[855] M. Mortenson, Utviklingslinjer i norsk oppredningsteknikk, *Særtrykk av Tiddskrift for kjemi, bergvesen og metallurgi* 2 (1949), p. 6

[856] Trondhjem Mekaniske Verksted, privatarkiv 310, NTNU Universitetsbiblioteket (Dora), industritegninger, Røros Kobberverk år 1885-1909 (three boxes)

[857] G. B. Nissen, *Røros Kobberverk 1644-1974* (Trondheim, 1976), pp. 191-92

Trondhjem Mechanical Workshops also made equipment for foreign mining companies. Evaporation devices water jackets were delivered in 1924, 1936 and 1938 to the Swedish Orkla Mining Company.[858] Illustrations show that various constructions, tanks, converters, furnaces and other devices were delivered to this company. Other drawings suggest that lifts and other equipment were made for Fosdalens Mining Works. Steel constructions were sold to this company in 1928-29.[859] Other deliveries were granulators to the Canadian company Dunderland Iron Ore Company and a number of devices for Birtavarre Mines and lifting devices and convertors and drums to the Swedish company Sulitjelma Ltd. (see drawing below):[860]



Source: *Trondhjem Mekaniske Verksted*, Privatarkiv 310 [private archive], NTNU University Library (Dora), industritegninger, Sulitjelma Gruver 1900-1956

Cash books from the Bede Metal & Chemical Co., an English company, which started operation at Killingdal Mines in 1895, gives an indication of the extent to which domestic capital goods was used. Frequent supply of tools, such as hammers, mine lamps, fuses, mine ladders, dynamite, chains, belts, wires, screws etc. were continuously purchased from local shops and workshops. Moreover, more

[858] O. Schmidt, *Aktieselskapet Trondhjems mekaniske verksted 1843-1943* (Trondheim, 1945), pp. 174-181
[859] O. Schmidt, *Aktieselskapet Trondhjems mekaniske verksted 1843-1943* (Trondheim, 1945), pp. 174-181
[860] *Trondhjem Mekaniske Verksted*, privatarkiv 310 [private archive], NTNU University Library (Dora), industritegninger, Røros Kobberverk år 1885-1909, industritegninger Fosdalens Bergverk 1895-1936 and industritegninger Sulitjelma Gruver 1900-1956

complex machinery were acquired from local workshops; a pump and "pump accessories" were bought from W. Fischer & Sön in July 1899;[861] an "electric plant: excavation turbine station" was purchased by Jörgen Nyhus and A. A. Reitan in June/July 1905;[862] E. Fjeldseth was paid for an electric installation in September 1910;[863] a boring machine was bought from Sverre Mohn in September 1918, among other things.[864] The company also used domestic workshops for the repair of machinery. Ørens Mechanical Workshop in Trondheim, for instance, was paid for the repair of a pump in June 1898 (see appendix 5 of Bede's cash books).[865] The cash books also have registers of imported equipment. In November and December 1919, for instance, customs were paid to Røros Custom Office for "diesel motor".[866] The same year a payment was made to Bachke & C for "forward machine from England in February".[867] The cash books reveal that local workshops and stores were used for inputs. This continued until the end of operation, year 1946.[868] Some machinery and other equipment were acquired by foreign subsidiaries in Norway, such as the German company Siemens-Schuckert in Christiania. A dynamite exploding electrical machine was bought by this company in August 1906 and an electric motor in November 1906.[869] The Swiss company Brown Boveri Ltd. Was paid to repair an electric motor in October 1915[870] and an electric motor was bought by Siemens-

[861] *Bede Metal Killingdal*, privatarkiv 107 [private archive], Statsarkivet i Trondheim, 10 kassabok sept. 1895.okt. 1906

[862] *Bede Metal Killingdal*, privatarkiv 107 [private archive], Statsarkivet i Trondheim, 10 kassabok sept. 1895.okt. 1906

[863] *Bede Metal Killingdal*, privatarkiv 107 [private archive], Statsarkivet i Trondheim, 11 kassabok nov. 1906-okt.1919

[864] *Bede Metal Killingdal*, privatarkiv 107 [private archive], Statsarkivet i Trondheim, 11 kassabok nov. 1906-okt.1919

[865] *Bede Metal Killingdal*, privatarkiv 107 [private archive], Statsarkivet i Trondheim, 10 kassabok sept. 1895.okt. 1906

[866] *Bede Metal Killingdal*, privatarkiv 107 [private archive], Statsarkivet i Trondheim, 12 kassabok nov. 1919-des. 1919

[867] *Bede Metal Killingdal*, privatarkiv 107 [private archive], Statsarkivet i Trondheim, 11 kassabok nov. 1906-okt.1919; 12 kassabok nov. 1919-des. 1919.

[868] *Bede Metal Killingdal*, privatarkiv 107, Statsarkivet i Trondheim, 11 kassabok nov. 1906-okt.1919; 12 kassabok nov. 1919-des. 1919; kassabok jan. 1920-des. 1925; kassabok jan. 1926-des. 1931; kassabok jan. 1932-jul. 1938; kassabok aug. 1930-aug. 1945

[869] *Bede Metal Killingdal*, privatarkiv 107 [private archive], Statsarkivet i Trondheim, 10 kassabok sept. 1895; okt. 1906; 11 kassabok nov. 1906-okt.1919

[870] *Bede Metal Killingdal*, privatarkiv 107 [private archive], Statsarkivet i Trondheim, 11 kassabok nov. 1906-okt.1919

Schuckert in April 1913.[871] However, the point to be made is that the great majority of tools, equipment, machinery and service were purchased domestically.

Aluminium companies possibly functioned differently than other mining companies and developed enclave tendencies to some degree. Norwegian Nitride Company Ltd., Norwegian Aluminium Company, Vigeland Works, NACO and BACO were, in contrast to other foreign companies in the mining sector, established as “greenfield” operations. Norwegian engineers did not have previous experience in this field, and companies imported most of the technology from France, Switzerland or other places.[872] Yet, these companies used Norwegian engineers and domestic managers to administrate operations. Members of Executive Board and administrating directors at these companies were Norwegian.[873] Moreover, local engineers were in a large degree initiators of these industrial projects. The Norwegian industrialist Sam Eyde was involved in the establishment of a number of companies and was one of the initiators of the Norwegian Nitride Company Ltd. The engineers Sigurd Kloumann and Emil Collett were heavily involved in the start-up of the Norwegian Aluminium Company and were both appointed managing directors of the company.[874] Professor at the Norwegian Institute of Technology (NIT) Harald Pedersen was engaged in the development of aluminium production with the Pedersen process. Thus, also in these greenfield projects the foreign control were reduced. This practice seems to have continued. Stonehill uses a sample from 1961 of 39 foreign-owned manufacturing and mining enterprises. In the case of administrative directors, nearly all were Norwegians in a sample of 54 foreign-owned manufacturing and mining enterprises.[875] Thus, instead of creating enclave tendencies and negative effects, as in Latin American countries, foreign companies were more integrated and created positive effects for the Norwegian

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[871] *Bede Metal Killingdal*, privatarkiv 107 [private archive], Statsarkivet i Trondheim, 11 kassabok nov. 1906-okt.1919

[872] E. Storli, *Out of Norway Falls Aluminium* (Trondheim, 2010), pp. 71-73 and 148

[873] K. Fasting, *Norsk Aluminium gjennom 50 år* (Oslo, 1965)

[874] http://nbl.snl.no/Sigurd_Kloumann [accessed 29 March 2015]

[875] A. Stonehill, *Foreign Ownership in Norwegian Enterprises* (Oslo, 1965), p. 82

economy. Multinationals have transferred modern technology, increased employment and contributed to efficient utilisation of natural resources.

Why did the multinational companies have such different effects in Chile and Norway? The country of origin has been argued to be of importance when it comes to the firm-specific impacts of multinational companies on a host economy. Alfred Chandler analysed large corporations in the late nineteenth and early twentieth centuries and found that companies were organised differently in the United States, Germany and England. In the United States, companies had paid managers and large corporations created oligopolistic competition. In England, family-owned businesses were "personally managed". In Germany, large, integrated companies were normally managed with salaried managers, as in the United States, but with a strong competitive climate between them.[876] Geoffrey Jones finds that the way multinationals has entered a country and the type of investment have played a role. "Greenfield" investments, i.e. constructing new operational facilities from the ground up, have resulted in new processes and productions, but the consequenses of such investments have not always been clear.[877] He explains that the willingness of a foreign company to transfer technology to the foreign affiliate:

> "…may be influenced by whether that subsidiary is wholly owned or a joint venture, although the reasons why the firm entered such an arrangement will be a significant factor. Licensing, franchising and direct investments strategies can be expected to differ in their impact on host countries."[878]

On the other hand, in spite of nationality, size and other characteristics, multinationals have had to adapt to and comply with the institutional setting and "rules of the game" of the country in which they invest. More than the country of origin of the multinational companies, it seems likely that the

[876] A. Chandler, *Scale and Scope: the dynamics of industrial capitalism* (The United States, 1990)
[877] G. Jones, *Multinationals and Global Capitalism* (Oxford, 2005), p. 260
[878] G. Jones, *Multinationals and Global Capitalism* (Oxford, 2005), p. 261

differences when it comes to economic impacts largely depend on the ability of the host country to actively benefit from and use the foreign technology. I will explore reasons for this in the next chapters.

9.4 Summary and concluding remarks

In this chapter, two entire mining sector have been analysed and compared. This is to some extent challenging, since mineral and metal productions developed in different ways and contributed differently to their respective economies. Some of the productions were huge, such as the Chilean copper industry, while others were smaller. Productions in both sectors showed periods of increase and downturns. For example, the copper production in Norway had severe problems in the 1920s, but increased thereafter. In Chile, when copper had a downturn in the late nineteenth century, silver and coal productions increased. After the saltpetre production stagnated in the 1920s, copper again became the most important production and export product. These changes in the productions may be explained by fluctuations in prices or changes in international markets. The systematic decline of productions in the 1930s, demonstrates how the Great Depression severely affected both economies, and especially the Chilean economy. The production of saltpetre deteriorated and never recovered after the Depression. However, the developments of these industries were not only linked to international fluctuations and economic crises, but were also largely connected to internal factors.

Some of the largest mining productions and companies within the two sectors have been analysed, notably saltpetre and copper for Chile and pyrite, copper, silver, iron and electro-metallurgical products for Norway. I have found some repeated traits within the two sectors, which suggests an overall more negative development in Chile and a more positive development in Norway. The two sectors differed mainly in four aspects, namely to the relative extent to which mineral ores were utilised; the technological level; linkages to the capital goods sector and the degree to which multinational mining companies were integrated in the economy.

Perhaps the most remarkable negative trait in Chile was the unutilised mineral ores and thousands of mines not being extracted. Chile had, and has, much natural resource potential, in terms of hydroelectric capacity, iron, silver, gold, sulphate, zinc, manganese and some of the world's largest copper deposits. The unutilised mineral and metal ores, together with the large hydroelectric capacity, could be used to begin new industries, but this potential was not taken advantage of. Norway did not seem to have the same problem as new mineral and metal productions initiated and the sector grew and began new large-scale electro-metalurgical productions.

The decline of Chilean copper production and its drop in the share of world production from the end of the nineteenth century are particularly noteworthy. From the late nineteenth century, the demand for copper in the world market increased and the two mining sectors were met with new challenges in terms of finding, removing and processing ores. High-grade ores had largely been extracted and low-grade ores remained in more remote areas and required deeper and bigger mines. The mining sector in Chile did not adapt to these new challenges. The domestic copper industry, which prospered until the late nineteenth century, failed to undergo the necessary technological changes to continue to be competitive and successful and begin technologically advanced large-scale mining. Contrasts between small and medium-sized traditional domestic firms using old simple technology and large foreign technologically complex and up-to-date enterprises indicated a technological gap within the mining sector from the beginning of the twentieth century. The foreign companies represented the technologically advanced part of the sector, first in saltpetre, and later in copper, iron and other productions, while the domestic industry lagged behind with a small production of less pure minerals and metals. Some domestic companies developed efficient small to medium-sized production with additional processing plants, but they were exceptions. The large differences when it came to the knowledge foundations between artisanal small-scale domestic companies, based on human and animal power and pirquen work on one hand, and large-scale advanced foreign companies using mechanised equipment and large electric power plants on the other, made it extremely difficult for domestic companies to learn and absorb knowledge from the foreign firms. It appears that the statement made by Reich is relevant in this context: “(O)nce off the technological escalator it’s difficult to get back on.”[879] The period between the late nineteenth century and first part of the twentieth century represents in this sense a period in which parts of the mining sector in Chile fell behind. If we believe Cohen and Levinthal, the capacity to absorb this complex knowledge at a later stage, probably would have been very difficult, because the gap between the knowledge bases was too big. In this sense, these years represent a turning point in the history of Chilean mining.

In Norway, on the other hand, there was no clear technological gap between domestic and foreign companies. There was no apparent problem of absorptive capacity among domestic companies. Actually, Kongsberg Silver Works and Røros Copper Works were sometimes ahead of foreign companies in the use of new technology. The transfer of knowledge and experiences between foreign and domestic companies in Norway even suggest a high level of absorptive capacity in this country.

The two countries also differed in terms of relations and linkages between the mining sector and the domestic capital goods industry. Mining companies in Norway imported technology from abroad, but both domestic firms and multinationals gradually increased the use of domestic workshops for supply of complex machinery, equipment and other relevant inputs for the continuous improvement of operational techniques. Such linkages between the sectors contributed to learning experiences and positive effects for the Norwegian economy as a whole. In Chile, on the other hand, such linkages between the capital goods and mining sectors, which had existed to some degree in the late nineteenth and early twentieth centuries, declined from the 1920s. The large foreign companies from the early twentieth century purchased practically all inputs from abroad. Why, then, did the mining

[879] Quote taken from M. Cohen and D. Levinthal, "Absorptive capacity: A new perspective on learning and innovation", *Administrative Science Quarterly*, vol. 35, Issue 1 (1990), pp. 136-137

companies in Chile not use domestic suppliers? This can be explained by the fact that complex and up-to-date technology, such as power plants, electric machinery and multipart processing equipment was not to be found in Chile. The Norwegian capital goods sector, on the other hand, had developed into a "leading branch." A small underdeveloped domestic capital goods sector and lack of linkages between industries certainly had negative consequences for the Chilean economy. Mechanical workshops were in the core of technological changes since their economic activities were based on the making of machinery, techniques and services, which were used directly in operational activities. Without this development, the country was cut off of "experiences in the design and use of machinery", which was argued to be essential for technological dynamism and continuous innovation. It should be mentioned that there is evidence of increased linkages in Chile between domestic engineering companies and other suppliers to the mining sector in recent decades.[880] Still, the capital goods sector in Chile remains smaller than the one in Norway. According to World Development Indicators the "machinery and transport equipment" share of value added in manufacturing in Chile was 3, 7 per cent in 1990 and declined to 1, 8 per cent in 2008. In Norway, on the other hand, this branch stood for 19, 4 per cent in 1990 and increased to 29, 9 per cent in 2008.[881] This is the case even though Chile is a larger economy and has a much larger mining sector, which require large proportions of inputs and up-to-date technology.

Multinational companies were crucial for Chile in terms of employment, capital investments, large-scale production and taxes. Some of these foreign companies dominated the large saltpetre production and some of the largest copper mines in the world. However, their dominance resulted in many cases in enclave economies, with foreign managers and engineers leading the operations and

[880] See J. Katz et al. "Instituciones y Tecnología en el Desarrollo Evolutivo de la Industria Minera Chilena." (Santiago, 2000); G. Moguillansky, "Chile, sector minero 1980-2000" (Santiago, 1998)
[881] Total manufacturing was slightly larger in Chile in terms of GDP: in 1970 it represented 25,8 per cent in Chile and in 2013 11,4 per cent. In Norway it accounted for 20,1 per cent in 1970 and 7,3 per cent in 2013. However, in constant 2005 USD the Norwegian sector was considerably higher: World Data Bank: World Development Indicators (WDI) & Global Development Finance (GDF)

without being integrated in the Chilean economy. Their control over some of the country's key natural resources made their negative effects particularly damaging for the economy. In successful resource-based economies, foreign companies, which have been much despised in Latin America, have historically played a big part in the development of some of the knowledge intensive and innovative natural resource industries. In Norway, foreign companies dominated mining productions, but were altogether more integrated in the domestic economy and resulted in relatively more positive effects than in Chile. First of all, the hiring of local engineers and managers at foreign companies increased domestic participation and control. Second, multinational companies brought technology, stimulated to employment and created strong linkages to domestic industries. They did not develop enclave tendencies and there was no conflict of interest similar to the ones found in Chile. The aluminium production companies were possibly an exception, as it is argued that they were more linked to their parent companies. However, local engineers were also employed at the aluminium companies, professors participated in the development of technology and domestic engineers and leaders dominated management. So, why did enclave economies develop in Chile and not in Norway? In spite of nationality, size and other features of the multinational companies, the firms would have had to adapt to and comply with the institutional setting and "rules of the game" of the country in which they invested. I argue, therefore, that it is domestic institutions, which largely determine whether multinationals companies have negative or positive effects on an economy. The role of the state seems crucial in this respect. In Chile, the state acquired much earnings in form of tax from the multinational companies, some say too little, but remained passive and did not prevent the enclave economies to form. In Norway, the state was active in gaining control over the companies through specific laws and regulations, which required inclusion of local participation and engineers (see chapter about factors explaining the divergence between Scandinavia and Latin America). I will come back to this subject in the last chapter.

The coal industry in Chile shows a different story than other metal and mineral productions. The companies were innovative and continuously adopted new and efficient techniques. For instance, coal companies were the first to use electricity as a source of power. The problems concerning foreign investments were reduced, because domestic investors dominated the industry. However, when looking at the mining sector in Chile as a whole, it did not develop optimally. There were some general traits within the sectors, which suggest that the sector in Norway contributed relative more to growth than the sector in Chile. Negative characteristics of the Chilean sector and positive traits of the Norwegian sectors are summarised as follows:

Simple categorisation of the two sectors

Trait	Chile	Norway
Utilisation of natural resources	Natural resource potential remained unutilised	New industries were continuously developed
Technological level	Technological gap between technologically backward domestic and technologically up-to-date foreign companies	No obvious gap between domestic and foreign companies
Multinationals	Developed into enclave economies	Were integrated in the economy
Linkages to capital goods industry	Declining linkages until they in practice stopped in the 1920s	Increasing linkages

We have seen that, in terms of GDP per capita, the Norwegian economy was growing from the 1930s, while the Chilean economy stagnated, fluctuated and did not grow in significant terms until the 1980s. Was the stagnating Chilean economy linked to negative traits of its mining sector? The answer is twofold. On one hand, the mining sector in Chile, in contrast to other industries, actually produced an excessive amount of goods. The sector was huge and mining products accounted for more than eighty per cent of exports. It contributed to the larger share of the income for the state, because other natural resources, such as forests and fish, were hardly utilised and manufacturing industries were underdeveloped.[882] Large-scale metal and mineral productions by multinational companies renewed parts of the sector, without which the economy perhaps would have stagnated even more.

[882] See M. Carmagnani, *Desarrollo Industrial y Subdesarrollo Económico El Caso Chileno (1860-1920)* (Santiago, 1998) and A. Pinto Santa Cruz, *Chile, un caso de desarrollo frustrado* (Santiago, 1959)

Thus, it was the mining sector that actually kept the economy going. It was the cornerstone of the economy. On the other hand, the country became extremely dependent on this sector. The size of it made its development particularly important and the challenges it faced, equally severe. The lack of innovation and advance in the sector prevented it from stimulating strong growth and becoming a real driving force of the economy. Without taking advantage of the country's mineral and metal deposits, reduce enclave tendencies, catching up and adopting new technology that characterised modern mining at that time, it would have been difficult for the sector to generate a boost in the economy. The persistent negative characteristics of the Chilean sector explain in this sense the stagnant economy. Was the growing Norwegian economy linked to the positive traits of its mining sector? In Norway, in contrast, the mining sector was not nearly as big as the Chilean mining sector, but was one of many export sectors. The country developed a number of relatively big, and growing, natural resource industries from an early stage, such as fishing, mining, timber and timber-related industries. This made the Norwegian economy less dependent on one industry and in turn less vulnerable. The boost in the economy from the 1930s and onwards was probably caused by several factors, such as an increase in the chemical productions and the large shipping industry. At the same time, together with other industries, the mining sector, in particular the large-scale electro-metallurgical industry, which had a sharp increase in production and exports from the early twentieth century, contributed to the strong economic growth that was happening at the time. I argue, therefore, that the diverging economic paths between Chile and Norway were linked to the different developments of the two mining sectors.

Why did Norway benefit relatively more from its natural resources than Chile did? Why did ore deposits remain unexploited and mining productions decline? One can imagine that lack of capital would be a problem in Chile and explain the little advancement of the mining sector. Chilean investors were criticised for seeking large incomes fast, which in turn is seen as a reason for the reduced investments in less profitable low-grade mines.[883] On the other hand, the National Mining Society argued in 1890 that the reason for the declining copper industry in the late nineteenth century was a lack of knowledge, and not capital. It was claimed that:

> "…capital is not exactly what is lacking in our industry to achieve a real industrial advance but the knowledge of the best methods of exploitation currently accepted in most developed countries…"[884]

Later, in 1925, Chilean industrialists actually invested in mining projects in neighbour countries, such as Argentina and Bolivia, which suggests that money accumulation was not the primary problem in Chile.[885] If lack of capital and investors was not the main problem, why did mining industrialists and entrepreneurs not invest more in valuable metals and mineral mining in the country? I will explore this by analysing institutions and organisations, which were directly involved in the development of knowledge for mining in the two countries.

A crucial point to be made here is that similar types of institutions for knowledge development in mining were established in Chile and Norway. During the nineteenth and twentieth centuries, both Chile and Norway developed a number of institutions, which aimed to create, transfer, adopt, modify and diffuse knowledge to build the mining sectors. Intermediate and higher mining engineering programs, geological maps and ore analyses, industrial societies, and technical magazines were developed and foreign engineers, technicians and other workers, study travels and industrial exhibitions were facilitated in both countries during the nineteenth and twentieth centuries (see chapter of methodology). Then again, although these institutions were formed in Chile, the mining sector did not develop optimally. This indicates that the mere presence of these institutions did not guarantee innovation and growth. On the other hand, even though they were of similar types and

[883] A. Pinto Santa Cruz, *Chile, un caso de desarrollo frustrado* (Santiago,1959), p. 74
[884] My translation: *Boletin de la Sociedad Nacional de Minería* (Santiago, 1890), p. 129
[885] For statistics on this subject see *Boletin de la Sociedad Nacional de Minería* (Santiago, 1925), pp. 68-70

had similar aims, there might have been differences between the two countries' institutions with regard to their functions, results, interactions and links to innovation. I seek, therefore, to analyse and compare these institutions more carefully.

10 Mining instructions in Chile and Norway: similar in character

> "The miners [and mining engineers] may be insignificant in numbers, but in respect of the value produced as a result of their labor, they are the most important element in the entire population."[886]
>
> Samuel Christy, University of California, Chicago Meeting, International Engineering Congress, August 1893

As seen in the previous chapter there was a gap in development between the Norwegian and Chilean mining sectors. In its totality, mining was technologically more advanced in Norway and contributed relatively more to growth than the sector in Chile. Why did Chilean and Norwegian mining sectors develop differently? In this chapter, the formal mining instruction on intermediate and higher level is analysed and compared. From the mid-nineteenth century, both countries had a number of technical schools and universities, which provided technical and engineering programs and other relevant higher education for mining. The establishment of formal mining education on both intermediate and higher level in the two countries was an important initiative to catch up with the rest of the world in terms of mining practices. The aim of these institutions was to build technological capabilities, spread useful knowledge and educate skilled engineers and technicians for the mining sector.

The main questions here are: (1) whether formal mining education in the two countries, at tertiary and technical level, provided relevant knowledge for mining and (2) whether there were any obvious differences between the two countries' mining instructions. The aim is to explore whether there were discrepancies in the character, or quality, of the teaching. Study programs, subjects and teaching forms are examined in relation to the technology and changes in the two sectors. In the last part of

[886] S. B. Christy, "The Growth of American Mining Schools and Their Relation to the Mining Industry", Chicago Meeting, part of the International Engineering Congress (California, august 1993), pp. 453-454

the chapter, the two mining educations are discussed and compared.

10.1 Formal mining instruction in Norway

Until the eighteenth century, training in Norway was mostly practical and took place at the mining companies either in Norway or other countries. One of the first traces of apprenticeship in Norway was a practice at the public company Kongsberg Silver Works established in the early seventeenth century. In 1633, the smelting accountant and the ore analyst, both German, started to teach young men in smelting and ore analysis. In 1715, another apprenticeship program, which sought to teach young men mining and metallurgy, was formed at the same company.[887] Additionally, the King established scholarships for two apprentices to do practical training at the smelting plant. After the practice, they were sent to study at foreign mining companies.[888] Around twenty apprentices acquired scholarships from program until 1757.[889] Practical apprentice programs at the mining companies continued during the nineteenth century. Røros Copper Works created a practical "mining cadet school" around mid-eighteenth century and operated between 1821 and 1848.[890]

Heinrich Schlanbusch, a German mining engineer, suggested creating a public mining seminar in 1687. It was not until seventy years later, in 1757, after the recommendation of one of the managers at Kongsberg Silver Works Michael Heltzen, that the Mining Seminar in Kongsberg was established. Nevertheless, formal mining education was founded early in Norway and the establishment represented one of the oldest technical schools in the world.[891] The mining engineering program was then transferred from Kongsberg to the Royal Frederick University in Christiania in 1814. To be accepted to the mining program it was required to have a preliminary exam in Latin, German, history,

[887] A. K. Børresen and J. T. Kobberrød (red.), *Bergingeniørutdanning i Norge gjennom 250 år* (Trondheim, 2007), p. 18
[888] *Tidsskrift for kemi og bergvæsen* (Oslo, 1932), p. 127
[889] A. K. Børresen and J. T. Kobberrød (red.), *Bergingeniørutdanning i Norge gjennom 250 år* (Trondheim, 2007), p. 18
[890] A. K. Børresen and J. T. Kobberrød (red.), *Bergingeniørutdanning i Norge gjennom 250 år* (Trondheim, 2007), p. 18
[891] B. I. Berg, *Gruveteknikk ved Kongsberg Sølvverk 1623-1914* (Trondheim, 1998), p. 167

geography and practical calculation or an academic title.[892] A specific "scholarship for mining students" were continuously provided to "the most disadvantaged students" in order to pay for rent and other expenses.[893] The program was from this moment divided in two. The theoretical mining instruction was provided at the University and the practical training in ore surveying, mines and smelting plants remained at Kongsberg Silver Works.[894]

10.1.1 Debate about the content of the instruction

A debate was raised about the content of the mining engineering program. Journals and newspapers, notably the Mining Journal and the Technical Magazine, but also other magazines and newspapers, published articles by engineers, professors and company leaders. Some, notably students, engineers and leaders of companies, claimed that the instruction should focus on practical assignments, laboratories and work experience instead of classroom teaching and scientific theories. For instance, in 1910 the director of Sulithjelma Copper Works, Holm Holmsen, stated in the Technical Magazine that the instruction was too theoretical and that mining engineers with an education from the University had "all felt what it meant to start working with an education that was not of the practical kind."[895] Rolf Grøndahl, a graduate from 1917, went as far as to suggest to "move the instruction to the mines" for a couple of semesters during the program. He suggested making the students work at mines and ore dressing plants during the day and provide theoretic instruction in classrooms in the evenings. This way, he claimed, it would be easier to learn about the relationship between "theory" and "practice".[896] Professor Harald Pedersen, on the other hand, did not agree with the claim that Norwegian engineering instruction was too theoretic.[897] He argued instead that in-depth knowledge of scientific theories was crucial to be able to solve problems in mining.[898] Some of the students also

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[892] *Universitets- og skoleannaler* (Kristiania, 1834-35), p. 214
[893] *Universitets- og skoleannaler* (Kristiania, 1834-35), p. 215
[894] *Tidsskrift for kemi og bergvæsen* (Oslo, 1932), p. 205
[895] *Teknisk Ukeblad* (Oslo, 1910), p. 632
[896] G. Brochmann (red.), *Vi fra NTH de første 10 kull: 1910-1919* (Stavanger, 1934), p. 150
[897] H. Pedersen, "Den tekniske høiskole er i kontakt med storindustrien", *Bergens Tidende* (9 of April 1929)
[898] H. Pedersen, "Samarbeidet mellem teknisk-videnskapelig forskning og industrien", foredrag i Polyteknisk Forening den 29. oktober 1929, *Teknisk Ukeblad* (Oslo, 2nd January, 1930), p. 6: For a review of this debate see

stressed the importance of a thorough theoretic instruction. The construction engineer Rolf Torngaard Retz, graduated from Norwegian Institute of Technology (NIT) in 1923, pointed out that theoretical knowledge was crucial in the work of the engineer. His experience was that engineers almost daily were confronted with a theoretical question, which could not be solved without solid knowledge of mathematics, mechanics or physics.[899]

The debate about whether to take a practical or theoretical approach was part of a more general discussion about how the education programs in engineering should be, and continued throughout this whole period.[900] The question underlying this discussion was whether the engineer graduates were fully capable workers after finishing their degree, or if they needed more practical experience. The NIT admitted that even though this was a "profession oriented" study, graduates were not ready for their profession in the same way journeymen were. The institution did not educate fully trained professionals, but rather aimed to offer an instruction which would provide the best possible foundation for the engineers in their work.[901] This view was supported by professors at this institution. Professor Harald Dahl published an article in 1937 in the Journal of Mining. He argued that:

> "(w)hen one speaks of the mining engineering education, the majority think of the study at NIT; but it is often ignored, that this is just a first step, and that the most important part of education is still ahead."[902]

His point was that the engineers needed more practice after the formal mining education to function

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G. A. Blom, *Fra bergseminar til teknisk høyskole* (Oslo, 1958); A. K. Børresen and J. T. Kobberrød (red.), *Bergingeniørutdanning i Norge gjennom 250 år* (Trondheim, 2007); A. K. Børresen, *Bergtatt: Johan H. L. Vogt – professor, rådgiver og familiemann.* (Trondheim, 2011)

[899] G. Brochmann (red.), *Vi fra NTH de første 10 kull: 1910-1919* (Stavanger, 1934), p. 458

[900] For a general review of this debate see T. J. Hanisch and E. Lange, *Vitenskap for industrien NTH – En høyskole i utvikling gjennom 75 år* (Oslo, 1985), p. 53

[901] T. Brandt and O. Nordal, *Turbulens og Tankekraft Historien om NTNU* (Oslo, 2010), p. 110

[902] My translation: *Tidsskrift for kemi og bergvæsen* (Oslo, 1937), p. 157

as good and capable mining engineers. The objective of the lectures was, according to him, to provide general knowledge to develop the students' judgement and provide them with the technical insight needed in their work after studies. The important thing was to teach the students critical thinking and how to "reflect on the problems they later need to solve."[903] It was, then, after graduation that the mining engineers really acquired experience and learned how to use theoretic sciences in practice.

10.1.2 The University

In the eighteenth century, the main purpose of the Kongsberg Mining Seminar was to educate engineers for mining companies. The University introduced from 1814 a scientific approach and the instruction was based on more advanced theoretic teaching than the one at the Mining Seminar. The University's aim was twofold: to provide (1) the mining industry with capable leaders for mining companies and (2) scientists to the University and research centres. The range of subjects was in general the same as the ones at the Seminar, but the demands were raised on advanced mathematics and a large emphasis was given to chemistry, metallurgy, physics and geology.[904]

An extensive study program

The average study period of the mining engineering program in the mid-nineteenth century was around four years, including the practice at Kongsberg Silver Works. The study program was extensive and included both courses in natural sciences and courses specifically directed towards mining (see appendix 10 for study programs of selected years).[905]

Natural science courses accounted for a large share of the mining engineering program. Annual reports of the University reveal that the emphasis was given to geology, mathematics, mineralogy and mechanics. Lectures in these courses were followed by other students too, not only mining

[903] *Tidsskrift for kemi og bergvæsen* (Oslo, 1937), pp. 157-161
[904] G. A. Blom, *Fra bergseminar til teknisk høyskole* (Oslo, 1958), pp. 132-133
[905] *Det Kongelige Norske Frederiks Universitets Aarsberetning 1871* (Christiania, 1871), p. 41

engineering students. Mathematics was divided in two: pure mathematics included subjects such as geometry, stereometry, trigonometry, algebra, equations, spherical trigonometry and calculation of infinity, and "applied mathematics" included training in its "…most direct appliance to the machine system."[906] Lectures in geology covered Norway's geological structures as well as the geology of foreign countries.[907] Mineralogy introduced the students to the structures of the minerals, mineral characteristics and the way they were utilised.[908] A large collection of minerals from Norway and European and American countries was used in teaching of this subject.[909] Finally, mechanics included lectures in statics, dynamics, hydrostatics and hydraulics.[910] These four natural science courses were all understood key knowledge domains for operational activities in mining (see chapter 8).

Besides the natural science subjects, the program included four courses specifically directed towards mining. These were mining construction, mine factory, metallurgy and machine drawing.[911] Specific topics covered in these courses were analysis of ores, smelting techniques, ore treatment and "knowledge of the solid earth."[912] In metallurgy, the students were introduced to the structures and characteristics of metals and how they were extracted.[913] Mining construction included the teaching of refraction methods, drainage and pumping, lightening, ore dressing and mapping.[914]

Diverse teaching forms

Descriptions of the teaching forms are included in the annual reports of the University. The courses were taught in different ways, depending on the kind of teaching method that seemed fit. Some

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[906] *Universitets- og skoleannaler* (Kristiania, 1834-35), pp. 214-215
[907] *Det Kongelige Norske Frederiks Universitets Aarsberetning 1861* (Christiania, 1861), p. 11; *Universitets- og skoleannaler* (Kristiania, 1866), p. 12
[908] A. K. Børresen and J. T. Kobberrød (red.), *Bergingeniørutdanning i Norge gjennom 250 år* (Trondheim, 2007), pp. 39-40
[909] *Det Kongelige Norske Frederiks Universitets Aarsberetning 1911* (Oslo, 1911)
[910] *Universitets- og skoleannaler* (Kristiania, 1834-35), p. 217
[911] *Universitets- og skoleannaler* (Kristiania, 1834-35), p. 215
[912] *Universitets- og skoleannaler* (Kristiania, 1834-35), p. 216
[913] A. K. Børresen, *Bergtatt: Johan H. L. Vogt – professor, rådgiver og familiemann.* (Trondheim, 2011), p. 67-68
[914] A. K. Børresen, *Bergtatt: Johan H. L. Vogt – professor, rådgiver og familiemann.* (Trondheim, 2011), p. 156

courses were suited to be taught as lectures or dictations in classrooms, while others were taught as a combination of lectures, exercises, laboratory tests and "out in the field" excursions. Subjects such as mineralogy, lithology, stratigraphy and "description of the Norway's geological conditions" were best provided as classroom dictations.[915] Crystallography was taught as lectures, but included also "practical assignments".[916] The students were also required to do "practical exercises" in mineralogy.[917]

Some courses, such as metallurgy and mining construction, were understood as "practical" and considered difficult to teach solely in a classroom and through dictations.[918] The metallurgical laboratory was used to assist the students in becoming acquainted with extraction processes. The students also worked in the chemical laboratory with quantitative as well as qualitative analyses.[919] Courses in geology and mineralogy included another instruction form, namely geological excursions. Practical knowledge of Norwegian geology and identifying ore deposits were best acquired during field trips and the students were obliged to participate in them.[920] Excursions were carried out every year and some students even went on several excursions.[921] Professors in geology, Baltazar Mathias Keilhau in the mid-nineteenth century and later Theodor Kjerulf and Johan Herman Lie Vogt, were given funds almost every year to go on geological excursions with students.[922] In 1861, for instance, "4 long excursions for "practical geological purposes" took place".[923] Practical training was provided at Kongsberg Silver Works. After the practice, the students had to do a practical test.[924]

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[915] *Det Kongelige Norske Frederiks Universitets Aarsberetning 1861* (Christiania, 1861), p. 11
[916] *Det Kongelige Norske Frederiks Universitets Aarsberetning 1861* (Christiania, 1861), p. 11
[917] *Det Kongelige Norske Frederiks Universitets Aarsberetning 1861* (Christiania, 1861), pp. 9-15
[918] *Universitets- og skoleannaler* (Kristiania, 1834-35), p. 215
[919] *Det Kongelige Norske Frederiks Universitets Aarsberetning,* for instance year 1861 (Christiania, 1861), pp. 27-28 and *Universitets- og skoleannaler* (Kristiania, 1910), pp. 136-37
[920] "Reglement for bergeksamen" (Approbert ved kronprosegentens resol. Av 7de mai 1894, jfr. Kgl. Resol. Av 9de mars 1909), Privatarkiv nr. Tek 4, *Johan Herman Lie Vogt*, Eske 25
[921] See *Universitets- og skoleannaler* (Kristiania, 1865), p. 11
[922] See *Universitets- og skoleannaler* (Kristiania, 1834-1910)
[923] *Det Kongelige Norske Frederiks Universitets Aarsberetning 1861* (Christiania, 1861), p. 11
[924] G. A. Blom, *Fra bergseminar til teknisk høyskole* (Oslo, 1958), p. 121

The students had to do a written exam before they graduated. The exam included subjects from mathematics, chemistry, mineralogy, physics, geology, metallurgy, mining construction and mining fabrication.[925] The exam was extensive and sought to cover all subjects in the study program. In 1865, for example, the exam included several written exercises in integral calculus, geometry, equations and mechanical formulas.[926] Additionally, the students were required to do drawings of constructions, machinery and maps.[927]

Modifications in the study program to adapt to technological changes in the industry

In 1871, "study of machines" became a course (and object of examination), and the amount of mathematics in the examinations was reduced.[928] The exam constituted from this point of two exercises of pure mathematics, two of rational mechanics and two of machine study.[929] Exercises in machine study were related to specific machines, such as lifting machines, as well as machine parts.[930] In 1874, one of the exercises involved explaining the theory of the effect of steam in a normal steam engine.[931] The changes in the curriculum reflect the changes in the industry that was happening at the time. As seen, there was a gradual mechanisation in mining in the second part of the nineteenth century and knowledge of how to use and repair machinery, such as steam engines, lifts and other mechanical devices, had become highly relevant. Thus, the introduction of "study of machines" in the study program would be a way of adapting to changes in the industry.

Further expansions and modifications were made in the study program. From 1897, the study program and exam system was divided into two sections. The first exam included an oral exam of mathematics, mechanics, physics, chemistry and mineralogy (with crystallography). Subsequently, the

[925] *Tidsskrift for kemi og bergvæsen* (Oslo, 1932), p. 132
[926] *Universitets- og skoleannaler* (Kristiania, 1866), p. 339
[927] *Tidsskrift for kemi og bergvæsen* (Oslo, 1932), p. 132
[928] *Det Kongelige Norske Frederiks Universitets Aarsberetning 1872* (Christiania, 1872), p. 149
[929] *Det Kongelige Norske Frederiks Universitets Aarsberetning 1872* (Christiania, 1872), p. 149
[930] *Det Kongelige Norske Frederiks Universitets Aarsberetning 1889-90* (Christiania, 1890), pp. 54-55
[931] *Det Kongelige Norske Frederiks Universitets Aarsberetning 1874* (Christiania, 1874), p. 34

students attended a course in qualitative and quantitative analysis and ore analyses, before being submitted to an exam in drawing. The exam included two exercises related to some of the following subjects: elements of descriptive geometry with practical exercises; construction of machine parts; measurement of a machine; simple timber connections used to make mining constructions; or elements of surveying.[932] In 1910, one of the exercises was as follows:

> "Give a brief overview of rock drilling machines by their operating equipment that is used with the indication of their benefits and shortcomings. Make thereafter a more detailed description of the different types of the compressed air machines (with sketches)."[933]

Before taking the second exam, the students were obliged to do a practice at a mining company for at least four months, whereof at least four weeks at a mine, two weeks at an ore dressing plant and at least four weeks at a smelting plant. The students made a report after the practice, including their work and practical tasks at mines, ore dressing and smelting plants.[934] At Kongsberg Silver Works, the students had access to all facilities and participated in operations "insofar as it [could] be done without inconvenience..." The functionaries were requested to assist the trainees in their practical assignments. The ore analyst was to teach the students in ore analyses, and he was provided "an appropriate remuneration by the government" for this work.[935] After the practice, the students were tested in their "practical capability" and carried out a technical exercise in mining, ore dressing or smelting and were requested to draw a map of a mine.[936] The second exam included an oral exam in geology and petrography, mining, metallurgy and technology, i.e. the branches of the chemical and

[932] "Reglement for bergeksamen" (Approbert ved kronprosegentens resol. Av 7de mai 1894, jfr. Kgl. Resol. Av 9de mars 1909), Privatarkiv nr. Tek 4, *Johan Herman Lie Vogt*, Eske 25
[933] My translation, *Universitets- og skoleannaler* (Kristiania, 1910), Pp. 116-17
[934] "Reglement for bergeksamen" (Approbert ved kronprosegentens resol. Av 7de mai 1894, jfr. Kgl. Resol. Av 9de mars 1909), Privatarkiv nr. Tek 4, *Johan Herman Lie Vogt*, Eske 25
[935] "Reglement for bergeksamen" (Approbert ved kronprosegentens resol. Av 7de mai 1894, jfr. Kgl. Resol. Av 9de mars 1909), Privatarkiv nr. Tek 4, *Johan Herman Lie Vogt*, Eske 25
[936] "Reglement for bergeksamen" (Approbert ved kronprosegentens resol. Av 7de mai 1894, jfr. Kgl. Resol. Av 9de mars 1909), Privatarkiv nr. Tek 4, *Johan Herman Lie Vogt*, Eske 25

mechanical technology that was closely connected to mining.[937] Additionally, the students were submitted to two written exams in the subject of machinery.[938] With these changes, there was a clear separation of the examination of natural sciences on one hand and specific mining subjects and practice on the other.

New subjects related to electricity were added to the curriculum. In 1909, electro-engineering was added as a separate course.[939] The lectures in this course covered mainly electricity, magnetism, primary and secondary elements, lamps, measuring devices, “machines and plants for direct and alternating current”, transformers and power transmission. Exercises in laboratory were also a part of the course, and consisted of linking machine parts and practicing the functions of machines and devices. Excursions were made to Christiania Power Station and the Kykkelsrud Plant.[940] Electrometallurgy was taught for the first time at the University in 1913.[941] The adoption of these subjects occurred right after electricity had become an important source of power in the mining sector. The mining engineering program was, thus, once again adapted to technological changes that were happening at the time.

10.1.3 Kongsberg Silver Works Elementary Mining School

In 1861, mining superintendent Holmsen recommended the establishment of an intermediate mining school with the aim of providing theoretic as well as practical instruction. The objective was primarily to provide training to workers from Kongsberg Silver Works, but also workers from other mining companies.[942] The Ministry of Finance agreed to open a public Mining School and Kongsberg Silver

[937] “Reglement for bergeksamen” (Approbert ved kronprosegentens resol. Av 7de mai 1894, jfr. Kgl. Resol. Av 9de mars 1909), Privatarkiv nr. Tek 4, *Johan Herman Lie Vogt*, Eske 25
[938] “Reglement for bergeksamen” (Approbert ved kronprosegentens resol. Av 7de mai 1894, jfr. Kgl. Resol. Av 9de mars 1909), Privatarkiv nr. Tek 4, *Johan Herman Lie Vogt*, Eske 25
[939] *Tidsskrift for kemi og bergvæsen* (Oslo, 1932), p. 134
[940] *Universitets- og skoleannaler* (Kristiania, 1911), pp. 92-93
[941] *Tidsskrift for kemi og bergvæsen* (Oslo, 1932), p. 134
[942] Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966), p. 8

Works Elementary Mining School was established in 1867, financed by the state.[943] The students had to be at least 18 years old and should have done at least one year practice at a mine or metallurgical plant before being admitted.[944] From 1870, it was required to do an admission test including writing and calculation.[945]

Practically-oriented study program

The study program was set to two years, two and half years from 1870, and the students were to work at the mining plants in Kongsberg during working hours.[946] The theoretic instruction was set to five to six hours Friday and Saturday and included the following courses: mathematics, accounting, mechanics and physics (including thermodynamics), mineralogy and geology (including the most common ores and rocks as well as the most common ores in Norway), drawing of machinery and constructions and practical assignments in ore surveying.[947] The short theoretical instruction in classrooms, practical exercises and continuous work at Kongsberg Silver Works suggest that the education was far more practically oriented than the mining engineering study at the University. As lectures were given only two days a week, there was probably only time to go through basic principles of the scientific disciplines. At the end of the program, the students were required to pass a written exam in mathematics and an oral exam in arithmetic, geology, mechanics and "study of rocks and mountains."[948]

Modifications of the study program

The theoretic instruction increased gradually. After a couple of years, the lectures increased to nine-twelve hours per week.[949] In 1899, the lectures increased even more and totalled 1560 hours.[950] The

[943] Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966), p. 9
[944] Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966), p. 10
[945] *Tidsskrift for kemi og bergvæsen* (Oslo, 1935), pp. 154-155
[946] Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966), pp. 10-11 and 14
[947] Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966), pp. 10-11
[948] Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966), p. 13
[949] Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966), p. 14
[950] Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966), p. 19

study plan included 428 hours of calculation and mathematics, sixty hours of mechanics, forty-four hours of physics, ninety hours of mining construction, fourty-eight hours of geology, 154 hours of Norwegian, 348 hours of drawing, 111 hours of mine surveying (with exercises) and 277 hours of measuring of ore (with exercises).[951] A course in mining construction was added after a couple of years.[952] In 1904, further changes were made in the study plan. Chemistry and metallurgy were introduced as new courses and the course in drawing was divided in two: machine study w/ drawing and construction w/ drawing. Moreover, the teaching hours of machine study, mining and mechanics increased.[953] The expansion of the program and increased focus on theoretic subjects reflected the increased complexity of mining operations and specialisations within the industry.

Reopening the Mining School

The Mining School was closed down temporarily in 1921.[954] It is not clear why teaching stopped. The industry, however, expressed its wish to reopen the school again. In 1930, a discussion was raised in relation to the argument that the country still needed mining technicians and foremen with theoretical training. Before the Mining School opened again in 1936, the debate was taken to the Parliament. The established Committee underlined that foremen had large responsibilities and there was a need to arrange the instruction so that the practical and theoretic instruction could go “hand in hand”.[955] It appears to have been no great resistance against this argument. However, there was a disagreement with regard to location. Some wanted to open a new school in Trondheim, near the central mining district. It was argued that Kongsberg Silver Works did not represent the great majority of mining companies, since the mining sector to a large degree was based on the extraction of pyrite, iron and copper. Fourteen mining companies wrote a letter to the Ministry in 1935 and

[951] Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966), p. 19
[952] Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966), p. 14
[953] Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966), pp. 21-24
[954] *Tidsskrift for kemi og bergvæsen* (Oslo, 1935), pp. 154-155
[955] Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966), p. 30

suggested to move the school to Trondheim.[956] However, the companies' wishes were not heard and in 1936, the Mining School once again opened at Kongsberg.[957]

With the reopening of the School, the admission requirements increased significantly. From 1936 a diploma from a technical school, or a preparatory course, was required to be admitted. Moreover, four years practice was necessary, instead of four months as earlier.[958] The instruction was divided, as before, into theoretic teaching and practical work at Kongsberg Silver Works. Every week the students studied three days in classrooms before working three days at the mines. The courses involved practical calculation, mathematics, mechanics, physics, drawing, chemistry, geology, machine study, mining, Norwegian and English.[959] In accordance with technological changes in the concentration and processing of ore from the turn of the century new courses in electrical engineering, ore dressing, construction and civil engineering, mining and ore surveying and the study of company and work were added to the program.[960]

10.1.4 The Norwegian Institute of Technology (NIT)

During the second part of the nineteenth century, representatives from industrial societies expressed the need for a higher technical education institution in Norway. The argument was that new large-scale industries were emerging and the size of companies increased with more employees. With this transformation, the country was in need of a technical institution, which could provide capable engineers and keep up with industrial development.[961] In 1900, the government approved a higher technical institute and the Norwegian Institute of Technology (NIT) opened in Trondheim in 1910. The

956 *Tidsskrift for kemi og bergvæsen* (Oslo, 1935), p. 154-55
957 *Tidsskrift for kemi og bergvæsen* (Oslo, 1935), pp. 154-55
958 *Tidsskrift for kemi og bergvæsen* (Oslo, 1935), pp. 156-57; Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966), p. 28
959 Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966), p. 42
960 Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966), p. 42
961 E. Benum, "Dannelse", "Tillid" og "Autoritet", in *Makt og Motiv Et festskrift til Jens Arup Seip*, J. A. Seip and O. Dahl (Oslo, 1975), p. 132

NIT provided formal education at the same level as the University and was much based on the German higher technical educational system.[962] The historian Edgeir Benum emphasises four requirements, which contrasted the institution from the existing technical schools. First of all, theory was to be given more space because it was a way of accumulating technical knowledge. Second, the education was to be divided into technical departments with different specialisations. Third, the study programs were to be longer than the ones at the technical schools and the requirements for students to enter the study programs were to be the same as for the University. Finally, the teachers should be appointed as professors to attract technical expertise and to give the institution international prestige.[963]

A committee was established in 1908 to discuss whether the mining engineering program should be moved to the NIT or remain at the University of Oslo. The Committee quickly came to a conclusion, and recommended that it be moved, since, they argued, the technical courses, such as machine study and construction studies, electro engineering and surveying were not very well developed at the University. The Committee's recommendation was followed, and mining education transferred to Trondheim in 1914.[964] The instruction at the Mining Division aimed to give the students "…the theoretical knowledge foundation and the practical skills which were, according to modern demands, necessary to fill the different positions and solve the different tasks in mining."[965] In addition to mining engineering the NIT offered study programs in architecture, electrical engineering, mechanical engineering, construction engineering and shipbuilding.

[962] T. J. Hanisch and E. Lange, *Vitenskap for industrien NTH – En høyskole i utvikling gjennom 75 år* (Oslo, 1985), p. 23
[963] E. Benum, "Dannelse", "Tillid" og "Autoritet", in *Makt og Motiv Et festskrift til Jens Arup Seip*, J. A. Seip and O. Dahl (Oslo, 1975), pp. 130-131
[964] My translation: Norges Tekniske Høiskole, *Beretning om virksomheten 1910-1920* (Trondhjem, 1920), p. 56
[965] My translation: Norges Tekniske Høiskole, *Beretning om virksomheten 1910-1920* (Trondhjem, 1920), p. 56

Continuing courses and teaching forms from the University

The new mining study program at the NIT maintained many of the same courses as the University and the instruction followed in general terms the same patterns with lectures, laboratory work, excursions and working practice. Courses in mathematics, geometry, mechanics, physics, chemistry, geology, mining operation, mineralogy and metallurgy were included in the program as before.

From the course descriptions that were published by the NIT, it is possible to gain insight into the subjects that were being taught. The course in mathematics included subjects such as graphic drawing of curves, geometry, integral drawing, area calculation, calculation of arc lengths and volume calculations etc.[966] Descriptive geometry included drawing of curves, control surfaces and other rotating objects etc.[967] Mineralogy and surveying were subjects which were directed towards geological mapping and ore surveying. The course in mineralogy covered crystallography, mineralogy and special ore minerals. The course in surveying included levelling, surveying, mapping and the use of surveying instruments.[968] Moreover, mineralogy and geology courses focused on crystallography and minerals, notably important Norwegian rock types.[969] The geological collection that had been used at the University was expanded and moved to the NIT. This collection was used directly in the teaching of these courses. It included minerals from many countries and was characterised as “one of the best in the world”.[970]

From 1914 petrography and rock microscopy were added as separate courses.[971] The courses in mechanical engineering included subjects of statics of solid bodies, doctrines of movements, friction, shock, hydrostatics, elements of building statics, dynamics, strength of materials etc.[972] A number of

[966] Den tekniske høiskole i Trondhjem, *Program for studieåret 1911-1912* (Trondhjem, 1912), p. 26
[967] Den tekniske høiskole i Trondhjem, *Program for studieåret 1911-1912* (Trondhjem, 1912), p. 27
[968] Den tekniske høiskole i Trondhjem, *Program for studieåret 1911-1912* (Trondhjem, 1912), pp. 27 and 34
[969] Den tekniske høiskole i Trondhjem, *Program for studieåret 1911-1912* (Trondhjem, 1912), p. 29
[970] *Tidsskrift for kemi og bergvæsen* (Oslo, 1935), p. 98
[971] Den tekniske høiskole i Trondhjem, *Program for studieåret 1911-1912* (Trondhjem, 1912), p. 22
[972] Den tekniske høiskole i Trondhjem, *Program for studieåret 1911-1912* (Trondhjem, 1912), p. 27

themes were covered in the physics course. Main subjects were devices and methods of measurement, calorimetry, theories of heat, mechanical and thermal properties of bodies, melting and freezing, heat conduction, wave motion, electrostatics, magnetism, electrolysis, electricity, optical instruments and metering.[973]

In metallurgy the students were taught methods of extraction (including ore dressing and smelting) and refining (for instance rolling, forging and pressing) of metals.[974] Professor Johan Herman Lie Vogt's lecture notes in metallurgy include detailed descriptions of furnaces, their functions, production, heat consumption, heat loss, efficiency, benefits, disadvantages etc. Vogt also had lectures about the characteristics of different minerals, such as nickel, copper, iron etc.[975]

In the mining operation course lectures covered subjects related to mining operations, such as magnetic and electric surveying, deep drilling, working methods, refraction of ore, blasting, drilling machines, timber and concrete, automatic transport, wagons and locomotives, lifts, pumps for drainage, centrifugal pumps, "natural and artificial ventilation", lightening, fires and other themes. In addition to these subjects topics related to administration, such as "technical and economic results", statistics and the valuation of mines was also included in the course (see table below):[976]

The Mining engineering program at the NIT in 1911

1st and 2nd years								
Subjects	1st semester		2nd semester		3rd semester		4th semester	
	Lectures	Exercises	Lectures	Exercises	Lectures	Exercises	Lectures	Exercises
Mathematics I	4	3	4	3				
Descriptive geometry	2	5						
Mechanical engineering I	3	3	3	3				
Mechanical engineering II					3	3	3	3
Physics	4		4					

[973] Den tekniske høiskole i Trondhjem *Program for studieåret 1911-1912* (Trondhjem, 1912), p. 28
[974] A. K. Børresen and A. Wale (red.), *Vitenskap og teknologi for samfunnet? Bergfagene som kunnskapsfelt* (Trondheim, 2005), p. 10
[975] Privatarkiv nr. Tek 4, *Johan Herman Lie Vogt*, Eske 32
[976] Den tekniske høiskole i Trondhjem *Program for studieåret 1919-1920* (Trondhjem, 1920), p. 28

Exercises in the physical laboratory						3*		
Inorganic chemistry	4		4					
Mineralogy and geology	2	1	2	1				
Mineralogy					2	2	2	2
Basic features of machine building	2	6	2	3				
Machine parts					4	6		
Simple lifting- and movement devices							2	
Mechanical technology							4	
House construction I					2		2	4
Physical chemistry with electrochemistry					2		2	
Social economics and law							3	
Qualitative analysis	2**)							
Quantitative analysis			1					
Surveying					3	3	3	3
Total hours	**23**	**18**	**20**	**10**	**13**	**17**	**18**	**12**
	41		**30**		**30**		**30**	
3rd and 4th years								
Subjects	5th semester		6th semester		7th semester		8th semester	
	Lectures	Exercises	Lectures	Exercises	Lectures	Exercises	Lectures	Exercises
Mining (with ore dressing, surveying, magnotometry, mining law etc.)	4	4	4	6	4	10	4	8
Geology and mineral ores	3	4	3	4	3	4	3	4
Metallurgy with chemical and metallurgical exercises	4	6	4	6	4	2	4	2
Mechanical technology	2		2					
Chemical technology					2		2	
The most important power engines	3	2	3	2				
Mechanical laboratory								

*) Electricity and magnetism
**) Additional exercises in the chemical laboratory
***) Temporarily only for the current year
Admission to the 3rd year requires at least one month stay at a mine, and for admission to the final exam a 4 month stay at a mine is required (herein the above month included). Of these 4 months 2 months must include participation in practical work and at least one month stay at a mine, at least 3 weeks at a crushing plant and at least 3 weeks at a smelting plant.
Source: Den Tekniske Høiskole I Trondhjem, Program for Studieåret 1919-1920, Trondhjem: A/S Centraltrykkeriet Ellewsen & Co., pp. 14-15

Almost all the courses included both lectures and exercises.[977] Different topics in mathematics, for instance, were to be "…practiced by [doing] numerous calculations."[978] In machine building, the

[977] Norges Tekniske Høiskole, *Beretning om virksomheten 1910-1920* (Trondhjem, 1920), pp. 54-55
[978] Den tekniske høiskole i Trondhjem, *Program for studieåret 1911-1912* (Trondhjem, 1912), p. 26

practical exercises included simple sketches, drawings and models and working drawings.[979] Laboratory work was part of the training in some of the courses, such as physics and chemistry. Exercises in the physical laboratory covered a number of measurement methods, experimental verification of physical laws and determination of physical constants.[980] Hours in the laboratory and practical exercises increased from the third year, and the students were gradually required to do assignments that were more practical. In addition to laboratory tasks and other practical exercises inquiries from mining companies with information about working processes, profits, costs, economic performances etc. were used in seminars as practical exercises.[981]

Excursions to mining companies and ore fields continued to bean important part of the practical instruction. As always, part of the instruction in surveying was given "in the field."[982] It was common for the students to go on a number of excursions during their studies, as was the case at the University.[983] The petrography course included a week's excursion to the Christiania Graben.[984] Some of the other courses also organised excursions or visits. For instance, house construction included, in addition to lectures, visits to construction sites, workshops and factories.[985] Sometimes professors and students even went on trips to Sweden. For instance, in June 1930 Professor Thorolf Vogt and mining engineer Magne Mortensen led an excursion to mines and plants at Persberg, Långban, Grängesberg and Falun. The students analysed the geological conditions on the surface and inside the mines and observed how refraction methods, ore dressing plants and machinery at the mining plants were used. During the same trip, they visited the Technical College in Stockholm, the mineralogical department at the National Museum, the Swedish Geological Survey and Sweden's biggest iron works

[979] Den tekniske høiskole i Trondhjem, *Program for studieåret 1912-1913* (Trondhjem, 1913), p. 42
[980] Den tekniske høiskole i Trondhjem, *Program for studieåret 1911-1912* (Trondhjem, 1912), p. 28
[981] *Tidsskrift for kemi og bergvæsen* (Oslo, 1937), p. 158
[982] Den tekniske høiskole i Trondhjem, *Program for studieåret 1911-1912* (Trondhjem, 1912), p. 27
[983] Norges Tekniske Høiskole, *Beretning om virksomheten 1910-1920* (Trondhjem, 1920), p. 58
[984] Den tekniske høiskole i Trondhjem, *Program for studieåret 1914-1915* (Trondhjem, 1915), p. 22
[985] Den tekniske høiskole i Trondhjem, *Program for studieåret 1912-1913* (Trondhjem, 1913), p. 27

at Domnarvet where they were shown how different smelting techniques worked in practice.[986]

Before the third year the students should do at least one month practice at a mining company. To do the final exam a total of at least four months at a mining company was required.[987] From 1930, the total number of months practice increased. From this time, it was necessary for the students to have done a practice of at least nine months to be admitted to the mining engineering program, whereof six months at a workshop and the rest at a mining works. This working practice came in addition to the practice at the end of the study.[988]

New courses in mechanical and construction engineering

The transfer of the mining engineering program to Trondheim permitted an increased focus on courses related to mining machinery and mine constructions (see table below):

New courses in machinery and construction in Norway (simple overview)

	1870	1880	1890	1900	1910	1920	1930	1940
Machine and construction:								
Machine study	-------	-------	-------	-------	-------	-------	-------	-------
Electro-engineering					-------	-------	-------	-------
Machine parts					-------	-------	-------	-------
Power engines					-------		-------	-------
House construction					-------	-------	-------	-------
Water construction						-------	-------	
Construction engineering							-------	-------
Mining machines								-------

By the time the mining engineering program was transferred to the NIT, most mining companies had numerous mechanical equipment and machinery, each of them constructed and operated differently. Technical constructions, such as water constructions, houses, transport plants and divisions for ore dressing and extraction etc. were common at the mining plants.[989] These changes in technology made

[986] Den tekniske høiskole i Trondhjem, *Program for studieåret 1929-1930* (Trondhjem, 1930), p. 44
[987] Norges Tekniske Høiskole, *Beretning om virksomheten 1910-1920* (Trondhjem, 1920), pp. 54-55
[988] Den tekniske høiskole i Trondhjem, *Program for studieåret 1930-1931* (Trondhjem, 1931), p. 9
[989] Norges Tekniske Høiskole, *Beretning om virksomheten 1910-1920* (Trondhjem, 1920), p. 56

new subjects in machinery, engines, machine parts etc. very relevant and useful for the industry.

The courses which included themes about machines and engines were divided in four parts (see table of courses in last section). Basic features of machine building included lectures about machine drawing, basic theories for construction and simple machine parts.[990] The machine part course included subjects such as wheels, belts, trains, gears, chain drives, links, cylinders, pipes, roads etc.[991] The house construction course included lectures about the quality designations of house building materials, dimensions and applications, drawing of house building constructions etc.[992] A course about power engines was formed in 1930 and included an overview of power engines, such as water power engines, steam boilers, heating furnaces and others.[993] In addition, two construction courses, construction engineering and steel and timber constructions were added to the program in 1939.[994]

Dividing the program

From 1931, the mining education was divided in two, one specialising in mining and one in metallurgy. The two programs included many of the same courses, but with slightly different specialisations. The specialisation in mining emphasised surveys and ore dressing and the specialisation in metallurgy included more courses in chemistry and metallurgy.[995] However, this new emphasis on chemistry and metallurgy happened long after the electro-metallurgical industry emerged. On the other hand, some specialised courses in chemistry were added earlier, in 1910, such as inorganic chemistry, which included lectures about chemical elements and their compounds, physical chemistry, electrochemistry and mechanical technology.[996]

990 Den tekniske høiskole i Trondhjem, *Program for studieåret 1912-1913* (Trondhjem, 1913), p. 42
991 Den tekniske høiskole i Trondhjem, *Program for studieåret 1912-1913* (Trondhjem, 1913), p. 43
992 Den tekniske høiskole i Trondhjem, *Program for studieåret 1912-1913* (Trondhjem, 1913), p. 27
993 Den tekniske høiskole i Trondhjem, *Program for studieåret 1939-1940* (Trondhjem, 1940), p. 58
994 Den tekniske høiskole i Trondhjem, *Program for studieåret 1939-1940* (Trondhjem, 1940), pp. 63-64
995 Den tekniske høiskole i Trondhjem, *Program for studieåret 1931-1932* (Trondhjem, 1932), pp. 61-62
996 Den tekniske høiskole i Trondhjem, *Program for studieåret 1912-1913* (Trondhjem, 1913), pp. 25 and 41-43

The reason for this late division of the program was that graduates in chemistry were given the responsibility for the metallurgical industry.[997] The electro-metallurgical industry required specialised knowledge in both chemistry and electricity. It was seen, then, as the electro-technical division's responsibility to educate leaders to the electro-metallurgical companies.[998]

Instruction of administration and economics

New courses in administration and economics were also added to the program. During the third and fourth years, the students had to take courses in social economy and law and bookkeeping.[999] The course social economy and law included topics about theoretic and practical working methods, production and its conditions, the relation between capital, work and nature, increase in value, capital interest, wages and others.[1000] A separate course for bookkeeping was introduced in 1913[1001] (see table below):

New economic and administrative courses in Norway (simple overview)

	1870	1880	1890	1900	1910	1920	1930	1940
Econ. and adm.:								
Economics and law					-------	----------	----------	----------
Bookkeeping					-----	----------	----------	----------
Finance						-------	----------	----------
Statistics							-------	----------

Large-scale companies, such as Elektrokemisk and Orkla Mining Company, employed several hundred workers and were divided into numerous departments. These large companies required new insight in administration, management, long term economic planning and business and explains the new courses in economy and administration.

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997 J. T. Kobberrød, "konjunkturer, kompetanse og konflikt" i *Vitenskap og teknologi for samfunnet? Bergfagene som kunnskapsfelt,* A. K. Børresen and A. Wale (red.) (Trondheim, 2005), p. 127

998 A. K. Børresen, *Bergtatt: Johan H. L. Vogt – professor, rådgiver og familiemann.* (Trondheim, 2011), p. 273

999 Norges Tekniske Høiskole, *Beretning om virksomheten 1910-1920* (Trondhjem, 1920), pp. 54-55

1000 Den tekniske høiskole i Trondhjem, *Program for studieåret 1919-1920* (Trondhjem, 1920), p. 23

1001 Den tekniske høiskole i Trondhjem, *Program for studieåret 1913-1914* (Trondhjem, 1914), pp. 34-35

Increased equipment for teaching

There was a general agreement that the transfer of the mining study program to the NIT was a good thing. Nevertheless, although the transferring of the program was to provide a more stimulating technical environment teaching facilities were lacking. The original plan was to construct a building for mining laboratories, material for excursions and practical exercises. However, this did not happen due to lack of finances.[1002] Although a small smelting plant was built, the institution lacked both an ore dressing laboratory and metallurgical laboratory.[1003] Several engineers and professors claimed that the teaching of ore dressing was precarious. The mining engineer Lars Krogh argued that the lack of facilities, and the lack of experience with mining equipment, was felt "…when entering practical activity."[1004] In the Mining Journal, it was claimed that the most important course, mining, was taught with the use of charts and drawings due to the lack of mining equipment.[1005]

Some efforts were made to improve the instruction facilities. Harald Pedersen explained that professors Getz, Johan Vogt and himself organised the research work and gradually obtained new equipment to be used in the laboratories. The ore dressing equipment and tools in the metallurgical laboratory were gradually upgraded and further developed, thanks to government funding and assistance from Hjalmar Batt, the director of industry at the Department of Commerce.[1006] The ore dressing laboratory was installed in a smaller building at the NIT, and the metallurgical laboratory, Pedersen's personal one, was in a facility in the outskirts of Trondheim. It soon appeared to be impractical to separate these two laboratories, and so microscopic equipment, workshops and a

[1002] *Tidsskrift for kemi og bergvæsen* (Oslo, 1935), p. 98
[1003] *Tidsskrift for kemi og bergvæsen* (Oslo, 1935), p. 98
[1004] G. Brochmann (red.), *Vi fra NTH de første 10 kull: 1910-1919* (Stavanger, 1934), p. 295
[1005] *Tidsskrift for kemi og bergvæsen* (Oslo, 1935), p. 98
[1006] H. Pedersen, "Samarbeidet mellem teknisk-videnskapelig forskning og industrien", foredrag i Polyteknisk Forening den 29. oktober 1929, *Teknisk Ukeblad* (Oslo, 2nd January, 1930), pp. 4-5

variety of other equipment were later transferred to the metallurgical laboratory.[1007] The mining and chemical engineering students received their laboratory practice at Pedersen's private laboratory until 1943.[1008] Pedersen claimed that the laboratory was "satisfactory" and argued that American and Swedish professionals had found it as "very decent."[1009] According to the Mining Journal, the NIT managed a "suitable laboratory" for ore dressing and the flotation equipment was especially praised.[1010]

10.1.5 Studying abroad

Norwegian engineers and workers have long traditions of studying abroad. Rolf Falc-Muus refers to a number of miners who went to the Falu Mining School in Sweden in the beginning of the nineteenth century. Røros Copper Works funded the education of some of these workers. They often studied in Sweden a couple of years before returning to Norway to work.[1011] This trend continued. Many mining engineers went to foreign institutions to continue formal studies and to acquire further specialisations in different subjects. The other option was to only study abroad. There was a steady flow of mining engineers going to other countries to study.

There seem to always have been at least a couple of Norwegian mining students abroad (see appendix 11 for mining engineer graduates). 118 of the 341 Norwegian mining engineers (34, 6 per cent) who graduated between 1787 and 1940 studied in another country. Eighty-three of these engineers studied partly in Norway and partly in another country, while thirty-five went abroad to study directly after high school. The mining engineers followed the general trend of Norwegian

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1007 H. Pedersen, "Samarbeidet mellem teknisk-videnskapelig forskning og industrien", foredrag i Polyteknisk Forening den 29. oktober 1929, *Teknisk Ukeblad* (Oslo, 2nd January, 1930), pp. 4-5

1008 A. K. Børresen, *Bergtatt: Johan H. L. Vogt – professor, rådgiver og familiemann.* (Trondheim, 2011), pp. 289-290

1009 H. Pedersen, "Samarbeidet mellem teknisk-videnskapelig forskning og industrien", foredrag i Polyteknisk Forening den 29. oktober 1929, *Teknisk Ukeblad* (Oslo, 2nd January, 1930), pp. 4-5

1010 *Tidsskrift for kemi og bergvæsen* (Oslo, 1935), p. 98

1011 R. Falck-Muus, *Bergmannsutdannelsen i gamle dager, norske bergmenn til Sverige som ledd i utdannelsen* (Oslo, 1949), pp. 114-129 engineers of the time. Before the Norwegian Institute of Technology (NIT) was established in 1910 the only option for Norwegians to acquire higher technical training, except mining engineering, was abroad. In the 1870s, there were around forty-fifty Norwegian students at technical schools on the Continent, mostly in Germany.[1012] At the turn of the century, there were more than 200 Norwegian students at German technical schools.[1013]

Mining engineers went to different countries. There was a steady flow to Germany and eighty-seven mining engineers studied there. Forty-eight studied at Freiberg Mining Academy, which was the foreign institution where most engineers studied. The *Technische Hoschules* in Charlottenburg (Berlin), München, Dresden, Aachen, Breslau, Freiberg, Hannover, Darmstadt and Karlsruhe were also popular institutions. Other European institutions were Zurich Technical University, University of Neuchatel, University of Strasbourg, University College in London, Durham University and University of Liège. Ten mining engineers studied in the United States, notably at Columbia University, Harvard University, University of Wisconsin and University of Pittsburgh. Furthermore, fourteen studied in Sweden, seven in England, seven in France, three in Switzerland and two in Austria.[1014] These were all countries with long traditions with mining.

[1012] G. Stang, "Ble det for mange ingeniører?" in *Trondheim Ingeniørhøgskole 1912-1987 Festskrift til jubileumsfeiringen 31. oktober 1987* (Trondheim, 1987), p. 34

[1013] T. Brandt and O. Nordal, *Turbulens og Tankekraft Historien om NTNU* (Oslo, 2010), p. 90

[1014] O. Alstad (red.) *Trondhjemsteknikernes Matrikel Biologiske meddelelser om samtlige faste og hospiterende elever av Trondhjems Tekniske Læreanstalt 1870-1915*, (Trondhjem, 1916); *Artiummatrikler studentene* [student yearbooks] (Kristiania/Oslo, 1855-1940); H. O. Christiansen et al. *25-års jubileumsberetning 1912-1937 Bergen Tekniske Skole Oslo Tekniske Skole Trondheim Tekniske Skole* (Norway, 1937); *Festskrift i anledning af Kristiania Tekniske Skoles 25 aars jubilæum* (Kristiania, 1898); R. Baggethun, *Horten Ingeniørhøgskole Horten tekniske skole En beretning om landets eldste tekniske skole gjennom 125 år* (Horten, 1980); S. Heier, *100 års biografisk Jubileums-festskrift, Horten Tekniske Skole 1855-1955* (Horten, 1955); KTS, *50 årsberetning om ingeniørkullet fra Kristiania Tekniske Skole 1896* (Oslo, 1946); Kristiania tekniske skole, *Ingeniørene fra KTS 1897-1947* (Oslo, 1947); *Ingeniører fra Kr.a Tekniske Skole 1897* (Kristiania, 1922); *K.T.S. ingeniørene av 1909: matrikkel utarbeidet til 25-års jubileet 1934* (Oslo, 1934); Oslo Tekniske Skole, *Skrift ved 50 års jubileet for ingeniørene fra K.T.S. 1894,* (Oslo, 1894), *KTS til Ingeniørkullet av 1910: 20 årsjubileum år 1910-1930* (Oslo, 1930); *Trondhjems Tekniske Mellomskoles virksomhet i de 3 første læseaar 1912-1915* (Trondhjem, 1916); *Skrift ved 50 års jubileet for ingeniørene fra K.T.S. 1894* (Oslo, 1944); L. Eskedal, *BTS-matrikkelen Ingeniører uteksaminert ved Bergen Tekniske Skole 1875-1975* (Bergen, 1975); TTL, *1897-1922* (Kristiania, 1922); Trondhjem tekniske læreanstalt, *Festskrift ved Afslutningen av Trondhjems Tekniske Læreanstalts 25de Læseaar* (Trondhjem, 1895); B. Bassøe, *Ingeniørmatrikkelen Norske Sivilingeniører 1901-55 med tillegg* (Oslo, 1961)

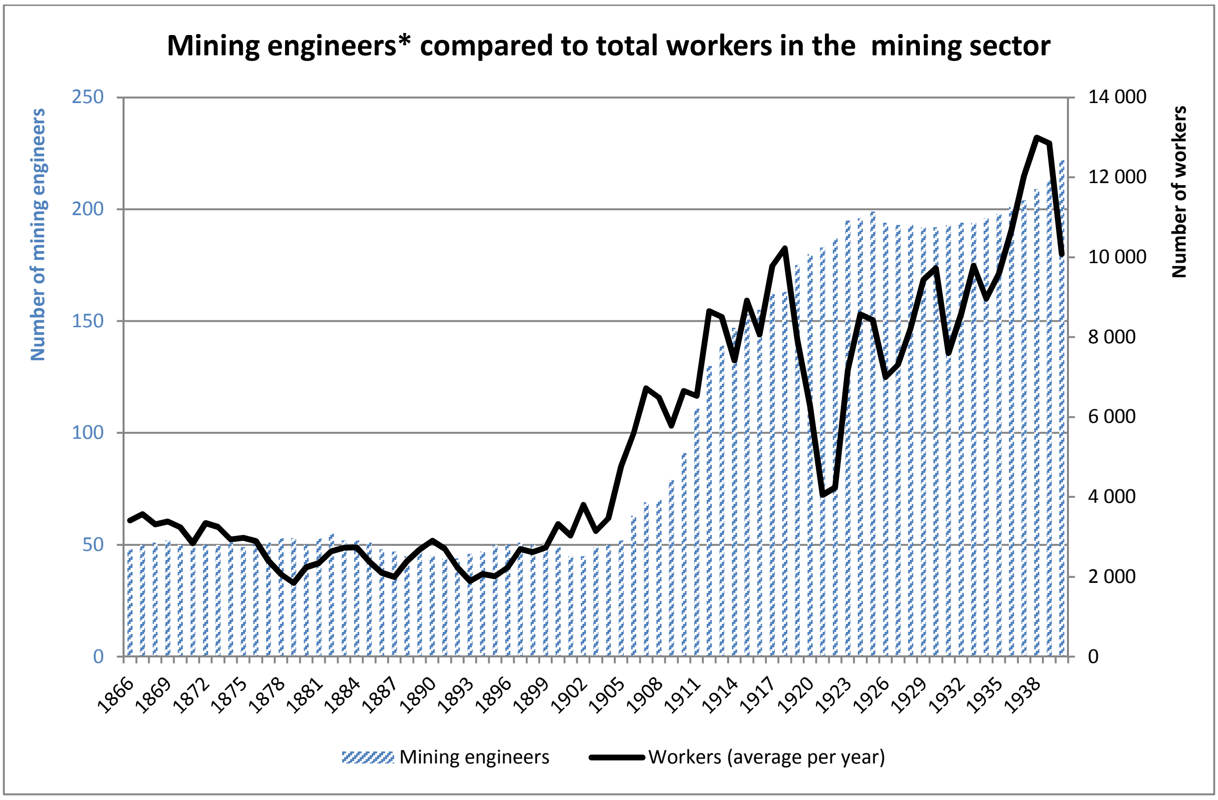
Studying abroad had two main functions. First of all, it meant that students were able to specialise in subjects or disciplines which had not been developed in Norway. Second, the students acquired valuable contacts and worked in an international scientific environment, sometimes with distinguished professors. Emilius Knutsen Looft, for instance, worked as an assistant for a professor in Wiesbaden before he became a mining engineer in 1889. Thereafter he went to Leipzig to study chemistry.[1015] Some of the engineers studied at two or three different institutions and in more than one country. This enabled students to become acquainted with different teaching traditions. Johan Herman Lie Vogt, for example, a well-known mining engineer and geologist, travelled to many countries and studied at a number of institutions. He went to Dresden after high school and studied two semesters at Dresdener Polytechnikum. In 1877, he went back to Christiania and finished his mining studies at the Royal Frederick University in 1880. In 1882, he went to Stockholm to study “the metallurgy of iron” and “quantitative-chemical analysis” at the Mining School. At the same time, he worked at the Stockholm University College. In 1884, after several excursions in Sweden and Norway, he went to Freiberg in Sachsen where he studied a couple of months at Freiberg Mining Academy. From Freiberg, he went on a number of excursions around Erzgebirge before studying a month at the Mining School in Clausthal and a month at Leipzig University. He travelled to Norway and later back to Stockholm University College and Germany before he studied one and a half months at the Collège de France in Paris.[1016]

10.1.6 Number of mining engineers and technicians

How many mining engineers and technicians graduated from Norwegian and foreign educational institutions? There was a gradual increase of mining engineer graduates in this period (see appendix 11). In the eighteenth century, only a couple of engineers graduated and until 1900 there were many

[1015] *Studentene fra 1884* (Kristiania, 1909), pp. 209-210
[1016] *Studentene fra 1876* (Kristiania, 1901), pp. 66-75

years with no graduates. After the turn of the century, the number of mining engineers increased considerably. Between 1901 and 1940, 224 engineers graduated. 1911 and 1912 represented peak years with nineteen and twenty graduates. Yet, there was a recession period in the 1920s with fewer students and in 1926 and 1927 there were no graduates. In spite of some variations in the number of graduates, the point to be made here is that the number increased drastically from 1905 with mining engineers graduating every year. Thus, hereafter there was almost a constant flow of mining engineers to the sector.



*Estimated career of 40 years
Calculations based on number of mining engineer graduates and the number of workers each year.

Although it is difficult to estimate the exact number of workers in the mining industry per engineer at any given time, due to lack of information about the length of their career, an estimate is still possible to make. There is information about the year the mining engineers graduated, which makes it possible to make an approximation of their career. Given that the mining engineers had an average career length of forty years the development of workers and professional workers would be as outlined in the graph above. The striped column represents the estimated number of mining engineers working in the mining industry at any given time. With this estimate the number of mining engineers and the number of workers correlated roughly during the whole period, except during the recession period around 1920.

Using this estimate the number of mining engineers in the mining sector increased from forty-eight in 1866 to 221 in 1940. The number of workers per mining engineer varied, but remained relatively low from thirty-five to ninety-two. At this point, it is suffice to say that the number of mining engineer graduates seems to have been relatively high.

Workers per mining engineers and technicians in Norway

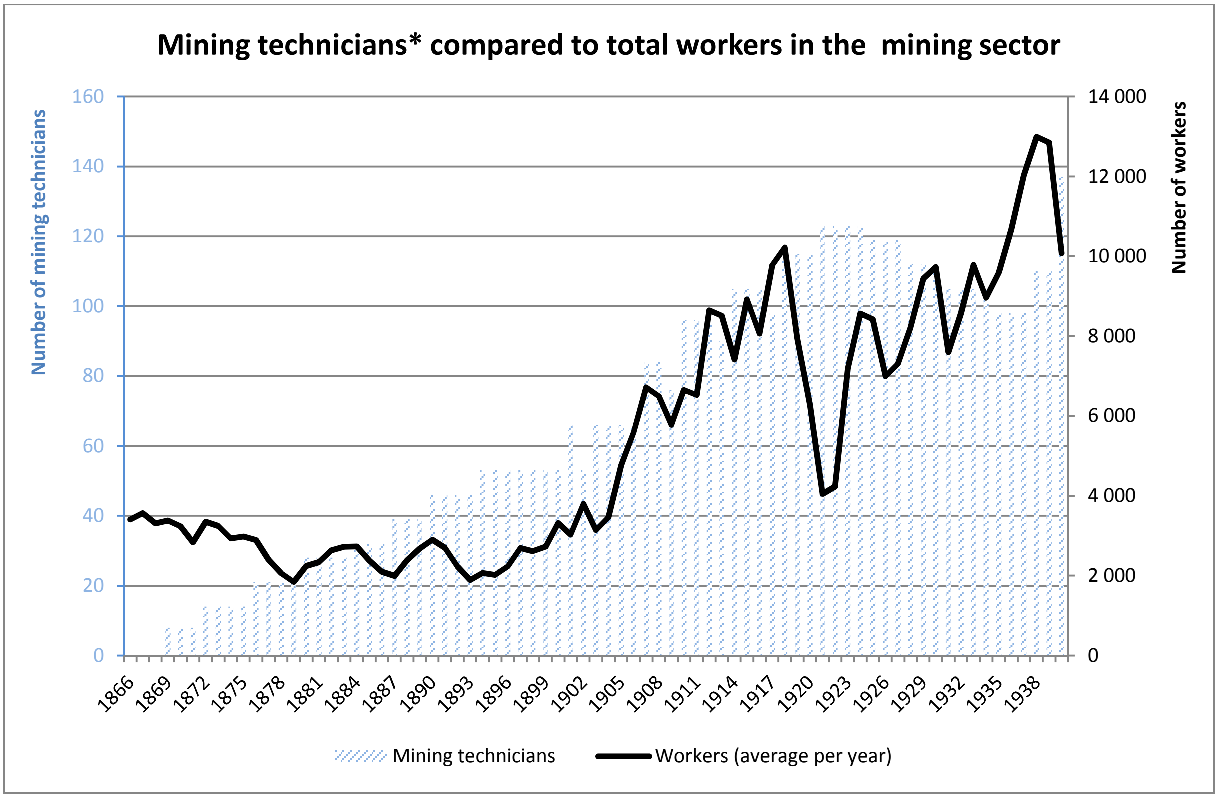
Estimated career of 40 years

Year	Workers	*Estimated number of mining engineers in mining*	***Estimated number of workers per mining engineer***	*Estimated number of mining technicians in mining*	***Estimated number of workers per mining technician***
1866	3408	*48*	**71**	-	**-**
1870	3239	*50*	**65**	*8 (year 1869)*	**405**
1875	2978	*49*	**61**	*14*	**213**
1880	2240	*50*	**45**	*28*	**80**
1885	2383	*51*	**47**	*32*	**74**
1890	2899	*45*	**64**	*46*	**63**
1895	2015	*51*	**40**	*53*	**38**
1900	3319	*49*	**68**	*53*	**63**
1905	4768	*52*	**92**	*66*	**72**
1910	6652	*91*	**73**	*96*	**69**
1915	8917	*152*	**59**	*105*	**85**
1920	6267	*179*	**35**	*115*	**54**
1925	8427	*198*	**43**	*119*	**71**
1930	9727	*191*	**51**	*112*	**87**
1935	9597	*197*	**49**	*98*	**98**
1940	10074	*221*	**46**	*137*	**74**

Calculated on the basis of number of mining engineer graduates and workers.

191 mining technicians graduated from the Kongsberg Silver Works Elementary Mining School between 1869 and 1940. The number of technicians increased gradually from groups of four to eight in the nineteenth century and groups of more than twelve after 1900. There were in total fewer

mining technicians than mining engineers and between 1922 and 1937 there were no mining technician graduates due to a temporary closure of the school. When the Mining School re-established in 1936 the institution could once again graduate mining technicians (see graph below):



*Estimated career of 40 years
Calculations based on number of mining technician graduates and the number of workers each year.

Using the same career length, forty years, there seems to have been an increasing number of mining technicians too. Until the 1890s, there were less than fifty mining technicians, but the number increased to 119 in 1925 and 137 in 1940. With this estimation the number of workers per mining technician decreased from more than 400 in 1870 to less than 100 after the late 1870s (see table above).

10.2 Formal mining instruction in Chile

Traditionally, training in mining was merely practical in Chile. Scientific careers were not well known and the work of mining engineers was carried out by some practitioners "… by pure routine", according to the Polish mining engineer Ignacio Domeyko.[1017] Formal mining education was first established in the 1830s. Domeyko came to Chile on the recommendation of the French mining engineer Charles Lambert in 1837 and was hired by the Government to teach mineralogy at a high school in Coquimbo.[1018]

In 1843, the old Real University of San Felipe from the eighteenth century reopened as the public University of Chile. The Faculty of Mathematics and Physical Science provided education in engineering from early on. Study programs of surveyor/geographical engineering, civil engineering and mining engineering were provided from 1853.[1019] With these programs, the Faculty of Mathematics aimed to have a polytechnic function.[1020] In order to be accepted to the study programs the students were required to pass high school and an exam of geography, cosmography, Spanish grammar, French or English, religion, elemental physics and chemistry, lineal drawing and ornament, history and literature. They also had to do a preparatory course in mathematics.[1021]

A regular arrangement for scholarships did not seem to have been established right away for the engineers. Sometime before 1910, on the recommendation of the Faculty, a permanent system of scholarships was introduced for young people from the province who wished to start a career as mining engineer.[1022] The National Institute of Mining Engineers provided a scholarship from 1935 for students with limited resources for three years.[1023] Two members of the Institute Juan B. Carrasco and John P. Chadwick, Manager of American Smelting Company, decided to establish their own

[1017] I. Domeyko, "Reseña de los trabajos de la Universidad desde 1855 hasta el presente", in *Anales de la Universidad de Chile* (October 1872), p. 19
[1018] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1891), p. 63; I. Domeyko, "Reseña de los trabajos de la Universidad desde 1855 hasta el presente", in *Anales de la Universidad de Chile* (October 1872), pp. 576-577
[1019] *Anales de la Universidad de Chile, 1859* (Santiago,1859), p. 978
[1020] I. Domeyko, "Reseña de los trabajos de la Universidad desde 1855 hasta el presente", in *Anales de la Universidad de Chile* (October 1872), p. 20
[1021] *Anales de la Universidad de Chile* (Santiago,1859), p. 978
[1022] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1910), p. 119
[1023] Instituto de Ingenieros de Minas de Chile, *Memoria presentada a la Junta General de socios*, Cuarta memoria (Santiago, 25 May, 1935), pp. 7-8

scholarships the same year with similar conditions. At least one mining engineer, Belisario Maureira Pezoa, obtained this scholarship. The coal companies Industrial Coal Company of Lota and the Coal and Foundry Company Schwager in Coronel offered another scholarship for students during the last three years of the mining study.[1024]

Simultaneously, public intermediate technical mining schools were established at some of the important mining districts around the country. The Mining School of Copiapó was founded in 1857 after finding large mineral deposits in the area and was the first of its kind in Latin America. The school was initiated and built by the Mining Board of that city, who expressed the need for a mining school in a growing mining district.[1025] The two mining schools of La Serena and Santiago were founded in 1887, but the Mining School of Santiago was closed down in 1912.[1026] Another mining school, the Industrial School of Saltpetre and Mining in Antofagasta, was founded in 1918, and provided a practical education directed towards the saltpetre industry.[1027] Knowledge of reading, writing and basic mathematics was necessary to be admitted, i.e. primary school, and the students had to pass a test, typically in reading, writing, arithmetic and catechism.[1028]

The Mining Schools provided a number of scholarships for the students. In 1888 the Mining School of Santiago informed that forty scholarships were provided, but "(t)his number may be increased to ten per year and reach up to sixty scholarships."[1029] By 1935, state scholarships had been established for students who wished to study at one of the Mining Schools or other technical schools. The scholarships were meant for "…students who prove not having the necessary resources to pay for the

[1024] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1935), p. 246
[1025] Escuela de Minas de Copiapó, *Boletin Centenario Escuela de Minas de Copiapó 1857-1957* (Santiago, 1957), p. 9
[1026] S. Macchiavello Varas, *El problema de la industria del cobre en Chile y sus proyecciones económicas y sociales* (Santiago, 2010), p. 126
[1027] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1926), p. 646
[1028] *Reglamento general para la Escuela Practica de Mineria de Santiago* (Santiago, 1888), pp. 3-4; *Prospecto de admision de alumnos para la Escuela de Minas de Copiapó* (Santiago, 1930), pp. 5-7
[1029] *Reglamento general para la Escuela Practica de Mineria de Santiago* (Santiago, 1888), p. 3

pension".[1030] Sometimes over half of the students were given scholarships.[1031] For instance, in 1918 the Ministry of Industry and Public Affairs declared that seventy of eighty students at the Mining School of Copiapó were provided funding.[1032]

10.2.1 Debate about the content of the instruction

In Chile too, as in Norway, there was a continuous debate about the content of the mining instruction. The Mining Bulletin became a medium for debate and a number of articles were published about this theme. Engineers, industrial leaders and professors wrote their opinions about how the teaching should be organised, teaching forms etc. Here too there were differences of opinion. On one hand, there were those who meant that the instruction was too focused on science and theories and lacked practical work and exercises. In one of the annual report of the University, it was referred to a debate in the country's newspapers in 1914 about the too "scientifically oriented" studies at the University. The press and members of the Congress started a "campaign" against "too much science" in teaching and insisted on the need to prepare men who could "perform their profession". The excess of mathematics was primarily in focus.[1033]

On the other hand, there were those who meant that practical work experience and learning by doing should first and foremost be acquired in the field after studies. They stood for a mining instruction, which emphasised the teaching of scientific theories. Their argument was that the educational institutions should provide the knowledge they were good at, namely scientific theories. Underlying this discussion lay the issue of which role the formal educational institutions should play in the forming of capable engineers. A Commission was appointed in the early 1920s to instruct the Faculty about how the engineering study programs should be organised. But, in spite of a wish for

[1030] *Prospecto de admisión de alumnos para las Escuelas de mina* (Santiago, 1932), p. 9
[1031] Ministerio de Industria y Obras Publicas presentada al Congreso Nacional, *Memoria* (Santiago, 1918), p. 126
[1032] Ministerio de Industria y Obras Publicas presentada al Congreso Nacional, *Memoria* (Santiago, 1918), p. 126
[1033] Anales de la Universidad, *Memoria de la Universidad de Chile, 1922* (Santiago, 1923), pp. 151-152

more practice, the Commission concluded that practical training should not be used at the expense of theoretical teaching. A restriction of theoretic instruction would "… let engineers in unfavourable conditions to solve new problems, complex or not, which the practice of the profession place before his eyes."[1034] This viewpoint had been established early on. Ignacio Domeyko, principal of the University of Chile from 1867, argued that the student learned "to study, think and reason; so that in any situation of life…[…]… he knows how to study, knows how to remember and cultivate the branches that are most necessary and useful…"[1035] As an answer to the general critiques of the engineering studies, the Faculty of Mathematics argued that the role of the universities and schools was to give engineers and technicians general scientific preparations and some practical training. The in-depth practical experience should be acquired through practical work. The role of the University was not, as some thought, to form fully trained industrial engineers.[1036]

A similar debate was raised with respect to the Mining Schools. The instruction received similar criticism for being too theoretic. There was a general agreement that the mining technician programs should be more practically-oriented than the mining engineering program, but some claimed that they did not focus enough on practical excercises. The mining engineer Guillermo Yunge, for instance, argued that a serious deficiency in the instruction was a lack of practice. The scarce practical training prevented the students from becoming "practical operators" at the mines, according to him.[1037] Moreover, Ignacio Díaz Ossa, Director of the Mining School in La Serena, was harsh in his criticism of the mining studies. He claimed that the students were not taught the necessary knowledge to practically perform their job. He gave a concrete example from the instruction at one of the mining schools: in mine surveying the professor normally discussed and demonstrated concepts of descriptive and analytic geometry to establish the systems of coordinates for projections and

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[1034] Anales de la Universidad, *Memora de la Universidad de Chile, 1922* (Santiago, 1923), pp. 156-157
[1035] My translation: I. Domeyko, "Reseña de los trabajos de la Universidad desde 1855 hasta el presente", in *Anales de la Universidad de Chile* (October 1872), p. 8
[1036] Anales de la Universidad *Memoria de la Universidad de Chile, 1922* (Santiago, 1923), pp. 171-172
[1037] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1903), p. 247

calculations of maps. The students passed the exams, but without knowing how to use the necessary instruments and how to actually make a map of a mine in practice.[1038] To perform as capable assistants they were recommended to acquire working experience. The director of the Mining and Saltpetre School in Antofagasta summed up the role of the Mining Schools in an article in the Mining Bulletin in 1926. He admitted that the graduates from the school did not know everything that was demanded in a working situation. On the other hand, they were prepared theoretically with the useful knowledge in mathematics and were instructed in practical laboratory work and excursions, which would enable them to work "with success" in the industry.[1039]

10.2.2 The University of Chile

The University had a scientific approach and sought to provide thorough scientific trainings. The mining engineering program, in particular, aimed to recruit capable leaders for the mining sector.[1040]

A broad study program

The mining engineering program was from the beginning set to four years (see appendix 12 for study programs of selected years).[1041] During the first years of the program, the mining engineering students followed many of the same courses as civil engineers and geographical engineers.[1042]

Mathematics and natural sciences was given a high priority. The first year included courses only in mathematics, i.e. superior algebra, spherical trigonometry, three dimensional geometry and descriptive geometry.[1043] The second year also covered courses in mathematics, in addition to mineral chemistry and physics.[1044] The third year focussed on courses related to geology and the fourth year

[1038] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1912), p. 557
[1039] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1926), pp. 644-646
[1040] I. Domeyko, "Reseña de los trabajos de la Universidad desde 1855 hasta el presente", in *Anales de la Universidad de Chile* (October 1872), pp. 577-578
[1041] *Anales de la Universidad de Chile* (Santiago,1883), p. 417
[1042] *Anales de la Universidad de Chile* (Santiago,1859), pp. 977-978
[1043] *Anales de la Universidad de Chile* (Santiago,1859), p. 977
[1044] *Anales de la Universidad de Chile* (Santiago,1859), p. 977

included a course in mechanics[1045] (see table below):

The Mining engineering program at the University of Chile

Year 1859

Courses	
1st year	Mathematics (superior algebra, spherical trigonometry, three dimensional geometry, descriptive geometry)
2nd year	Mineral chemistry Physics Mathematics
3rd year	Docimasy Mineralogy Geology Measuring of mines Topography
4th year	Mechanics Exploitation of mines Laboratory analysis

Source: Anales de la Universidad de Chile (Santiago, 1859), p. 977

The engineering program of the year 1900 included a detailed description of the courses and topics that were taught. The course in physics covered a wide range of topics, such as mechanical concepts, measurement instruments, weight and gravity, hydrostatics, gases and pneumatic machines, molecular phenomena, acoustics, optic geometry and physics, heat, electric statics and related machinery, electric dynamics and electro optics.[1046] The course in mechanics included general principles of mechanics, definitions of impulsion, percussion, force, etc.[1047] Geology included subjects in dynamic geology, geotechnical geology and petrography.[1048] Mineralogy covered forms of mineral and crystallography and physical characteristics of different mineral and metal groups.[1049] In the chemistry course, the characteristics of different types of metals, among other subjects, were treated.[1050] The course in docimacy covered topics about the treatments of ores, such as mechanic operations by dry methods, instruments and devices, specialised methods for lead, copper, silver,

[1045] *Anales de la Universidad de Chile* (Santiago,1859), p. 977
[1046] *Programas del curso de injenieria de la Universidad de Chile* (Santiago, 1900), pp. 5-24
[1047] *Programas del curso de injenieria de la Universidad de Chile* (Santiago, 1900), pp. 107-108
[1048] *Programas del curso de injenieria de la Universidad de Chile* (Santiago, 1900), pp. 63-66
[1049] *Programas del curso de injenieria de la Universidad de Chile* (Santiago, 1900), pp. 59-62
[1050] *Programas del curso de injenieria de la Universidad de Chile* (Santiago, 1900), pp. 33-38

gold, mercury and tin.[1051]

In addition to natural science courses, the program also included courses specifically directed towards mining. These were ore testing, ore surveys and minerals, mine measuring, mining operations and laboratory analysis.[1052] Survey methods, use of different instruments, construction and drawing of maps were taught in the topography course.[1053] The course in mining operation included instruction about the process of making and utilising mines. The course covered subjects about ore deposits, research, removing of rocks (the use explosives, equipment, drilling etc.), excavation (underground and open-pit mining, making of galleries, adits etc., dimensions, hardness of rocks, roads), fortification, utilisation methods, transport (locomotives, horses, machines etc.), extraction of minerals and metals (cables, devices, winches, bombs, engines, electric power etc.), drainage (natural drainage, pumps, tubes, engines, centrifuges etc.) ventilation (gases, precautions, fires, natural ventilation, systems of ventilation), lightening (devices, lamps, candles, safety lamps, electric lightening), lifting (cables, stairs, safety, engines etc.), mechanic preparation of minerals (crushers, cylindrical crushers, mills, rotation, drum systems, concentration methods, measuring of mines (maps, devices, tripods, compasses, theodolites, levels).[1054]

A combination of instruction methods

Teachers used a combination of instruction methods. Common teaching techniques were lectures in classrooms; students carried out practical exercises and did analyses in the laboratories.[1055] In geology, for instance, in addition to lectures, the students did assignments and were trained in the practical use of microscope. The course in docimacy was given partly as lectures and partly in

[1051] *Programas del curso de injenieria de la Universidad de Chile* (Santiago, 1900), pp. 51-54
[1052] *Anales de la Universidad de Chile* (Santiago, 1859), pp. 976-977
[1053] *Programas del curso de injenieria de la Universidad de Chile* (Santiago, 1900), pp. 127-146
[1054] *Programas del curso de injenieria de la Universidad de Chile* (Santiago, 1900), pp. 67-74
[1055] *Anales de la Universidad de Chile* (Santiago,1883), p. 417

laboratory.[1056]

An important part of the instruction was geological surveys and excursions. The University reported of annual geological excursions to the Andes Mountains and the coal mining districts.[1057] It is unclear how long these excursions were, but they were probably less than three months. The principal of the University, Valentín Letelier, found that the excursions were too short. He argued in 1909 that the students needed more practical training in this field and recommended them to find ways to learn more about mineral analyses.[1058]

The students also did one year practice at a mining company; four to five months at a metallurgical plant, sometime at a mine and the rest of the year doing analysis of minerals at the University laboratory.[1059] After the practice was finished the students did a practical test which involved drawing a mine or metallurgical plant and making a detailed report of metallurgical analyses.[1060] From 1909, the practice increased. Since then the students worked additionally for four months at a mine or metallurgical plant during vacations.[1061] There are records of students doing practical training at Chuquicamata, El Teniente, Naltagua, Panulcillo, Curanilahue, Mafil, Saltpetre Company of Antofagasta and other saltpetre companies. According to the University, the students and professors used all kinds of facilities at these companies and received generous help from company leaders.[1062]

To acquire an academic certificate in mining engineering the students did a final exam, which included topics from all the courses. In addition, the students did a practical exam, which included (1) two ore testing exercises and a description of the used methods and (2) a measurement of a mine

[1056] *Programas del curso de injenieria de la Universidad de Chile* (Santiago, 1900), pp. 51 and 66
[1057] Anales de la Universidad, *Memora de la Universidad de Chile, 1922* (Santiago, 1923), p. 161
[1058] *Anales de la Universidad de Chile* (Santiago,1909), pp. 157-59
[1059] *Anales de la Universidad de Chile* (Santiago,1883), p. 417
[1060] *Anales de la Universidad de Chile* (Santiago,1883), p. 417
[1061] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1910), p. 118
[1062] *Anales de la Universidad de Chile* (Santiago,1919), pp. 297-298

and an exact map of how this was applied.[1063]

Expansion of the study program

A number of modifications were made in the study program to adapt to technological development in the industry. First of all, in 1889 the mining engineering program increase from four to five years. The study program still emphasised courses in natural sciences such as mathematics, physics, chemistry, mechanics and geology. Nearly the entire first year covered subjects in mathematics. But, the additional year allowed for more courses. A course in machines, especially applied to mining, was added to the curriculum, in addition to mineralogy and the use of blowtorch, industrial physics, metallurgy, technology and analytic chemistry, construction materials and general construction, utilisation of mines and political economy and administrative law.[1064] Metallurgy included teaching of the classification of metals and minerals, temperatures, smelting methods, roasting, calcination, mechanic and electro-chemical procedures, fuels, devices, furnaces, engines, metallurgical processes etc.[1065] The emphasis was given to the "(p)hysical state in which the ore must be for the metallurgical processes to take place" and the metallurgical procedures.[1066] The course in ore testing covered the general methods for mineral and metal processing, such as calcination, roasting, smelting etc. and the use of furnaces, equipment, instruments.[1067] The course in drawing included the drawing of devices, machine elements, construction details and models.[1068]

Part of the reform of 1889 was to divide the study program in two: mining and metallurgy. The two programs did not differ considerably, but the latter had more focus on metallurgy and included more hours in the metallurgical laboratory[1069] (see table below):

[1063] *Anales de la Universidad de Chile* (Santiago,1859), pp. 977-978
[1064] *Anales de la Universidad de Chile* (Santiago, 1890), pp. 118-119
[1065] *Programas del curso de injenieria de la Universidad de Chile* (Santiago, 1900), pp. 167-187
[1066] *Programas del curso de injenieria de la Universidad de Chile* (Santiago, 1900), p. 167
[1067] *Programas del curso de injenieria de la Universidad de Chile* (Santiago, 1900), pp. 51-54
[1068] *Programas del curso de injenieria de la Universidad de Chile* (Santiago, 1900), p. 76
[1069] *Anales de la Universidad de Chile* (Santiago, 1890), pp. 118-119

The mining engineering program at the University of Chile
Year 1889

	Courses (every course 6 hours)
1st year	Analytic geometry (2 and 3 dimensions) Superior algebra Differential and integral calculus Descriptive geometry (and applications) Drawing and graphic work
2nd year	Rational mechanics and theoretic hydraulic Topography, theoretic part (1st semester) Topography, instruments and practice Topography (2nd semester) Sternotomy General physics General chemistry Drawing, graphical work and practice
3rd year	Machines (especially applied to mines) Mineralogy and use of blowtorch Industrial physics, technology and analytic chemistry Astronomy and geodesy Drawing, graphic work and practice
4th year	Construction materials and general construction General and applied geology Docimasy, industrial and analytic chemistry Exploitation of mines, 1st part (measuring and tillage) Drawing, graphic work and practice
5th year	General construction (2nd part) Accounting General metallurgy Exploitation of mines, 2nd part (mechanic preparation) Special metallurgy Political economy and administrative law: mining law Analytic chemistry Drawing, graphic work and practice

Source: *Anales de la Universidad de Chile* (Santiago, 1890), pp. 118-119

In 1919, the mining study was further expanded to six years.[1070] The new study program gave more importance to chemical engineering. Several different subjects in chemistry were taught, for instance general chemistry, qualitative and quantitative analytic chemistry, physical chemistry, electrochemistry and industrial chemistry.[1071] With the technological changes and specialisations in the processing of ores that were happening at the time, new subjects within chemistry and

[1070] *Anales de la Universidad de Chile* (Santiago, 1919), pp. 923-924
[1071] *Anales de la Universidad de Chile* (Santiago, 1920), pp. 316-317

metallurgy would be useful for the industry. New subjects in chemistry and metallurgy were added even before the reform of 1919. In 1908, the subjects electro-metallurgy and electro-chemistry were included in the study program, which meant that the students were trained in new processing techniques with the use of electricity.[1072] In 1923, a new discipline in engineering was introduced, called chemical and metallurgical engineering.[1073]

Increased emphasis on mining machinery, construction and electricity

New courses, which focused on mechanics, mining machinery and construction, were gradually added to the program. In 1889, these courses were machines (especially applied to mines), construction materials and general construction and exploitation of mines, 2nd part (mechanic preparation). This gradual modification of the study plan and new focus on courses in machinery and construction indicate two things. First of all, it was a way to adapt to the use of new mechanical technology, such as drilling machines, mechanical lifts and transport, crushing and milling machinery etc., which in Chile was primarily used at foreign companies. Second, it was possibly an attempt to encourage a mechanisation of the underdeveloped domestic companies. At the same time, a new focus was set on subjects in electro-engineering. In 1909, the Study Commission decided to extend the teaching of this subject. The total hours per week in the electrical laboratory were increased to four hours the third year and to six hours the fourth year, in addition to drawing one hour weekly the third year and two hours lectures the fourth year.[1074] These changes happened, as electric power became an important source of power in mining.

In 1919, specialised courses in saltpetre technology and steel were added. The saltpetre industry represented one of the largest productions and knowledge in this field was crucial. The production of

[1072] *Anales de la Universidad de Chile* (Santiago, 1908), pp. 360-361
[1073] *Anales de la Universidad de Chile* (Santiago, 1923), p. 366
[1074] *Anales de la Universidad de Chile* (Santiago, 1909), pp. 77-78

steel had begun, which makes this course also very relevant[1075] (see table below):

New courses in machinery and construction in Chile (simple overview)

	1870	1880	1890	1900	1910	1920	1930	1940
Machine and construction:								
Machines (for mining)			----------	----------	----------	----------	----------	----------
Construction			----------	----------	----------	----------	----------	----------
Electrical engineering					----------	----------	----------	----------
Architecture					----------	----------	----------	----------
Saltpetre technology						----------	----------	----------
Steel industry						----------	----------	----------
Transport: railways, road and air cables						----------	----------	----------

Further modifications were made. Small adjustments were continuously implemented to make it more "suitable" for mining engineers. The course "material resistance" was replaced by applied mechanics in 1923 and included foundations and hydraulics which, as argued, was more relevant for mining engineers.[1076]

New courses in administration and economics

The reform in 1889 also included administrative and economic courses.[1077] As seen, these subjects were perhaps especially important in Chile, where some of the largest mining companies in the world operated with thousands of workers.

In 1908, administrative and economic subjects were divided in three: project formation and budgets, administrative law, legislation and economy and mining law[1078] (see table below):

[1075] *Anales de la Universidad de Chile* (Santiago, 1920), pp. 316-317
[1076] *Anales de la Universidad de Chile* (Santiago, 1924), p. 616
[1077] *Anales de la Universidad de Chile* (Santiago, 1890), pp. 118-119
[1078] *Anales de la Universidad de Chile* (Santiago, 1908), pp. 360-361

New courses in administration and economics in Chile (simple overview)

	1870	1880	1890	1900	1910	1920	1930	1940
Econ. and adm.:								
Political economy and law			----------	----------				
Project formation and budgets					----------	----------	----------	----------
Administrative law, legislation and economy					----------	----------	----------	----------
Mining law					----------	----------	----------	----------

Improving teaching conditions

A lack of finances was a continuous problem. Professors and mining engineers complained about the lack of teachers, necessary tools, equipment, devices, chemicals etc.[1079] The professors at the University were aware of the deficiencies of the study, but often lacked money to improve it. For instance, it was sometimes difficult to find money to go on excursions with the students and there was a lack of teaching materials and classrooms.[1080] The Principal of the University, Valentín Letelier, found that the facilities used in teaching up until 1909 were precarious. This was, according to him, partly due to the fact that the engineering studies did not have an own building.[1081] In 1911, the ex-minister of industry Javier Gandarillos confirmed that the Faculty of Mathematics had several times requested funds from the Government to raise a building for engineering studies with the necessary facilities and laboratories, but without luck.[1082]

However, improvements were gradually carried out. The Government used contacts in Europe to employ professors for the courses which lacked teachers. From the late 1860s the course in mining, which represented most challenges, always had a teaching professor.[1083] Professors were continuously hired to teach new courses in the program.[1084] A separate building for the engineering

[1079] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1910), p. 119
[1080] *Anales de la Universidad de Chile* (Santiago, 1915), p. 85
[1081] *Anales de la Universidad de Chile* (Santiago, 1909), pp. 157-59
[1082] Anales de la Universidad, *Memora de la Universidad de Chile, 1911* (Santiago, 1912), pp. 1328-1330
[1083] I. Domeyko, "Reseña de los trabajos de la Universidad desde 1855 hasta el presente", in *Anales de la Universidad de Chile* (October 1872), p. 21
[1084] I. Domeyko, "Reseña de los trabajos de la Universidad desde 1855 hasta el presente", in *Anales de la Universidad de Chile* (October 1872), p. 25

studies with new laboratories and materials was approved in 1911 and inaugurated in 1922.[1085]

10.2.3 The Mining Schools

To be admitted to the Mining Schools the students had to be between thirteen and sixteen years old, with the exception of the Mining School of Santiago where the students were between sixteen and twenty years old.[1086] The aim of the Mining Schools was to provide the mining sector with technically skilled leading assistants. Carlos Schulze confirmed in 1910 that: "(t)he objective pursued by the government to establish and sustain these establishments is certainly to educate the common people for secondary positions in mining."[1087]

Practically oriented mining instruction

The three mining schools of Copiapó, La Serena and Santiago provided formal mining instruction. The study programs included both theoretical teaching of natural science subjects and practical training, laboratory work, excursions and work experience. The study plans included a broad set of courses in natural sciences, such as mathematics, physics, chemistry, mechanics and geology. Additionally, the program included subjects directed specifically towards mining and metallurgy, such as utilisation of mines and mine surveying. In 1857, the study program at the Mining School of Copiapó lasted three years and included the following courses:

[1085] Anales de la Universidad, *Memora de la Universidad de Chile, 1911* (Santiago, 1912), pp. 1328-1330
[1086] Escuela Práctica de Minería de Santiago, *Reglamento general para la Escuela Práctica de Mineria de Santiago* (Santiago, 1888), pp. 3-4
[1087] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1910), p. 330

Study program at the Mining School of Copiapó
Year 1857

Year	Courses
1st year	Geography Sacred history History of Chile Spanish grammar Religion Arithmetic Elements of geometry Bookkeeping Lineal drawing
2nd year	Elements of industrial mechanics Mine surveying and essential knowledge concerning utilisation of mines
3rd year	Elements of chemistry and mineralogy Testing and practical knowledge of benefitting minerals

Source: Escuela de Minas de Copiapó, *Boletin Centenario Escuela de Minas de Copiapó 1857-1957* (Santiago, 1957), p. 7

The courses and teaching methods suggest that the instruction was much like the engineering program that was provided at the University. However, for several reasons it was clear that the schools had a more practical profile. First of all, having work experience at mining or metallurgical plants before starting the study program was preferable.[1088] Second, the study programs were normally shorter than the program at the University and varied generally from two to four years.[1089] The short study program included fewer courses and there was only time for a short theoretical introduction to the subjects.[1090] For instance, the course in utilisation of mines included some basic topics, such as distribution of work, ventilation, drainage and transport inside the mines. The course in mechanics included the construction and use of pumps, machinery used for extraction at the mines, resistance and materials for mine constructions, foundry plants and transport.[1091] Chemistry was limited to simple methods of testing and processing and the course in mineralogy covered

[1088] Escuela Práctica de Minería de Santiago, *Reglamento general para la Escuela Practica de Mineria de Santiago* (Santiago, 1888), pp. 3-4
[1089] Escuela de Minería de Santiago, *Programa i reglamento en la Escuela de Mineria de Santiago*, 2da edicion (Santiago, 1902), p. 51
[1090] Escuela de Minas de Copiapó, *Boletin Centenario Escuela de Minas de Copiapó 1857-1957* (Santiago, 1957), p. 7
[1091] Escuela de Minas de Copiapó, *Boletin Centenario Escuela de Minas de Copiapó 1857-1957* (Santiago, 1957), p. 7

copper and silver, and to a certain degree gold, lead and mercury.[1092] Third, classes were often combined with practical assignments outside the school. Classes at the Mining School in Santiago, for instance, were suspended twice a week so that the students could do “practical exercises” with help from professors. The students went on geological excursions and visited mining and metallurgical establishments to become acquainted with operations and machinery.[1093] The director of the Mining School in Santiago Ernesto Frick explained in the Mining Bulletin in 1890 that excursions were made to Los Bronces, the Descubridora Company and the Fortuna Mine, where the students observed mining in action and learned about enmaderation, installation of cables etc.[1094]

After finishing the three years, the students did a practice of six months; three months at a mine and three months at an amalgamation plant. The practice involved assisting in mining operations as normal employees, often under the orders of a mining engineer. After finishing the courses and practice, the student had to present and pass a final exam.[1095]

Adapting the study program to development in mining

The curriculum at the Mining Schools were also modified, as the engineering programs at the University. The schools had a tendency to include more courses and to increase the number of years. In 1875, the Mining School of Copiapó added a course about the Mining Code to the curriculum and one year was added to the program.[1096] Advanced mathematics was reduced in 1896[1097] after the National Mining Society argued that the students should know “…how to use the formulas, know the

[1092] Escuela de Minas de Copiapó, *Boletin Centenario Escuela de Minas de Copiapó 1857-1957* (Santiago, 1957), pp. 7-8
[1093] Escuela Práctica de Minería de Santiago, *Reglamento general para la Escuela Practica de Mineria de Santiago* (Santiago, 1888), p. 5
[1094] Escuela Práctica de Minería de Santiago, *Boletín de la Sociedad Nacional de Minería* (Santiago, 1890), p. 80
[1095] Escuela de Minas de Copiapó, *Boletin Centenario Escuela de Minas de Copiapó 1857-1957* (Santiago, 1957), pp. 7-8
[1096] Escuela de Minas de Copiapó, *Boletin Centenario Escuela de Minas de Copiapó 1857-1957* (Santiago, 1957), p. 12
[1097] Escuela de Minas de Copiapó, *Boletin Centenario Escuela de Minas de Copiapó 1857-1957* (Santiago, 1957), p. 12

details, but [did] not need to know how to deduce these formulas theoretically or to possess deep knowledge of engineering."[1098] This suggests a clear difference to the theoretic mining engineering program, which emphasised mathematical courses.

The Schools responded to the technological changes in mining by gradually introducing specialisations to the programs. After the turn of the century, the Mining school of Santiago divided the program into two specialisations, one in mining and one in metallurgy.[1099] In 1891, the National Mining Society recommended to add a course in electricity to the study plan, especially knowledge of electricity that was used in mining.[1100] It was not until later, however, that a course in electricity was added. The study program of 1930, decades later, included such a course at the Mining School of La Serena (see table below). By 1935, a course in electricity had also been adopted at the Mining School of Copiapó.[1101]

Study program at the Mining School of La Serena
Year 1930

Year	Subjects	Hours per week
1st year	Aritmetics and geometry	6
	Drawing	2
	Spanish	2
	History and civic education	2
	Physics and applied chemistry	1
	Workshops (including one hour a week of craft technology)	27
2nd year	Mathematics	6
	Spanish	3
	Physics	6
	Chemistry	6
	History and civic education	2
	English	3
	Economic geography	2
	Gymnastics	2
	Song	1
	Technical drawing	2
	Workshops and laboratories	10
3rd year	Mathematics	4
	Trigonometry	2
	English	3

1098 *Boletín de la Sociedad Nacional de Minería* (Santiago, 1891), p. 160
1099 Escuela Práctica de Minería de Santiago, *Programa i reglamento en la Escuela de Mineria de Santiago*, 2da edicion (Santiago, 1902), p. 51
1100 *Boletín de la Sociedad Nacional de Minería* (Santiago, 1891), p. 160
1101 Escuela de Minas de La Serena, *Prospecto de admision de alumnos para la Escuela de Minas de La Serena* (La Serena, 1930), p. 3; Escuela de Minas de Copiapó, *Prospecto de admision de alumnos para la Escuela de Minas de Copiapó* (Santiago, 1935), pp. 22-23

	Gymnastics Song Technical drawing Mechanics Physics and applied chemistry Elements of construction Mineralogy and geology Analytic chemistry Workshops and laboratories	2 1 2 2 4 2 2 3 16
4th year	English Gymnastics Song Technical drawing Mineralogy and geology Utilisation of mines and saltpetre works Elements of construction Electricity Machines Analytic chemistry Metallurgy Topography and measuring Laboratories	3 2 1 2 3 3 2 2 3 3 2 2 15
5th year	English Gymnastics Song Utilisation of mines and saltpetre works Mechanic preparation of minerals Social and mining legislation Accounting and control Saltpetre technology Machines Metallurgy Electricity Tpography and measurements Laboratories	2 2 1 3 3 2 2 3 3 2 2 2 15

Source: *Prospecto de admision de alumnos para la Escuela de Minas de La Serena* (La Serena, 1930), pp. 1-3

By the 1930s, other specialised subjects had also been added to the study program at the Mining School of La Serena. These were new courses related to mining machinery, such as technical drawing, elements of construction, mechanical preparation of minerals, saltpetre technology, machines etc. as well as administrative courses, such as economic geography, accounting and control and social and mining legislation.[1102] By 1935, the Mining School of Copiapó had also added new courses, such as machines, construction, saltpetre technology, industrial technology and geographical economy.[1103] The new courses meant a prolongation of that the study program. Nevertheless, the program suggests that practice were still given priority, since the majority of hours per week were spent in laboratories and workshops. The program at the Mining School of La Serena had increased to five

[1102] Escuela de Minas de La Serena, *Prospecto de admision de alumnos para la Escuela de Minas de La Serena* (La Serena, 1930), pp. 1-3

[1103] Escuela de Minas de La Serena, *Prospecto de admision de alumnos para la Escuela de Minas de La Serena* (La Serena, 1930), pp. 1-3; Escuela de Minas de Copiapó, *Prospecto de admision de alumnos para la Escuela de Minas de Copiapó* (Santiago, 1935), pp. 22-23 years by 1930, but instruction was given on a considerably lower level than the University, because the only requirement to be admitted to the program was six years of primary school.[1104]

Gradual upgrading of laboratories and workshops

Lack of finances was a continuous problem at the Mining Schools. Professors and directors at the three mining schools complained about the lack of teaching space, materials, classrooms and decent laboratories.[1105] The Director of the Mining School in Santiago, Ernesto Segundo Frick, wrote an article about this school in the Mining Bulletin in 1890 directed to the Government. One of his points was that students from different years had to share classrooms, which meant that they distracted each other and it became difficult for them to learn.[1106] The school lacked good teaching facilities, such as adequate laboratories, a decent mineral collection, machine models and up-to-date devices for testing and analyses.[1107] Decades later, the conditions at the Mining Schools were still not optimal. The director of the Mining School of Copiapó between 1910 and 1927, Don Guillermo Amenibar Ossa, argued that the teaching material was poor. The personnel and directives had to take initiatives to cover deficiencies due to the fact that "…the government had forgotten them." Funding was sometimes obtained from North American companies, with which the School could buy "indispensable materials".[1108] For instance, Braden Copper Company and Chile Exploration Company financed a small hydroelectric plant, which was installed at the Mining School of Copiapó in the beginning of the twentieth century.[1109]

On one hand, the fact that private companies helped financing the Mining Schools support the

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[1104] Escuela de Minas de La Serena, *Prospecto de admision de alumnos para la Escuela de Minas de La Serena* (La Serena, 1930), p. 4

[1105] See *Boletín de la Sociedad Nacional de Minería*, for instance the years 1890, 1903 and 1912

[1106] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1890), p. 81

[1107] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1890), p. 81

[1108] Escuela de Minas de Copiapó, *Boletin Centenario Escuela de Minas de Copiapó 1857-1957* (Santiago, 1957), p. 29

[1109] *Revista minera sostenida por los profesores de la escuela practica de minas de Copiapó* (Copiapó, 1918), p. 11

argument that learning facilities at the Mining Schools were not optimal. They possibly had no other option but to acquire funds from private companies. On the other hand, companies were perhaps interested in providing teaching materials because they would benefit from employing experienced mining technician graduates. Both Braden Copper Company and Chile Exploration Company had large electric power plants. Students with practical skills on how to operate such plants were probably very useful to them. It was in fact a common for companies in many countries to finance equipment for technical schools. Mining companies in Germany actually provided technical schools with large institutes. In Sweden, iron companies gave financial support to the Technological Institute in Stockholm. In Norway Maskin A/S K. Lund & Co, agent for the American company Ingersoll Rand Co., announced at a conference that it would donate a complete compressor plant with drills and tools to a value of 8 000 NOK to the NIT.[1110]

The Mining Schools were gradually equipped with more and better equipment and laboratories, also with financial support from the state. In the mid-nineteenth century, the Mining School of La Serena managed to obtain funds for smelting furnaces and additional structures to the school building.[1111] The Mining School of Copiapó developed a mechanical workshop, ironworks, carpentry and foundry by 1930. From the third year the students worked in laboratories, carried out topographic studies, metallurgical tests, projects, drawings etc.[1112] The mechanical workshop included seven mechanic wheels, two drills, two planers and four fully equipped mechanic benches. The mineralogical laboratory had more than 9 000 samples; the chemical laboratory included furnaces; the physical laboratory had several instruments for experiments. The School also had a geological laboratory, a topographic drawing cabinet and a construction and material resistance cabinet.[1113] Moreover, the

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[1110] *Tidsskrift for kemi og bergvæsen* (Oslo, 1937), p. 159
[1111] C. C de bon Urrutia, *La Escuela de Minas de La Serena Derroto de sus Orígenes* (La Serena, 1992), p. 77
[1112] Escuela de Minas de Copiapó, *Prospecto de admision de alumnos para la Escuela de Minas de Copiapó* (Santiago, 1930), p. 22
[1113] Escuela de Minas de Copiapó, *Prospecto de admision de alumnos para la Escuela de Minas de Copiapó* (Santiago, 1935), p. 18

Mining School of La Serena created an ore-dressing workshop, with the aim of providing the students practice in milling equipment machines for concentration; milling, flotation, amalgamation and cyanidation.[1114]

10.2.4 Studying abroad

Few Chilean mining engineers studied abroad. From the mid-nineteenth century and 1940 there are traces of six students going to other countries to acquire formal studies. The three distinguished students Manuel A. Osorio, Teodisio Cuadros and Antonio Alfonso went to Europe in the mid-nineteenth century on the recommendation of Professor Ignacio Domeyko. These three students were repeatedly mentioned in bulletins, magazines and mining reports as examples of Chilean mining engineers continuing formal education in European countries. They were sent to Europe with a state scholarship to study at the Mining Academy in Freiberg and the Mining School in Saint Etienne.[1115] Around twenty years later, in 1870, it was decided to send three more engineering students to Europe. The purpose was to provide specialised professors to the University. Three young students, one of them mining engineer, were sent to France and Belgium where they took University courses. They also visited important industrial plants in England and Germany.[1116] Another example is mining engineer Casimiro Domeyko Alamos, Igancio Domeyko's grandson, who studied mining at the University of Chile before graduating at the Mining School in Freiberg around 1893.[1117] In 1920, two mining engineers were sent to the United States to study "industrial chemistry and electricity" for at least two years.[1118] Guillermo Alamos was probably one of them. He graduated as a mining engineer in the United States before 1923.[1119] However, except for these specific cases there was no continuous arrangements for students going abroad to study.

1114 *Boletín de la Sociedad Nacional de Minería* (Santiago, 1937), p. 1427

1115 *Boletín de la Sociedad Nacional de Minería* (Santiago, 1891), p. 63; I. Domeyko, "Reseña de los trabajos de la Universidad desde 1855 hasta el presente", in *Anales de la Universidad de Chile* (October 1872), pp. 576-577

1116 L. Galdames, *La Universidad de Chile 1843-1934* (Santiago, 1934), p. 79

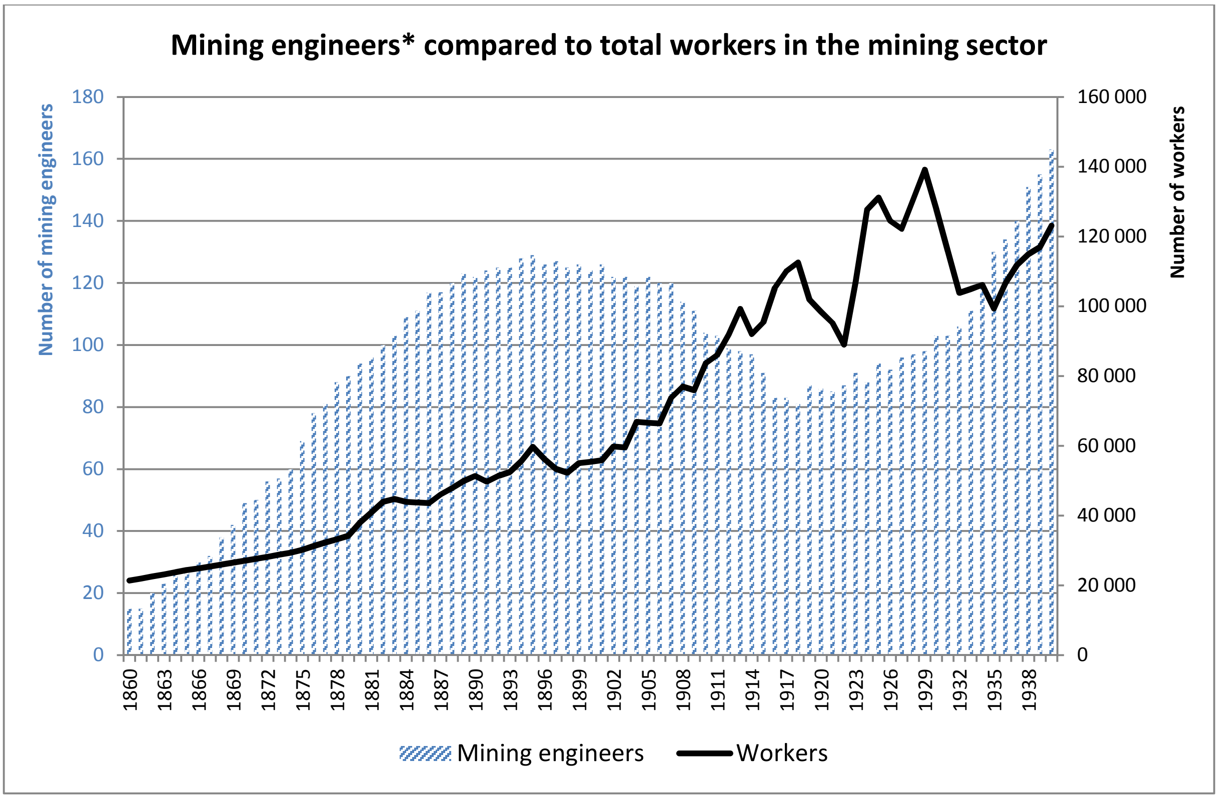
1117 *Album Histórico de la Escuela Univ. de Minas de Copiapó 1857-1950* (Santiago, 1950), p. 10

1118 *Anales de la Universidad de Chile* (Santiago, 1920), pp. 319-20

1119 Compañía de Minas Beneficiadora de Taltal, *memoria 1923* (Valparaíso, 1923, segundo semestre)

10.2.5 Number of mining engineers and technicians

In 1856, the University of Chile started the mining engineering program. From 1856 to 1940, 302 Chilean mining engineers graduated from this institution or from foreign educational institutions. The number of graduates varied from year to year, from no graduates to 12 in 1935 and 1938. The period of few or no graduates between 1887 and 1917 reflected a down period in the mining industry with less activity. From 1918, the number of graduates increased again (see appendix 13).



*Estimated career of 40 years
Calculations based on number of mining engineer graduates and the number of workers each year.
The total number of workers is unclear due to
the unorganised system of mining: "pirquen" which meant that miners were not employed in a regular sense, but worked as much as they wanted and paid a fixed price or parts of the outcome to the owner.
This system may have made it difficult to calculate the exact number of workers.
Sources: *Egresados de Ingeniería Civil de Minas Universidad de Chile 1856-2003* (Santiago, 2003); *Album Histórico de la Escuela Univ. de Minas de Copiapó 1857-1950* (Santiago, 1950), p. 10; *Boletín de la Sociedad Nacional de Minería* (Santiago, 1891), p. 63; J. Braun et al., *Economía chilena 1810-1995 Estadísticas históricas* (Santiago, 2000)

Chile also lacks information about the exact number of workers per engineer at any given time.

However, an estimate is also possible to make in this case. There is information about the year the mining engineers graduated, which makes it possible to make an educated guess of their career. Given that the mining engineers had an average career length of forty years the development of workers and mining engineers would be as outlined in the graph above, with the striped column representing the mining engineers working in the industry.

Using this approximation, the number of mining engineers in the mining sector increased from fifteen in 1860 to 124 in 1900 and 163 in 1940. The number of workers per mining engineer varied, but remained normally over 400, and between 1 000 and 1 400 between 1915 and 1930. It is not clear at this point whether the supply of mining engineers was low, because that would require an analysis of the demand. However, these numbers would indicate, at least, that the relative number of mining engineers was not high (see table below):

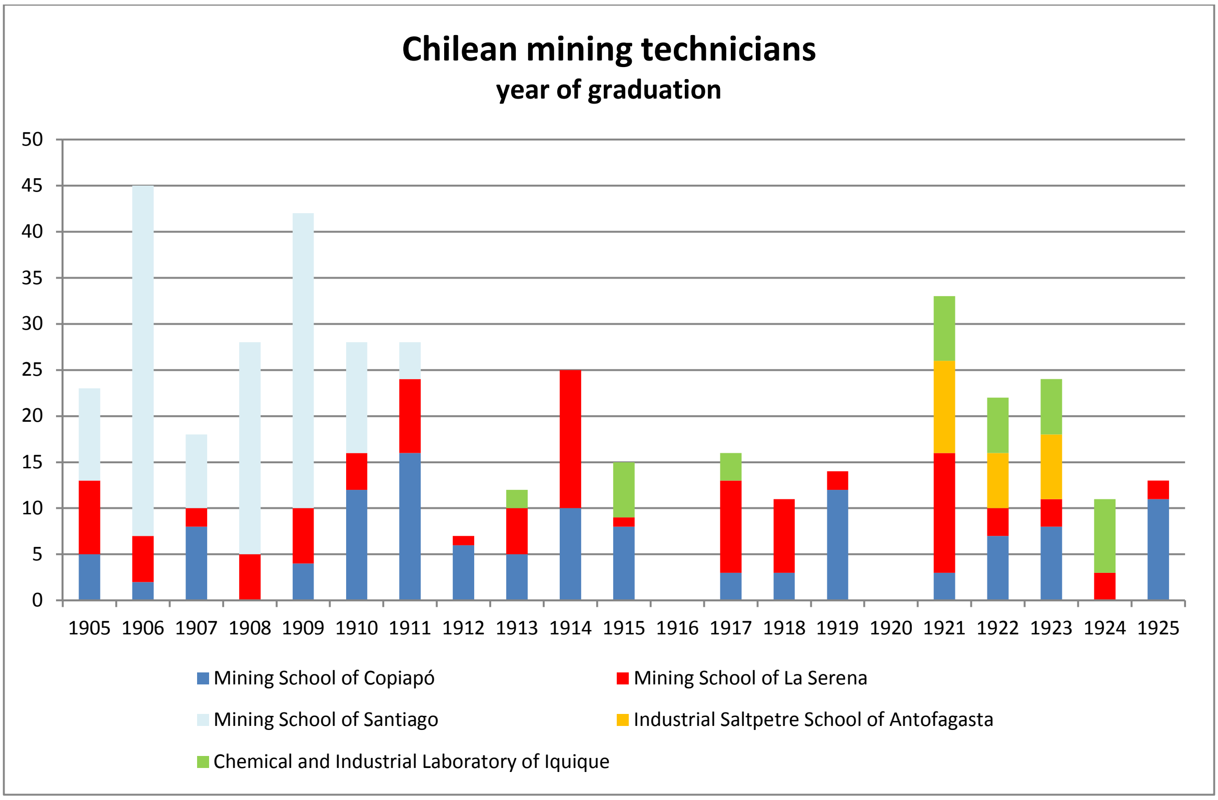
Workers per mining engineers in Chile

Estimated career of 40 years

Year	Workers	*Estimated number of mining engineers in mining*	***Number of workers per mining engineer***
1860	21 367	*15*	***1 424***
1865	24 396	*27*	***903***
1870	27 033	*49*	***552***
1875	30 207	*69*	***438***
1880	37 935	*94*	***404***
1885	43 789	*111*	***394***
1890	51 345	*122*	***421***
1895	59 713	*129*	***463***
1900	55 398	*124*	***447***
1905	66 626	*122*	***546***
1910	83 677	*104*	***805***
1915	95 421	*91*	***1 049***
1920	98 442	*86*	***1 145***
1925	131 168	*94*	***1 395***
1930	127 882	*103*	***1 242***
1935	99 344	*130*	***764***
1940	123 065	*163*	***755***

What about mining technicians? Claudio Canut de bon Urrutia, the author of the book *Escuela de*

Minas de La Serena, refers to statistics of the number of students at this Mining School, and confirms that a total of 1 274 students were enrolled between 1887 and 1914, but only ninety-two graduated.[1120] According to *Album Histórico Escuela de Minas de Copiapó* 108 graduated from the Mining School of Copiapó between 1902 and 1920.[1121] From the year 1905 to 1925, the total number of graduates from each mining school is known. There were in total 415 graduates during these twenty years. 1906 represents the year with the most mining technician graduates, with forty-five graduates. Later, in 1906, the number decreased to eleven graduates and thirteen in 1924 and 1925. Some years there were no graduates. The decrease after 1912 was partly due to the fact that the Mining School of Santiago closed down that year. Before 1905 and after 1925, however, information is unavailable (see table below):



Sources: Oficina Central de Estadística. *Anuario Estadístico de la República de Chile, Educación* (Santiago, 1905-1925)
*Information of 1916 and 1920 is unavailable
**Mining School of Santiago closed in 1912 and Industrial Saltpetre School of Antofagasta opened in 1918.

[1120] C. C de bon Urrutia, *La Escuela de Minas de La Serena Derroto de sus Orígenes* (La Serena, 1992), p. 95
[1121] *Album Histórico de la Escuela Univ. de Minas de Copiapó 1857-1950* (Santiago, 1950)

The available numbers indicate that the provision of mining technicians was in general considerably higher than mining engineers. Nevertheless, in spite of a higher number of mining technicians there was a tendency of a relative decrease of mining technicians. Due to lack of the numbers of mining technicians at any given time, it is not possible to make the same estimate as for mining engineers. However, considering the large number of workers in the sector, sometimes over 100 000 workers, the number of graduates for the available years indicate that there were also very few mining technicians. The last chapter provide a further discussion on this matter.

10.3 Comparisons

Norway had a longer tradition with formal mining education than Chile. Formal mining engineering started in 1757 with the Mining Seminar in Kongsberg, while Chile opened the mining engineering program at the University of Chile more than a hundred years later, in 1854. At an intermediate technical level, on the other hand, Chile started a couple of years before Norway. The Mining School of Copiapó opened in 1857, while Kongsberg Silver Works Elementary Mining School was established ten years later, in 1867.

In spite of a longer tradition in Norway, the two mining educations were comparable from the mid-nineteenth century. In both countries, the mining engineering program represented a long study (4-6 years) and was theoretically and scientifically oriented, while mining technician programs were shorter (2-5 years) and more focused on practical excercices and work. Debates were raised in both countries about the content of the mining engineering instruction and how the programs should be organised. These discussions continued during the whole period and no general agreement was reached in either of the countries. In spite of some efforts to include more practice, the theoretic and scientific approach maintained both places. The debates reveal at least two things. First of all, engineers, industrial leaders, politicians and professors were all very much concerned with how the mining education programs should be organised and which subjects they should include. This consideration suggests that the industry was very much interested in recruiting formally trained graduates. Second, it was clear that one could not expect the graduates to be fully trained immediately after graduation. The instruction provided at the educational institutions most likely offered a solid scientific and theoretic preparation, but it was not enough. Professors in both Norway and Chile pointed out that to become capable engineers and technicians, knowledge of scientific theories should be combined with a long practice and hands-on work experience. These discussions were part of an on-going debate about whether formal technical education should be practically oriented or theoretically oriented, which is still going on today in many countries.

Were the formal mining instruction in the two countries relevant for the mining industries? In both countries, the educational institutions provided teaching of general natural science courses in combination with courses, which were directed towards specific tasks in mining. The foundation of the mining engineering programs were natural science courses, notably mathematics, physics, mechanics, geology, chemistry and mineralogy. Additionally, the programs included specific mining courses, such as the use and repair of mining machinery, courses about mine structures and constructions, metallurgy, ore survey etc. This combination of courses and subjects suggests that the mining engineers received thorough and in-depth instructions. The knowledge domains, on which mining activities were built, outlined in a previous chapter, roughly matched the mining engineering programs in both countries (see table below):

Simple overview of knowledge domains and mining engineering study programs

Knowledge domains (natural sciences)	Mining instruction in Chile		Mining instruction in Norway	
Mathematics Physics/mechanics Geology Mineralogy Chemistry Metallurgy (electro-engineering, magnetism etc.) Construction engineering Electro-engineering	**Continuous courses:** Mathematics Mechanics Geology Mineralogy Chemistry (metallurgy) Ore testing Ore surveys Mine measuring Utilisation of mines	**New courses (first adopted):** Drawing: 1889 Machines (specially applied to mines): 1889 Construction: 1889 Political economy and administrative law: 1889 Electro engineering: 1908	**Continuous courses:** Mathematics Mechanics Geology Mineralogy Mining construction Mine factory Metallurgy (ore treatment and analyses) Machine drawing	**New courses (first adopted):** Study of machines: 1871 Electro engineering: 1909 House construction: 1911 Social economics and law: 1911

It is clear that the educational institutions in both countries provided highly relevant knowledge for the mining sectors. Instructions in both countries combined theoretical learning, learning by observing and learning by doing by mixing different teaching forms:

1) Lectures in classrooms
2) Practical exercises, such as drawing and laboratory work
3) Geological excursions and visits to companies and plants
4) Working practice at mining companies

The mining technician programs included similar courses, but the teaching was based on a shorter introduction of these subjects. The somewhat shorter mining technician programs in both countries excluded in-depth teaching of scientific theories, but included instead more hands-on practice and excercises.

Changes were made continuously in the study programs in both countries. New courses and changes in the study programs happened normally after new technology had been adopted and spread throughout the sector. For instance, new courses in mining machinery were introduced in the programs after mining industries had started a mechanisation process. It was the same with electro-engineering, which was introduced as new courses both places in the early twentieth century, after the shift to electric power at many mining companies around the turn of the century (see table below):

Courses adopted in the mining engineering programs for the first time

Adoption of course in:	Norway	Chile
“machines”	1871	1889
“electro engineering”	1909	1908
“construction”	1911	1889
“economics, law and administration”	1911	1889

Additionally, specialisations and divisions were gradually made in the programs from the turn of the century, with one program focusing on mining and the other on metallurgy. These changes responded to the increasing number of productions, specialisations and new techniques that were adopted at the time. The study programs in both countries adapted to and supported the increasingly technologically complex mining industries.

Equipment and teaching facilities at the educational institutions were perhaps not in the best conditions. In both countries students, professors, company leaders, and others, complained about a lack of well-established laboratories, workshops, cabinets and other teaching facilities. However, the situation seems to have improved gradually. Old laboratories and workshops were upgraded and mining engineering instruction was moved to new institutions with better facilities. In Norway, this occurred when the mining program was transferred to the NIT in 1914 and in Chile, it happened as a new building for the engineering studies at the University of Chile was constructed in 1922.

Does formal mining instruction contribute to explain the more developed and better performing mining industries in Norway and the unorganised and less efficient mining productions in Chile? In terms of the qualitative content of instruction and courses, probably not. This comparative analysis of the study programs cannot conclude that the mining instruction in Norway was qualitatively different, or provided more relevant or useful knowledge for the mining industry than the one in Chile. Instead, the content of the study programs were remarkably similar in terms of courses, subjects, topics and teaching methods, except for some small variations in the setup and organisation of the courses. From 1889, the mining engineering program in Chile was longer than the one in Norway, which even suggests that the graduates from the University of Chile might have had a more solid scientific foundation than the ones from the Norwegian institutions. I argue, therefore, that the gap in development between the two sectors cannot be explained by differences in character, or quality, of the mining instructions.

Instead, differences become more apparent when it comes to number of graduates and numbers of engineers who studied abroad. Around one third of the Norwegian mining engineers studied partly or exclusively at foreign educational institutions. In the Chilean case, only six mining engineers studied abroad. Students at foreign institutions specialised in subjects and scientific areas, which were not taught in Chile and Norway and acquired contacts, which we have seen were vital for technology transfers. The fact that very few Chilean mining engineers studied abroad made it very difficult for them to acquire such valuable contacts and to become acquainted with foreign sciences and technology. There were, however, other ways for the mining engineers to obtain foreign knowledge, such as working experience and study trips abroad, which will be analysed in the next chapters.

To this point, the clear difference between the two countries is the number of mining engineers and technicians compared to the size of the two mining sectors. From 1850 to 1940, a period which both countries educated mining engineers, the total number was 287 in Norway, while it totalled 302 in Chile. There was a steady provision of mining engineers in both countries from the mid-nineteenth century, but given that the size of the mining sector in Chile was tenfold larger than the mining sector in Norway in terms of unutilised mineral deposits, number of workers, productions and exports, Chile's 15 additional mining engineers seems far too few. Thousands of small and big companies formed the mining industry in Chile and after the turn of the century, it increased to even more. It would seem impossible to cover all the leading positions at the mining companies, research and teaching positions at educational institutions, and so on, with this small number of mining engineer graduates. To cover all companies, as well as the University, Mining Schools and research institutions, several thousand mining engineers would have been required.

Estimates suggest that the mining sector in Norway had access to relatively more mining engineers than the mining sector in Chile. If the mining engineers had a career of forty years, there was a gradual decrease of workers per mining engineer after the turn of the century from ninety-two in 1905 to forty-six in 1940, which suggests that the relative number of mining engineers augmented. In Chile, on the other hand, the relative number of mining engineers declined. In 1885 there were 394 workers per mining engineers, while the number increased to 1395 in 1925, before it decreased to 755 in 1940 (see table below):

Number of workers per mining engineer in Chile and Norway
Estimated career of forty years

Year	***Norway***	***Chile***
1866	*71*	*903 (year 1865)*
1870	*65*	*552*
1875	*61*	*438*
1880	*45*	*404*
1885	*47*	*394*
1890	*64*	*421*
1895	*40*	*463*
1900	*68*	*447*
1905	*92*	*546*
1910	*73*	*805*
1915	*59*	*1 049*
1920	*35*	*1 145*
1925	*43*	*1 395*
1930	*51*	*1 242*
1935	*49*	*764*
1940	*46*	*755*

However, to find out in fact whether the supply of mining engineers and technicians was low in Chile and high in Norway, a further in-depth analysis of the career paths, travels and work of the mining engineers and technicians is appropriate.

11 Mining engineers, technicians and other professionals in Chile and Norway: discrepancy in extent

As seen, Chile and Norway differed significantly when it came to literacy. The emphasis in the literature on literacy as a condition for long-term economic growth suggests that it may explain the differences in development between the two countries. On the other hand, the supply and demand of mining engineers, technicians and other professionals directed specifically towards the mining sectors deserves attention.

As seen, the mining instruction was broad and included a variety of subjects, which were meant to cover the broad spectre of branches and operations within mining. However, mining engineer and technician graduates needed additional practice and work experience before performing as capable workers in the industry. Did the mining engineers and technicians in the two countries acquire any practical training? If so, what kind of training? Were there any differences in the two countries in this respect? Norwegian and Chilean mining engineers were specifically meant to lead operations at mining companies and processing, do scientific work, conduct geological ore surveys and mapping. The role of the mining technician was primarily to lead operations at the mines and work as the mining engineer’s assistant. Additionally, the increasingly complex technology in mining required professional workers with many different qualifications, notably in electro-engineering, construction engineering, mechanical engineering and chemists, but also other specialisations, in addition to mining engineering.

As seen in the previous chapter, educational institutions in Norway, including the ones who studied abroad, supplied comparatively more mining engineer and technician graduates than Chile, even though the mining sector in Chile was much larger than the Norwegian sector. This chapter goes further, discussing (1) the supply and demand of mining engineers from the industries’ perspective and (2) the supply and demand of all professional workers relevant for mining. These include domestically educated workers, workers who had studied abroad and foreign professional workers.

Did mining engineers and technicians work in mining? Were there enough workers with relevant skills in the two sectors? Were there any differences between the two countries in this respect?

11.1 Plenty of professionals in the mining sector in Norway

11.1.1 Enough mining engineers and technicians

Were there enough mining engineers and technicians in Norway? In the beginning of the nineteenth century after the mining education had been transferred to the University the number of mining engineer students was said to be too small. It was argued that this was due to too high admission requirements and a long and complicated study program.[1122] A lack of mining engineers was argued to have continued until the early twentieth century. In 1910, the mining engineer Holm Holmsen argued in Technical Magazine that foreigners and other types of engineers filled leading and engineering positions at “a number” of mining companies due to “lack of competent mining engineers”.[1123] Reviewing the backgrounds of the managers of five important mining companies confirms that foreigners were used. The French mining engineer Charles Defrance established the Vigsnes Copper Company in 1865 and became its director.[1124] Sultihjelma Mining Company was established by the Swedish Consul Nils Persson in 1886. At the Swedish Alten’s Copper Mines the German Fr. Schütz was the director of the company from 1897 and was replaced by a Swedish (Otto Witt) in 1902.[1125] Furthermore, highly regarded foreign engineers were sometimes contracted for specific tasks: Anton Sophus Bachke hired for instance the Swedish engineer Witt to elaborate a plan for removing rocks at one of the mines at Røros Copper Works at some time in the late nineteenth century.[1126] Orkla Mining Company used foreign directors in the first phase; in 1906, the Swedish Per

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[1122] See G. A. Blom, *Fra bergseminar til teknisk høyskole* (Oslo, 1958), pp. 124-125
[1123] *Teknisk Ukeblad* (Oslo, 1910), p. 632
[1124] F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005), p. 8
[1125] http://www.alta.museum.no/sider/tekst.asp?side=160 [accessed 29th March 2015]
[1126] F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005), p. 109

Larsson was director[1127] and in 1909 the German engineer F. Esser became technical director.[1128] After mining engineer Holm Egeberg Holmsen left the company, the Swedish mining engineer Waldemar Carlgren was hired and the English ore dressing engineer Herrmann was employed from 1907.[1129] The use of foreign professionals indicates that there was a shortage of engineers in the Norway. Then again, foreign companies were normally taken over by Norwegian engineers after a couple of years. In 1884, the mining engineer Olaf Aabel Corneliussen became manager at Vigsnes Copper Company.[1130] In 1912, August Nachmanson took over as administrating director at Orkla Mining Company and hired mining engineer Nils Erik Lenander as technical manager. In 1904 mining engineer Emil Knudsen became president of Alten's Copper Mines and the mechanical engineer Andreas Quale was appointed to director in 1905.[1131] In 1892, after his time at Vigsnes, Corneliussen became director of the Sulitjelma Mining Company.[1132] The provision of mining engineer graduates increased from the late nineteenth century and probably explains the replacement of foreigners by Norwegian engineers. By the late 1870s there were mining engineers graduating almost every years.

Chemists, mechanical and construction engineers sometimes acquired positions, which involved leading and organising mining operations. These were tasks, which were normally assigned to mining engineers. Was this another sign of a lack of mining engineers? Mining engineer Wolmer Marlow argued in 1926 that "…in a number of positions where one would expect to find mining engineers, these are filled by mechanical or construction engineers.[1133] Marlow's statement seems to have reflected reality to some degree, at least from the turn of the century. Mechanical engineer Botolf Bredesen, for instance, was mining engineer at Røstvangen Mines from 1906 before he became

[1127] Orkla Grube-Aktiebolag, *Løkken Verk En Norsk Grube Gjennom 300 År* (Trondhjem, 1954), p. 358
[1128] Orkla Grube-Aktiebolag, *Løkken Verk En Norsk Grube Gjennom 300 År* (Trondhjem, 1954), p. 364
[1129] Orkla Grube-Aktiebolag, *Løkken Verk En Norsk Grube Gjennom 300 År* (Trondhjem, 1954), pp. 359-360
[1130] *Studenterne fra 1868* (Kristiania, 1919), pp. 65-68
[1131] http://www.alta.museum.no/sider/tekst.asp?side=160 [accessed 29th March 2015]
[1132] *Studenterne fra 1868* (Kristiania, 1919), pp. 65-68
[1133] *Tidsskrift for kemi og bergvæsen* (Oslo, 1926), p. 31

construction engineer at the same company in 1908.[1134] Jon Mogstad, mechanical engineer, became ore surveyor at Kjøli Mines in 1906 and Carl Nielsen, mechanical engineer, was mining engineer at Folldal Mining Company from 1907 before he became manager at Stordø Pyrite Mines.[1135] Arne Forfang, construction engineer, worked as chief of ore dressing at Sulithjelma Copper Company from 1913 and Fredrik Hagerup Jenssen, construction engineer, worked as ore surveyor at Folldal Mines from 1906.[1136] Some of these engineers acquired managing positions at mining companies. Hans Abel Hjelm was mechanical technician in 1884 from Christiania Technical School and became later manager at a mine in Ofoten.[1137] Jens Westly, chemist from Bergen Technical School, worked as a chemist at the smelting plant at Sulithjelma Copper Company from 1904 before he became chief of the plant in 1906. He was employed at Elektrokemisk Ltd. from 1916 before becoming manager at Fiskå Works and technical director at Elkem Bjølvefossen Ltd. from 1928.[1138] However, the use of other engineers in these positions did not necessarily mean that there were too few mining engineers. As seen, mining companies used increasingly complex constructions and mechanical structures, which certainly required in-depth experience in this field. Engineers with educational background in these subjects were therefore an advantage, in combination with mining engineers.

Taking a closer look at the debate about mining education, we see that the focus was not on a lack of mining engineers, but on the content of the instruction and teaching facilities. It should be emphasised that Holmsen's statement in Technical Magazine in 1910 was in fact motivated by a desire to transfer the mining engineering program to the NIT, and with "lack of competent mining engineers" he referred principally to scarce teaching facilities at the University rather than too few

[1134] O. Alstad (red.) *Trondhjemsteknikernes Matrikel Biologiske meddelelser om samtlige faste og hospiterende elever av Trondhjems Tekniske Læreanstalt 1870-1915*, (Trondhjem, 1916)
[1135] O. Alstad (red.) *Trondhjemsteknikernes Matrikel Biologiske meddelelser om samtlige faste og hospiterende elever av Trondhjems Tekniske Læreanstalt 1870-1915*, (Trondhjem, 1916)
[1136] O. Alstad (red.) *Trondhjemsteknikernes Matrikel Biologiske meddelelser om samtlige faste og hospiterende elever av Trondhjems Tekniske Læreanstalt 1870-1915*, (Trondhjem, 1916)
[1137] *Festskrift i anledning af Kristiania Tekniske Skoles 25 aars jubilæum* (Kristiania, 1898)
[1138] L. Eskedal, *BTS-matrikkelen Ingeniører uteksaminert ved Bergen Tekniske Skole 1875-1975* (Bergen, 1975)

engineers. In fact, there are indications that there were too many mining engineers. After the turn of the century, the Committee, which evaluated the transfer of the mining study program from the University to the NIT, argued that "…the over-production of mining engineers that had taken place since 1905 was not justifiable."[1139] The mining engineer Wolmer Marlow affirmed later, in 1926, that "(t)he need for mining engineers in this country is not great. It is possibly room for one or two per year."[1140] This comment was related to the relatively small Norwegian mining industry. Even though productions augmented and the number of companies increased, the annual demand for mining engineers was not great. Even so, the number of graduates kept increasing, and far beyond two per year after this date. There was an increased interest for the mining engineering program, which was observed in the number of applicants. In the 1930s, the number of applicants was large, and according to Professor Harald Pedersen, they were not able to accept all of them.[1141] The fact that as many as one third of the mining engineers, 127, went to other countries to work at some point during their career, indicates that there was an overprovision of mining engineers. The majority of the ones who went abroad, 121, graduated after 1870, which was more or less from the time the number of mining engineers started to increase. On the other hand, the majority of the mining engineers who went abroad to work came back again to Norway. Only nine of the mining engineers stayed abroad and in 34 of the cases it is not clear whether they came back or not.[1142]

[1139] A. K. Børresen, *Bergtatt: Johan H. L. Vogt – professor, rådgiver og familiemann.* (Trondheim, 2011), p. 273
[1140] *Tidsskrift for kemi og bergvesen*, (Oslo, 1926), p. 31
[1141] *Tidsskrift for kemi og bergvæsen* (Oslo, 1935), p. 99
[1142] O. Alstad (red.) *Trondhjemsteknikernes Matrikel Biologiske meddelelser om samtlige faste og hospiterende elever av Trondhjems Tekniske Læreanstalt 1870-1915*, (Trondhjem, 1916); *Artiummatrikler studentene* [student yearbooks] (Kristiania/Oslo, 1855-1940); H. O. Christiansen et al. *25-års jubileumsberetning 1912-1937 Bergen Tekniske Skole Oslo Tekniske Skole Trondheim Tekniske Skole* (Norway, 1937); *Festskrift i anledning af Kristiania Tekniske Skoles 25 aars jubilæum* (Kristiania, 1898); R. Baggethun, *Horten Ingeniørhøgskole Horten tekniske skole En beretning om landets eldste tekniske skole gjennom 125 år* (Horten, 1980); S. Heier, *100 års biografisk Jubileums-festskrift, Horten Tekniske Skole 1855-1955* (Horten, 1955); KTS, *50 årsberetning om ingeniørkullet fra Kristiania Tekniske Skole 1896* (Oslo, 1946); Kristiania tekniske skole, *Ingeniørene fra KTS 1897-1947* (Oslo, 1947); *Ingeniører fra Kr.a Tekniske Skole 1897* (Kristiania, 1922); *K.T.S. ingeniørene av 1909: matrikkel utarbeidet til 25-års jubileet 1934* (Oslo, 1934); Oslo Tekniske Skole, *Skrift ved 50 års jubileet for ingeniørene fra K.T.S. 1894,* (Oslo, 1894), *KTS til Ingeniørkullet av 1910: 20 årsjubileum år 1910-1930* (Oslo, 1930); *Trondhjems Tekniske Mellomskoles virksomhet i de 3 første læseaar 1912-1915* (Trondhjem, 1916); *Skrift ved 50 års jubileet for ingeniørene fra K.T.S. 1894* (Oslo, 1944); L. Eskedal, *BTS-matrikkelen Ingeniører uteksaminert ved Bergen Tekniske Skole 1875-1975* (Bergen, 1975); TTL, *1897-1922* (Kristiania, 1922);

What did the mining engineers work with? Did they work in the mining sector in Norway at all? There were probably some periods in which it was difficult for mining engineers to acquire relevant work due to the fact that mineral prices fluctuated and the industry was volatile. In the late nineteenth century the professors Keilhau, Strecker and O. J. Brock told the students that mining engineering was a difficult profession and it was not always easy to acquire work.[1143] The mining engineer Emil Knudsen told about his work situation in the 1870s and explained that: "…there was little prospect of getting any job."[1144] Later, in 1926, mining engineer Wolmer Marlow argued that when exceeding two mining engineer graduates per year the rest were usually unemployed. If they were so lucky to come across other work, it normally had "…little or nothing to do with their education as mining engineers."[1145] Mining engineer John Nikolai Johns gives an example. He started first in mining, but explained in 1928 that: "(n)ow I, like many other engineers, had to earn a living outside my field."[1146]

There were probably times when mining engineers had problems acquiring relevant work, but it is important to stress that these statements were made during recession periods. In the 1870s-80s and the 1920s, the industry suffered from low prices and productions decreased. However, an analysis of the career paths of mining engineers suggests that the majority of the graduated mining engineers worked in mining productions or related activities. It has been possible to acquire information about all Norwegian mining engineers and their working careers between 1787 and 1940. Of all the 341 mining engineer graduates only twenty-one started to work in other sectors and one died young.[1147] This does not mean that all mining companies had mining engineers employed at all times, but it

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Trondhjem tekniske læreanstalt, *Festskrift ved Afslutningen av Trondhjems Tekniske Læreanstalts 25de Læseaar* (Trondhjem, 1895); B. Bassøe, *Ingeniørmatrikkelen Norske Sivilingeniører 1901-55 med tillegg* (Oslo, 1961)
[1143] *Tidsskrift for bergvæsen* (Oslo, 1916), p. 14
[1144] F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005), p. 58
[1145] *Tidsskrift for kemi og bergvæsen* (Oslo, 1926), p. 31
[1146] *Studentene fra 1903* (Oslo, 1928), p. 186
[1147] Alf Gudbrand Wang Berg graduated in 1911 and died in 1913.

shows that there was a steady provision to the sector. Actually, it was claimed in the Mining Journal in 1932 that ever since the mining engineering instruction transferred to the University in 1814 there were Norwegian mining engineers at “practically all the mining works.”[1148] There were mining engineers working in all sorts of mineral productions, such as copper, silver, iron, pyrite, nickel and aluminium (see appendix 14 for recruitment of mining engineers to companies). In the nineteenth century mining engineers worked at mining companies such as Kongsberg Silver Works, Røros Copper Works, Ulefoss Iron Works, Ytterøen Pyrite Mines, Værdalens Nickel Works, Vinoren Silver Works, Sigdal Nickel Works, Modums Blaafarve Works, Vigsnæs Copper Works, Evje Nickel Works, Hadeland Mining Works and Sulitjelma Copper Works. There was a tendency to work at large companies with several hundred workers. A closer look at the companies shows that the mining engineers were recruited to both domestic and foreign firms. After the turn of the century, they were recruited to new companies, notably Sulithjelma Mines, Sydvaranger Mine Ltd., Orkla Mining Company, Vigsnes Copper Works and Åmdal Copper Works. Many mining engineers were recruited to Røros Copper Works and Kongsberg Silver Works. From 1789 to 1940, fifty-two mining engineers worked at Røros Copper Works. The company employed gradually more and more mining engineers. Twenty-five of them, almost half, were hired after 1890.[1149] Mining engineers often started their career at Kongsberg Silver Works. This company recruited mining engineers continuously from early on. The students often did the obligatory practice there and continued as trainees, a position that was meant to provide newly graduated engineers the opportunity to practice.[1150] From 1793 to 1940, seventy-five mining engineers were registered at this company. From the 1830s, mining engineers were hired

[1148] *Tidsskrift for kemi og bergvæsen* (Oslo, 1932), p. 135
[1149] *Studentene fra… (1831-1943);* Den Norske Ingeniørforening, *Biografiske Oplysninger om Kandidater med eksamen fra Bergseminaret på Kongsberg*, 1932; G. Brochmann (red.), *Vi fra NTH de første 10 kull: 1910-1919* (Stavanger, 1934); Amundsen, *Vi fra NTH de neste 10 kull 1920-1929*, 1950; L. Eskedal, *BTS-matrikkelen Ingeniører uteksaminert ved Bergen Tekniske Skole 1875-1975* (Bergen, 1975); The Norwegian engineers who studied abroad is based on B. Bassøe, *Ingeniørmatrikkelen Norske Sivilingeniører 1901-55 med tillegg* (Oslo, 1961)
[1150] F. Sæland, *Bergingeniør Emil Knudsens erindringer Inntrykk fra et bergmannsliv 1856-1897* (Kongsberg, 2005), p. 58

every one to two years.[1151]

Mining engineers often made long careers in the mining sector. Thomas Georg Münster is a typical example. He did the practical test at Kongsberg Silver Works in 1879 and was amanuensis at the metallurgical laboratory from 1874 to 1881. Afterwards he moved back to Kongsberg to become aspirant at the Silver Works. In 1882, he became an assistant at the Norwegian Geological Survey. From 1888 to 1889, he worked as a secretary at the Silver Works and analyst of ore from 1890 to 1892, before he became coin guard (myntguardein)[1152] in 1892. From 1885 to 1896, he was member of the Silver Works' presidency.[1153] Another illustrating example is Laurits Weidemann Meinich, who graduated in 1861. In 1862, he became manager of Holtaalens Copper Works; in 1869 he became trainee at Kongsberg Silver Works; in 1866 manager at Grimeliens Copper Works; 1867 manager at Lindvikens Pyrite Mines, Hardanger; 1869 manager at Bøilestad Copper Works in Froland; 1872 manager of Rom Nickel Works in Askim; 1877 again trainee at Kongsberg Silver Works; from 1877-79 director at Kongsberg Elementary Mining School; from 1878 to 1880 assistant at the Norwegian Geological Survey; in 1880 coin master (myntmester); in 1899 Superintendent of mines in Southeastern Mining District, before becoming mayor in Kongsberg in 1891.[1154] Mining engineers' long careers in mining continued into the twentieth century. Halvard Dale, is another example of the many places a mining engineers worked during a career. He became mining engineer in 1919 and did practice at Kongsberg Silver Works, Tinfoss Iron Works and Dalen Mines. He subsequently worked as an engineer at professor Pedersen's Research Laboratory in Trondheim before he went to Germany and Austria on a study trip with the Orkla Fund in 1920. In 1922, he started as a chemist at Stordø

[1151] *Studentene fra… (1831-1943);* Den Norske Ingeniørforening, *Biografiske Oplysninger om Kandidater med eksamen fra Bergseminaret på Kongsberg*, 1932; G. Brochmann (red.), *Vi fra NTH de første 10 kull: 1910-1919* (Stavanger, 1934); Amundsen, *Vi fra NTH de neste 10 kull 1920-1929*, 1950; L. Eskedal, *BTS-matrikkelen Ingeniører uteksaminert ved Bergen Tekniske Skole 1875-1975* (Bergen, 1975); The Norwegian engineers who studied abroad is based on B. Bassøe, *Ingeniørmatrikkelen Norske Sivilingeniører 1901-55 med tillegg* (Oslo, 1961)

[1152] Responsible for the production of silver coins at Kongsberg Silver Works

[1153] *Studentene fra 1872* (Kristiania, 1897), pp. 129-130

[1154] J. K. Bergwitz, *Studentene fra 1856* (Kristiania, 1906), pp. 28-29

Pyrite Mines. In 1923, he went to Wilmington in the United States and worked as a chemist at V. Hybinette before he became a research engineer at Research Dep. Westinghouse El. & Mfg. Co. in Pittsburgh. In 1927, he returned to Norway and worked as a metallurgist at A/S Haugsvik Smelting Works in Glomfjord. Subsequently, he worked in the aluminium production and from 1946; he worked as head engineer at Årdal and Sunndal Works.[1155]

Although mining engineers were not meant for any particular position, leading positions and engineering work were the most common. Usual positions at the beginning of a career were assistant engineer positions, mining leader positions, chemists, geologists or operational engineers. 124 mining engineers worked as mine leader, operational engineer or head engineer some time during their career. Forty-seven mining engineers acquired a leading position at a processing or smelting plant as smelting masters, smelting accountants or metallurgists. 108 of the engineers acquired a position as manager or operational manager at a mining company or institution, eighty of the engineers acquired a directing position, and fifteen became a member of Board of Directors at a mining company. Forty-two mining engineers became mining superintendents.

Mining engineers were recruited to scientific and teaching positions. Seventeen of the mining engineers had an academic career and became professors either at the University or the NIT. It also occurred that professors went over to the industry after acquiring long scientific experience. Sjur Amundsen Sexe, for instance already worked as amanuensis at the Mineral Cabinet by the time he graduated in 1840. After graduation, he became aspirant at Kongsberg Silver Works and mining superintendent assistant in 1841. In 1846, he became mining superintendent at Kongsberg Silver Works, before he became a teacher at Nissen School in Christiania and lectured in physics at the University in 1852. In 1860, he became lecturer in mining construction and physical geography and

[1155] *Studentene fra 1915* (Oslo, 1965), pp. 46-47 functioned as professor for 1866.[1156] Another example is Alfred Getz who became mining engineer in 1889. From 1885 to 1889, he was amanuensis at the Mineral Cabinet at the University. He did field trips for Norwegian Geological Survey during studies. From 1889 to 1893, he was in Spain and worked as a mining assistant at Minas de Bedas. In 1894, he bought a company called A/S Werned and in 1899 was manager at Vigsnes Copper Works. In 1902, he worked at the Ministry of Finance as a consultant for mining affairs and 1903 he became administrating director at Røros Copper Works. In 1912, he became professor in mining at the NIT.[1157] These examples indicate that mining engineers acquired practical experience in both scientific research and mining companies. Some of the professors had close relationships with the industry and functioned as consultants for mining companies.[1158] The point to be made here is that the mining engineers had leading engineering and scientific positions at companies, research institutions and universities. This suggests that they normally acquired the work and positions that they were meant for.

What about the mining technicians? Were they considered enough? The mining companies sent workers to the Mining School in Kongsberg to be trained with the purpose of returning to their respective companies after studies, which meant that probably all the mining technicians started to work in mining. The majority of the technicians were from Kongsberg Silver Works, although some of them started to work at other mining companies later in their career.[1159] Røros Copper Works, for instance, sent workers continuously.[1160] Companies, both domestic and foreign, continuously recruited mining technicians. Normally large companies, such as Fehn Mines (Ulefoss Iron Works),

[1156] B. I. Berg, *Gruveteknikk ved Kongsberg Sølvverk 1623-1914* (Trondheim, 1998), pp. 439-443
[1157] *Studenterne fra 1880* (Kristiania, 1905), pp. 110-111
[1158] See A. K. Børresen and A. Wale (red.), *Vitenskap og teknologi for samfunnet? Bergfagene som kunnskapsfelt* (Trondheim, 2005); A. K. Børresen, *Bergtatt: Johan H. L. Vogt – professor, rådgiver og familiemann* (Trondheim, 2011)
[1159] Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966), p. 19
[1160] Andreas Kongsgaarden, graduated mining technician in 1880, became head of mine at Røros Copper Works in 1895; Johannes Medalen, graduated in 1884, became head of mine at Røros from 1900; Ole Hallgren and Knud Knudsen, graduated in 1901, became head of mine in 1902 and 1905; Peter Skancke, graduated in 1907, became head engineer at Røros in 1930; O. Øisang, *Rørosboka: Røros bergstad, Røros landsogn, Brekken og Glåmos kommuner: 3-4: Røros Kobberverks historie,* 2. Bind (Trondheim, 1942)

Sulitjelma Mining Company Ltd., Bossmo Mines and Kjøli Mine sent workers to the Mining School (see appendix 14 for recruitment of mining engineers to companies).[1161]

The debate about the mining technician education was also about the content of the instruction, subjects etc. rather than about an insufficient number of mining technicians. There are few indications of too few mining technicians, except between 1922 and 1937, the period in which the School was closed down. During this time, the industry called for the School to be reopened. Mining engineer and superintendent Carl Carsten Riiber claimed in 1935 that "…(q)ualified educated mining leaders are not to come by and the requirement of a satisfactory arrangement of the school can no longer be rejected."[1162] This possibly caused complications for mining companies for a while, but after the School reopened, there was again a steady provision of mining technicians to lead mines.

11.1.2 Large flow of professional workers

Mining engineers and technicians only represented a small share of the skills and specialists that were used in the mining sector. Did the mining industry have access to skilled workers and professionals? Were there workers in the industry with relevant education, i.e. construction engineers, mechanical engineers, electricians, economists etc.? An examination of the background of the workers entering the sector indicates that professional workers with formal education diversified by the turn of the century. Before the 1870s, only a couple of mining engineers totalled the professional workers in the sector. Later, from the late nineteenth century, workers with degrees in mechanical engineering, electrical engineering, construction engineering, chemistry, and others, gradually entered the sector (see appendix 16 for the composition of professional workers in the sector).

[1161] Statens bergskole, *Bergskolen 100 år Jubileumsberetning 1866-1966* (Trondheim, 1966), p. 21
[1162] *Tidsskrift for kemi og bergvæsen* (Oslo, 1926), p. 154

Professional workers normally acquired working positions, which were associated with their formal education. Jon Mogstad, for instance, graduated as mechanical engineer and worked as a mechanical engineer at Folldal Works from 1907.[1163] Birger Berg-Hansen graduated as electro-engineer and started to work as electro-engineer at Sulihjelma Copper Company in 1895.[1164] Peter Kjølseth studied electro-engineering at the Chalmers University of Technology around 1890 and also started to work at Sulitjelma Copper Company.[1165] This company began electric smelting of copper in the early twentieth century, which explains the entry of electro-engineers around this time. The correlation between education and work supports the argument that the knowledge, which the formal technical instruction represented, was relevant for mining companies.

Some professionals had long careers in mining. Vilhelm Birkedal Lange, for instance, graduated from Trondhjem Technical School in 1903 and started to work thereafter as an assistant at Løkken Mine. In 1906, he became construction engineer at Foldal Works and power plant and 1st assistant at the construction division at Orkla Mining Company in Meldalen. In 1919, he became director at the Bede Metal and Chemical Company, and from 1940, he functioned as administrating director at Røros Copper Works. In 1947, he became director at Killingdal Mining Company.[1166] The development of the metallurgical industry was in particular followed by a large flow of chemists (see appendix 16 for the composition of professional workers). Hans Thorvald Lindeman graduated as chemist in 1887 and started at Røros Copper Works in 1888 as a chemist.[1167] Birger Olof Gerhard Dillner graduated as a chemist in 1900 and worked as a chemist from 1905 at the Northern Mining Company.[1168] Halvor Johnsen Bentzrud, graduated chemist in 1901, started to work as a chemist at Tinfoss Iron Works

[1163] O. Alstad (red.) *Trondhjemsteknikernes Matrikel Biologiske meddelelser om samtlige faste og hospiterende elever av Trondhjems Tekniske Læreanstalt 1870-1915*, (Trondhjem, 1916)
[1164] *Studenterne fra 1897* (Kristiania, 1922), pp. 20-21
[1165] *Studenterne fra 1885* (Kristiania), p. 153
[1166] O. Alstad (red.) *Trondhjemsteknikernes Matrikel Biologiske meddelelser om samtlige faste og hospiterende elever av Trondhjems Tekniske Læreanstalt 1870-1915*, (Trondhjem, 1916)
[1167] O. Alstad (red.) *Trondhjemsteknikernes Matrikel Biologiske meddelelser om samtlige faste og hospiterende elever av Trondhjems Tekniske Læreanstalt 1870-1915*, (Trondhjem, 1916)
[1168] O. Alstad (red.) *Trondhjemsteknikernes Matrikel Biologiske meddelelser om samtlige faste og hospiterende elever av Trondhjems Tekniske Læreanstalt 1870-1915*, (Trondhjem, 1916)

around 1905.[1169] Workers with formal education in economy, administration and law also entered the sector from the turn of the century. Jens Edvard Thomle, for example, graduated as lawyer from the University of Oslo in 1886 and was bookkeeper at Kongsberg Silver Works from 1895 to 1900.[1170] Elling Bolt Holst Bang graduated from a business school in 1905 and was employed at Sulitjelma Mining Company after studies.[1171] Eilert Sundt-Ohlsen graduated from high school in 1905 and took courses in economics and commerce. He worked as an office clerk at Salangen Mining Company after studies before he moved to Zabrze in 1910 to work for the same company. In 1912, he started to work at Sydvaranger Mining Company at the office in Kirkenes before becoming office manager in 1919 and later assistant director at the same company.[1172]

The recruitment to Løkken Works illustrates the variety of professionals and specialists at the companies and the high technical level. The firm started copper mining in 1654 in Meldal near Trondheim and worked on extracting the largest deposit of copper sulphide in Norway. By the end of the nineteenth century, there was a need to increase production to obtain a profitable operation. In 1904, Løkken Works was taken over by the Swedish Orkla Mining Company and major technological changes were carried out.[1173] First of all, the number of workers increased from around 10 to over 400 in 1906 and around 670 in 1911.[1174] Advanced equipment, such as mining pumps for drainage, air-driven drilling machines, dynamite, compressors, pumps etc. were installed and production increased drastically. The equipment was operated by electric power.[1175] These technological changes were supported by an increased diversification in the workers' educational background. In the nineteenth century, only a couple of professional mining superintendents were involved in mine

[1169] L. Eskedal, *BTS-matrikkelen Ingeniører uteksaminert ved Bergen Tekniske Skole 1875-1975* (Bergen, 1975)
[1170] *Studentene fra 1879* (Kristiania, 1904), pp. 216-219
[1171] *Studentene fra 1904* (Oslo, 1929), p. 19
[1172] *Studentene fra 1905* (Oslo, 1930), pp. 390-391
[1173] Orkla Grube-Aktiebolag, *Løkken Verk En Norsk Grube Gjennom 300 År* (Trondhjem, 1954), p. 253
[1174] Bergverkstatistikk, 1906; Bergverksstatistikk, 1911
[1175] Orkla Grube-Aktiebolag, *Løkken Verk En Norsk Grube Gjennom 300 År* (Trondhjem, 1954), p. 254

surveying and the organisation of production.[1176] Later, from the end of the nineteenth century a range of workers with different types of education were employed. The majority of these workers were mining engineers, but there were also a number of electro engineers, mechanical engineers, construction engineers and chemists (see table below):

Recruitment of professional workers at Løkken Works (Orkla Mining Company)

Year started*

Year	Mining engineers	Electro engineers	Mechanical engineers	Construction engineers	Chemists	High school	Military background	Lawyers	Water, road and bridge engineers	Ship building engineers	Unknown	Total
1895-00			1									**1**
1901-05	2		1	1								**4**
1906-10	6**		2	3	1*****						1	**13**
1911-15	5 ****	1		3		1	2				1***	**13**
1916-20	4	4		3			1		1	1		**14**
1921-25	2	1	1								1	**5**
1926-30	1	3			4	2						**10**
1931-35	2	2	6		3						1	**14**
1936-40	4	2	1	1	2	2		2	1			**15**
Total	**26**	**13**	**12**	**11**	**10**	**5**	**3**	**2**	**2**	**1**	**4**	**89**

*In some cases, the year of employment is unclear, but with a time-span of five years, it has been possible to roughly chategorise when the professional workers started at the company.

** incl. two foreign engineers; Swedish engineer Per Larsson and Waldemar Carlgren and German engineer d Esser; mining engineer Fredrik Nybom is mentioned in *Løkken Verk*, but is not to be found in the lists over Norwegian mining engineers; he might have been a foreign mining engineer

*** August Nachmanson, managing director from 1912, probably had formal education, but his background is unknown.

**** incl. Swedish engineer J. Witting; The Swedish district master Norelius was hired together with the Swedish engineer J. Witting, but his background is unknown

***** English ore dressing engineer Mr. Herrmann

Sources: Studentene fra… (1831-1943); Den Norske Ingeniørforening, Biografiske Oplysninger om Kandidater med eksamen fra Bergseminaret på Kongsberg, 1932; Brochman, *Vi fra NTH de første 10 kull 1910-1919*, 1934; Amundsen, *Vi fra NTH de neste 10 kull 1920-1929*, 1950; L. Eskedal, *BTS-matrikkelen Ingeniører uteksaminert ved Bergen Tekniske Skole 1875-1975* (Bergen, 1975); The Norwegian engineers who studied abroad is based on *Ingeniørmatrikkelen* by Bjarne Bassøe and Orkla Grube-Aktiebolag, *Løkken Verk*, 1954

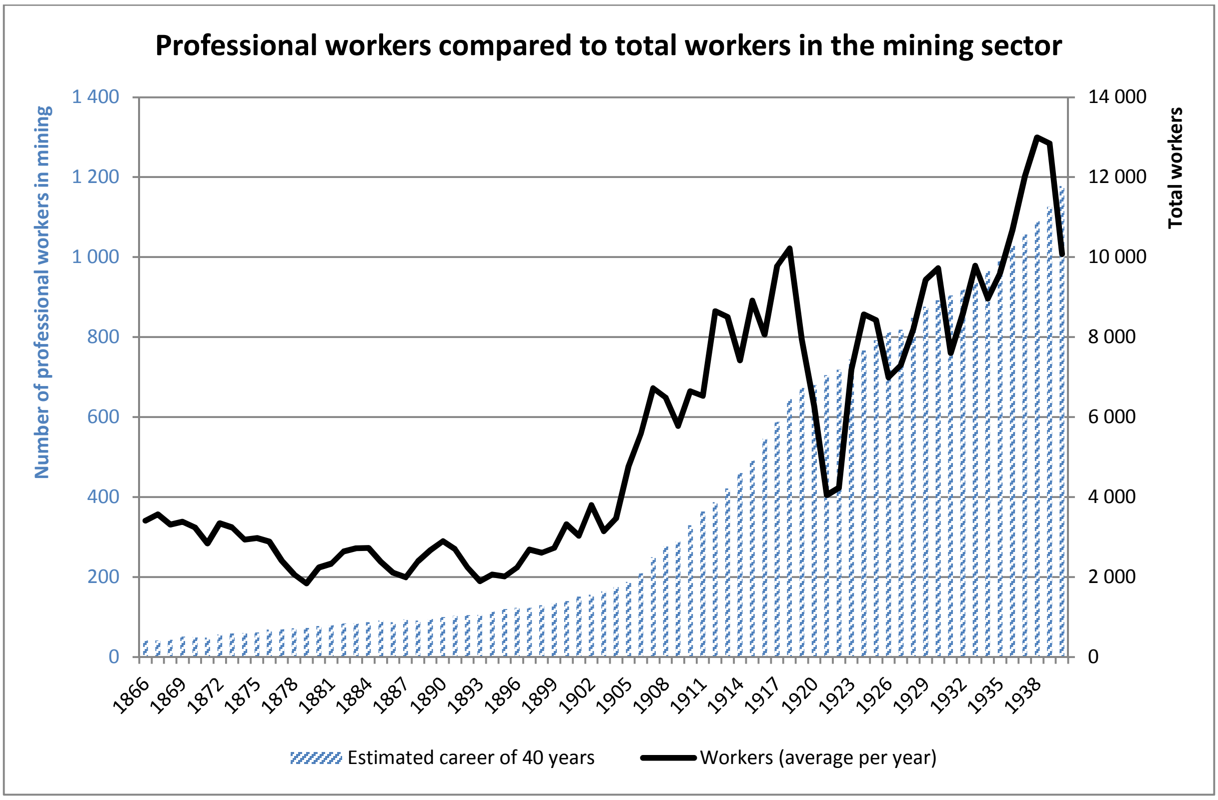
[1176] Henrick Christian Strøm, mining engineer from the Kongsberg Mining seminar and Freiberg Mining Academy, did surveys at the Løkken mine in the early 19th century, Mathias Wilhelm Sinding, mining engineer from the University of Christiania, contributed to a reorganisation of the production from copper to pyrite-copper in the mid-19th century and August Schønbek Ellefsen, mining engineer from the University of Christiania, was involved in evaluations of the operation in the late 19th century: Orkla Grube-Aktiebolag, *Løkken Verk En Norsk Grube Gjennom 300 År* (Trondhjem, 1954), pp. 115, 120 and 128

Some of the mining engineers had a long career in the company. Mining engineer Torfinn Natrud, for example, was hired at the company in 1928 after he had worked at Røros Copper Works. In 1930, he became construction leader for Orkla Metal, one of the divisions of the company, and became later manager for the company.[1177] Mining engineer Arne Okkenhaug was hired as second engineer at the company in 1918. He left the company to work as assistant professor in mining and ore dressing at the NIT from 1921, but returned to the company in 1922. From 1938, he was first mining engineer and head engineer from 1952.[1178] Some of the other professionals also had a long career in the company. Fredrik Sophus Ringe, for example, had a background from the military and graduated from a military academy in 1901. He started to work at the company in 1918 as an accountant before he became main cashier in 1921 until 1945.[1179] The construction of railway and the use of electricity to provide power to drills, drainage equipment and lightening demanded employment of electro-engineers, mechanical engineers and construction engineers from the early twentieth century. Electricity was also used later, for transport and lifts inside the mines.[1180] In 1931, a new smelting plant was established, and this explains the increase of chemists from the late 1920s.

As for the whole sector the number of professional workers increased. Before 1900, less than ten graduates were recruited each year, while there were 62 in 1916, after a down period from the 1920s. An analysis of the professionals in the industry indicates that their share of all workers increased. There is a lack of information about the length of their career, which makes it difficult to find out about the total number of professional workers at any given time. Many of the workers, especially other specialists than mining engineering, did often not work in the mining sector during their whole career and sometimes switched sectors. Since the length of their working period in the mining sector varied considerably, it is very challenging to make a correct estimate. Given that they

[1177] *Studentene fra 1907* (Oslo, 1932), p. 279
[1178] *Studentene fra 1914* (Oslo, 1939), p. 232
[1179] *Studentene fra 1898* (Oslo, 1923), pp. 264-265
[1180] T. Bergh et al. *Brytningstider: Orklas historie 1654-2004* (Oslo, 2004), p. 39

had an average career length of forty years, the professionals compared to total workers would be as outlined in the table below:



*In 79 of the cases, the exact year of employment in the mining sector is uncertain.
Calculations based on Bergverksstatistikk (1866-1940); Studentene fra… (1831-1943); Den Norske Ingeniørforening, Biografiske Oplysninger om Kandidater med eksamen fra Bergseminaret på Kongsberg, 1932; Brochman, Vi fra NTH de første 10 kull 1910-1919, 1934; Amundsen, Vi fra NTH de neste 10 kull 1920-1929, 1950; L. Eskedal, BTS-matrikkelen Ingeniører uteksaminert ved Bergen Tekniske Skole 1875-1975 (Bergen, 1975); The Norwegian engineers who studied abroad is based on Ingeniørmatrikkelen by Bjarne Bassøe.

With the approximation of forty year careers in the mining sector workers with education as share of all workers in the sector is roughly estimated. Although 40 years is possibly an exaggeration for many of the workers, it gives us an indication of their proportion. Using this estimate the share of professional workers increased gradually from 1, 2 per cent in 1866 to 6 per cent in 1895 and 11 ,7 per cent in 1940 (see table below):

Professional workers as share of total workers
Estimated 40 years career in mining

Year	Workers (average per year)	*Estimated number of professional workers in mining*	*Estimated professional workers as share of total workers in mining*
1866	3408	*42*	*1,2*
1870	3239	*50*	*1,5*
1875	2978	*62*	*2,1*
1880	2240	*78*	*3,5*
1885	2383	*92*	*3,9*
1890	2899	*100*	*3,4*
1895	2015	*120*	*6*
1900	3319	*140*	*4,2*
1905	4768	*188*	*3,9*
1910	6652	*330*	*5*
1915	8917	*491*	*5,5*
1920	6267	*680*	*10,9*
1925	8427	*792*	*9,4*
1930	9727	*892*	*9,2*
1935	9594	*991*	*10,3*
1940	10074	*1178*	*11,7*

Sources: Bergverksstatistikk (1866-1940); *Studentene fra… (1831-1943);* Den Norske Ingeniørforening, *Biografiske Oplysninger om Kandidater med eksamen fra Bergseminaret på Kongsberg*, 1932; Brochman, *Vi fra NTH de første 10 kull 1910-1919*, 1934; Amundsen, *Vi fra NTH de neste 10 kull 1920-1929*, 1950; L. Eskedal, *BTS-matrikkelen Ingeniører uteksaminert ved Bergen Tekniske Skole 1875-1975* (Bergen, 1975); The Norwegian engineers who studied abroad is based on *Ingeniørmatrikkelen* by Bjarne Bassøe.

The large, and increasing, number of professionals indicates that the provision was plentiful. However, even if the number and share of professional workers increased, did the mining industry consider their demand to be covered? The ongoing debate in newspapers and technical journals suggests that there was not a lack of supply. The discussion was not about a shortage of professionals and specialists, but instead about whether the educational institutions created too many of them.[1181]

[1181] An exception is the aluminium industry, which developed from the early 20th century. Foreign engineers were heavily involved in the development of this industry. This was argued to be due to lack of knowledge in this area among Norwegian engineers: E. Storli, *Out of Norway Falls Aluminium* (Trondheim, 2010), pp. 71-73 and 148. On the other hand, Norwegian engineers were also involved in this industry. First of all, Professor Harald Pedersen made a process for smelting of bauxite with limestone and coke to obtain a high quality sulfur-free pig iron and aluminium-rich slag in electric ovens. This process was the basis of the production at Norwegian Aluminium Company. Furthermore, there were Norwegian engineers employed at these companies too. The Norwegian construction engineer Sigurd Kloumann was also involved in the establishment of Norwegian Aluminium Company, together with the chemist Emil Collett. They were both appointed managing directors at the company. The student yearbooks refer to a number of graduates who worked in the aluminium industry, for example mining engineer Gustav Newton Kirsebom became consultant for Norwegian Aluminium Company, mining engineer Rolf Mastrander became engineer geologist at the same company in 1917 and

This was seen in connection with the fact that many technicians and engineers went abroad to work. The emigrating engineers were part of a larger emigration of Norwegians, which started in the early nineteenth century. After the creation of the three technical schools in Christiania, Bergen and Trondheim in the 1870s, at least half of the cohorts each year left the country.[1182] In this context it was discussed whether the emigration affected industrial development negatively. With a large departure of engineers leaving Norway there were few left to develop industries in the country. For instance, in 1886 Technical Magazine wrote that:

> "(l)arge quantities of young skilled men, artisans and factory workers emigrate to countries where their intelligence is made useful…[…] It would be interesting to see how much technical skills that has gone to waste for our country because they have had to seek their education abroad and then remained there."[1183]

Emigration of technicians and engineers also continued after the creation of the NIT. The historian Gudmund Stang found that between 1870 and 1930 there was a gradual increase in the number of Norwegian engineering graduates leaving Norway. The peak year was 1924 when more than 150 engineers went abroad.[1184] Professor Harald Pedersen referred to this emigration of engineers in an article in 1929. He saw this in connection with a lack of work opportunities in Norway.[1185] In the late 1920s, the economy was in recession, which resulted in a high degree of emigration of engineers in this period, he argued.[1186] This changed in the 1930s. By this time, Stang finds that there was a

electrochemist and metallurgist Gunnar Schjeldrup was member of the Executive Board for this company from 1938: http://nbl.snl.no/Harald_Pedersen [accessed 29th March 2015]; http://nbl.snl.no/Sigurd_Kloumann [accessed 29th March 2015]; *Studentene fra 1904* (Oslo, 1929); *Studentene fra 1907* (Oslo, 1932); G. Brochmann, *Studentene fra 1913* (Oslo, 1938)

[1182] G. Stang, "Ble det for mange ingeniører?" in *Trondheim Ingeniørhøgskole 1912-1987 Festskrift til jubileumsfeiringen 31. oktober 1987* (Trondheim, 1987), p. 34

[1183] My translation: *Teknisk Ukeblad* (Kristiania, 20 May, 1886), pp. 101-102

[1184] Stang, "The Dispersion of Scandinavian Engineers 1870-1930 and the Concept of an Atlantic System", STS-Working Paper No 3/89, 1992, p. 26

[1185] *Dagen*, 9th April 1929, Bergen

[1186] *Adresseavisen*, Trondheim 1st of July 1929 massive re-emigration of engineers.[1187] As seen in the previous chapter, work experience abroad contributed directly to transfer of knowledge and innovation in the Norwegian mining sector. In the same line of argument, Professor Harald Pedersen encouraged working abroad and was not concerned about engineers leaving the country:

> "I myself find it very convenient that the engineer and architect go abroad at a young age. Some come home with useful experience, and those who remain abroad can often do great services for their country."[1188]

The travelling workers probably encouraged industrial developed, more than prevented it. The point to be made here is that there was no general agreement that there was a lack of engineers in the country.

11.2 Few professional workers in the mining sector in Chile

11.2.1 Few mining engineers and technicians

Professors and members of the National Mining Society continuously complained about the lack of mining engineers in Chile. Articles were written almost every year about the problem of the scarce number of students at the University and mining engineers in the sector (see appendix 17 for list of articles in the Mining Bulletin in which a lack of mining engineering students or mining engineers were, discussed or mentioned). The National Mining Society and professors at the University of Chile were all concerned that the number of mining engineers was too small. In 1910, professors at the Faculty of Mathematics pointed out with concern that the lack of mining engineering students: "…has been felt even more in recent times".[1189] Compared to other engineering studies the mining

[1187] Stang, "The Dispersion of Scandinavian Engineers 1870-1930 and the Concept of an Atlantic System", *STS-Working Paper* No 3/89 (1992), p. 41
[1188] My translation: H. Pedersen, «Den tekniske høiskole er i kontakt med storindustrien», *Bergens Tidende* (9 of April 1929)
[1189] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1910), p. 115

engineering program was the least popular. Between 1898 and 1918, only twenty-three engineers chose to specialise in mining, while 304 studied to be civil engineers.[1190] The number of mining engineering students did not increase much after this. During the 1910s and 1920s, the number of civil engineer students was around ten higher than the mining engineer students.[1191] This was a tendency, which maintained. In the annual report of the University of 1913 Counsellors of the Faculty of Mathematics declared that mining companies constantly requested more mining engineers.[1192] From around 1919, the lack of students and engineers seemed to have been particularly scarce, as the lack of these was mentioned several times each year. Yet, not only professors were concerned about the number of mining engineering students. Mining company leaders, consultants and engineers in the mining sector wrote continuously about the lack of available mining engineers. The National Mining Society consisted of owners of mines, company leaders and engineers and published articles on this subject almost every year (see appendix 17). The Mining Bulletin wrote in 1925 that the fact that Chile was "in essence a mining country" was not in line with the fact that civil engineering was a much more popular study program than mining engineering. It was explicitly stated that "the number of mining engineers graduated in Chile was not enough to cope with the demand".[1193] Eleven years later, in 1936, the National Institute of Mining Engineers still argued that the lack of professionals for the mining sector was felt each day and that the University did not provide a sufficient number of mining engineer graduates.[1194]

Were there mining engineers at all working in the Chilean mining sector? In 1910, professors at the University of Chile argued that there were too few jobs for mining engineers after they finished their studies.[1195] However, his comment does not necessarily mean that they did not acquire work in the

[1190] R. Mellafe et al., *Historia de la Universidad de Chile* (Santiago, 1992), p. 122
[1191] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1925), p. 663
[1192] *Anales de la Universidad de Chile* (Santiago, 1913), pp. 66-67
[1193] My translation: *Boletín de la Sociedad Nacional de Minería* (Santiago, 1925), p. 663-4
[1194] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1936), p. 379
[1195] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1910), p. 115

sector, only that the competition might have been hard. In 1877, Ignacio Domeyko confirmed that mining engineers worked in mining. He stated in a report that "many mining engineers and surveyors" led some of the most important mines of the country.[1196] Of the seventy-three mining engineers that are traced between 1850 and 1940 they all worked in mining, or did related work, expect for one who worked in the railway industry.[1197] Although there is not information about all the graduates, it is an indication that there was at least work for them in the industry. Mining engineers often became leaders of mining productions, such as saltpetre, silver, copper, iron, gold, tin, coal and so on. Mining engineers worked at large companies with several thousand workers, but also smaller pirquen dominated companies. An interesting observation is that there was a tendency for the mining engineers to work at domestic companies. Many of the engineers worked at companies such as Coal Company of Lota, the Magallanes Coal Society, Parga Coal Company, Descubridoras of Caracoles Mines and the Desengano Mining Society, Los Bronces Operating Mining Company etc. (see appendix 18 for mining engineers employed at companies). Except perhaps for the coal companies, these were not large-scale advanced companies, but rather small-scale technologically backward firms.

Mining engineers had working positions which involved being in charge of a section, division or a whole company. Sixteen mining engineers were registered as managers and twenty-one as directors of one or more mining companies or institutions. As the Chilean mining engineers, as the Norwegian ones, often worked at numerous mining companies during their career. An illustrating example is Otto Harnecker who graduated in 1867. He was hired at the Coal Company of Lota, but worked also in copper mining, in Caracoles with silver mining, with the extraction of saltpetre in Pisagua and

[1196] I. Domeyko, "Reseña de los trabajos de la Universidad desde 1855 hasta el presente", in *Anales de la Universidad de Chile* (October 1872), pp. 577-578

[1197] Eugenio Bobiller Luiparra, graduated in 1882, worked at San José de Oruro Company in Bolivia and Huanchaca Company of Bolivia

Tocopilla and established later Peña Blanca, a copper foundry plant.[1198] Carlos Avalos became mining engineer in 1877. He was hired by Matías Cousiño at the Coal Company of Lota as ore surveyor and consultant of legal issues.[1199] He was also member of the Board of Directors at Mining Company of Collahuasi Ltd. and functioned as consultant for different companies. He made for instance reports of the tin industry and the Chuquicamata copper mine.[1200] The tendency to work different places continued after the turn of the century. Another example is Ernesto Muñoz Maluschka who graduated in 1918. He became administrator of the silver firm Mining Company Las Vacas after studies, before administrating the copper firm Mining Company of Chañaral. He was in charge of the technical division at the Mining Company of Aconcagua from 1922 and became later chief of the technical division of the Credit Bank of Mining. He also administered a large gold mine as and became consultant engineer at several silver and copper companies.[1201]

There were few Chilean mining engineers at foreign companies. Five Chilean mining engineers were registered at foreign companies, namely the Mining Company Monte Blanco (Bolivian and Chilean), Anglo-Chilean Company of Collahuasi (English and Chilean), Bethlehem Chile Iron Company (North American) and Río Blanco Copper Corporation (North American). Additionally, in the annual report of the University in the year 1922 it was affirmed that sixteen of the graduated engineers worked at a saltpetre company in the northern part of Chile, of which companies were often British.[1202] However, these examples are few and there were in fact no mining engineers working at the large famous North American copper companies. Hence, Chilean mining engineers were very little involved in

[1198] A. Millán Urzúa, *La minería metalica en Chile en el siglo XIX* (Chile, 2004), pp. 80-81; *Boletín de la Sociedad Nacional de Minería* (Santiago, 1929), pp. 375-6
[1199] A. Millán Urzúa, *La minería metalica en Chile en el siglo XIX* (Chile, 2004), pp. 80-81
[1200] Prospecto de la Socidad Anónima Minera Riqueza de Collahuasi, *Informe i planos* (Santiago, 1907); C. G. Avalos et al., *Sociedad Estañífera "Totoral" Informe de los injenieros Srs. Carlos G. Avalos, José Richards, M. I. M. M. Y A. Toro Lorca* (Santiago, 1906)
[1201] E. Muñoz Maluschka, *Andina Historia del nacimiento de una mina* (Chile, 1987), p. 55; *Boletín de la Sociedad Nacional de Minería* (Santiago, 1931); Compania de Chañaral y Taltal, *Undecima memoria y balance* (Santiago, 1936); La Compañía Minera "Las Vacas", *Informe 1920,* (Valparaíso, 1921); Instituto Minera Tarapaca, *Memoria* (Iquique, 1940); Compañía Minera de Chañaral, Memoria y balance (Santiago, 1925)
[1202] Anales de la Universidad, *Memoria de la Universidad de Chile, 1922* (Santiago, 1923), p. 166

these projects.

On the other hand, mining engineers were involved in the development of public institutions, notably teaching and scientific research. Twenty-five mining engineers became professors at the University, the Mining Schools or other technical schools. Moreover, public institutions, which aimed to promote mining productions and industrial development in the mining sector, were gradually established from the turn of the century. The Department of Saltpetre and Mining, Department of Mining and Petroleum and the Ministry of Development, both established in 1930, were state institutions with the purpose of encouraging mining. The Credit Bank of Mining was established in 1927, evaluated mining districts, and provided loans to domestic companies that wished to utilise minerals in the country. One particular objective was to reduce the dominance of foreign companies in the copper production.[1203] Twelve mining engineers worked at these institutions.

However, there were few examples of links between the University and the industry and professors doing work for mining companies, as there were in Norway. Professors were concerned with the mining industry, and often commented on different subjects, but there were no continuous use of University laboratory for innovation purposes. An exception was in the start-up phase of Braden Copper Company, when William Braden used the laboratory at the University of Chile to analyse ore samples from the mine.[1204] Ferranti and colleagues find that the few links between universities and industries partly explain the low degree of industrial development in the mining sector. They stress that "… even today, there is relatively little interaction between the copper companies and universities or other think tanks."[1205]

Civil engineers, of whom there were many more, replaced mining engineers to a certain degree. In

[1203] Law number 4 112, Credit Bank of Mining
[1204] L. Hiliart, *Braden Historia de una mina* (Chile, 1964), p. 51
[1205] D. De Ferranti et al. *From Natural Resources to the Knowledge Economy* (Washington D. C., 2002), p. 61

the Mining Bulletin of 1925 the National Mining Society explained that "a large number of" the civil engineers from the University started to work in the industry even though they did not have knowledge of and experience in mining.[1206] They worked in mining, as it was stated, first of all because of the lack of mining engineers. Companies hired civil engineers because there were no mining engineers to be found.[1207] Mining technicians also worked as substitutes for mining engineers. Some of the mining technicians acquired positions that were meant for engineers, that is to say leading divisions and departments at mining companies. For instance, the director of the Mining School of Copiapó Guillermo Amenábar Ossa, found that mining technicians from the two Mining Schools of La Serena and Copiapó fulfilled the functions of "…mining leaders, assayers and engineers, preparing maps and solving communication problems and ventilation etc."[1208] Although it was common for mining technicians to have intermediate positions, some acquired managing positions. After he had worked as a planner in Lota until 1912, a surveyor in Chañaral, engineer at Pampa Austral Company and map planner in Santiago Nicoás Puelma Quevedo became administrator at numerous companies.[1209] With the small number of mining engineers, it was perhaps natural that mining technicians, with a similar education, only less theoretic, took their place when needed.

What did the mining technicians do after finished graduation? Some argued that mining technicians normally did not start to work in mining. The Mining Bulletin wrote in 1910 that the majority of the mining technicians started to work in other sectors. Engineer Carlos Schulze stated that only in a few cases were ex-students of the mining schools hired to the mining industry. According to him "…most of them, after completing their studies, [did] not engage in mining and pursue[d] other careers."[1210] However, a number of references, statements and articles of the time suggest the majority of the

[1206] *Boletin de la Sociedad Nacional de Minería*, (Santiago, 1925), p. 663-4
[1207] *Boletin de la Sociedad Nacional de Minería*, (Santiago, 1925), p. 663-4
[1208] *Revista minera, sostenida por los profesores de la escuela practica de minas de Copiapó* (agosto 1918), p. 13; (octubre 1918), p. 6
[1209] Escuela de Minas de Copiapó, *Boletin Centenario Escuela de Minas de Copiapó 1857-1957* (Santiago, 1957), p. 12
[1210] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1910), p.. 330

mining technicians made careers in mining. In 1877, Ignacio Domeyko confirmed that the mining industry recruited graduates from the Mining Schools of La Serena and Copiapó.[1211] A magazine published by the Mining School of Copiapó listed the work of eighty-eight graduates from 1902 to 1917 and found that "near all" worked in the mining sector or with work related to mining.[1212] Thirty-nine of these worked at mines, processing plants, saltpetre industry or laboratories; twenty-nine worked in engineering, in Chile or abroad, in the fiscal saltpetre delegation or as drawers in technical offices; four worked as professors; one continued studies to become electrical engineer; four worked in "different occupations"; three died early and the situation of eight were unknown.[1213] Claudio Canut de Bon Urrutia supports this argument and affirms in his book *Escuela de Minas de La Serena* that the graduates from this school acquired work at mining companies immediately after studies.[1214] The Mining Bulletin confirms that mining technicians worked in a broad spectre of operations and positions, such as saltpetre, copper, metal processing and other productions. Much later, in 1937 "several graduates" from the Mining School of La Serena worked in the sector, according to the Mining Bulletin: "Several of these stand out in extraction of mines, in processing plants, in saltpetre companies, in laboratories etc."[1215]

It has been possible to track some of the mining technician graduates from the Mining School of Copiapó and learn more about their careers and work. The *Centenary Newsletter of the Mining School of Copiapó* reveals information about 192 of the graduates and ex-students between 1891 and 1940 from the Mining School of Copiapó. 154 of them worked either at mining companies or other institutions related to the mining sector (see appendix 20 for mining technicians employed at

[1211] I. Domeyko, "Reseña de los trabajos de la Universidad desde 1855 hasta el presente", in *Anales de la Universidad de Chile* (October 1872), pp. 577-578
[1212] *Revista minera, sostenida por los profesores de la escuela practica de minas de Copiapó* (agosto 1918), pp. 8-10
[1213] *Revista minera, sostenida por los profesores de la escuela practica de minas de Copiapó* (agosto 1918), pp. 8-10
[1214] C. C de bon Urrutia, *La Escuela de Minas de La Serena Derroto de sus Orígenes* (La Serena, 1992), p. 95
[1215] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1937), p. 1424

companies).[1216] Twelve of the graduates from this School worked in teaching and research and became teachers or professors at industrial schools or at the University.[1217] Another common career was the Credit Bank of Mining. Thirty-one of these technicians worked at the Credit Bank of Mining, an institution that sought to promote domestic mining productions.[1218] Nevertheless, the majority worked directly with mining operation at different mining companies. Domestic companies, referred to in the Newsletter, were the Coal Company of Lota, the Mining Company of Taltal, Mining Company of Coquimbo-Atacama, the National Smelting Plant of Paipote, Elisa de Bordos Mining Company and the Mines of Don Federico Melendez.

Mining technicians, in contrast to the mining engineers, worked at both domestic and foreign companies. In the British-dominated saltpetre industry, there were a total of twenty mining technicians.[1219] At the saltpetre company Pedro de Valdivia, one became assayer, one became chief of the Mine Department, one became chief of a crushing plant and one became board operator. At the saltpetre company María Elena two mining technicians worked as mining engineers, one was plant foreman, and seven became chief of a department at the company; either the sulphate plant, the iodine plant, the chemical laboratory, chief of engineers, the section of crystallisation and refrigeration or chief of guard. At the saltpetre company Tarapacá and Antofagasta one became topographer, one worked as topographer, one worked as assistant and three became chiefs of a department of the company; either administrator of one of the offices, the department of extraction or department of roads and works.

Some mining technicians even started to work at the large copper companies. As there are few, if any, traces of mining engineers working at large copper companies, the role of mining technicians there is

[1216] *Album Histórico de la Escuela Univ. de Minas de Copiapó 1857-1950* (Santiago, 1950)
[1217] *Album Histórico de la Escuela Univ. de Minas de Copiapó 1857-1950* (Santiago, 1950)
[1218] *Album Histórico de la Escuela Univ. de Minas de Copiapó 1857-1950* (Santiago, 1950)
[1219] Escuela de Minas de Copiapó, *Boletin Centenario Escuela de Minas de Copiapó 1857-1957* (Santiago, 1957); *Prospecto de admision de alumnos para la Escuela de Minas de Copiapó* (Santiago, 1935)

interesting. Canut de Von Urrutia argues that graduates from the Mining School of La Serena "…mainly [worked] at Bethlehem Chile Iron Mines Company, Braden Copper Company and Chile Exploration Company etc."[1220] *Newsletter of the Mining School of Copiapó* suggests the same. Thirty-six were registered at the large North American copper companies; twelve worked at Braden Copper Company at El Tentiente, forteen worked at Chile Exploration Copper Company at the Chuquicamata mine and ten worked at Andes Copper Company in Potrerillos. At the Braden Copper Company, the mining technicians were spread out at different departments: two worked as mining engineers, four as chemists, one as chief of laboratory, one as chief of mining, one as assistant chief of plant, one as accountant and one worked at the engineering office. At the Chuquicamata mine, Chile Exploration Company, one mining technician was in charge of measurement and topography, one worked at the general chemical laboratory, one worked at the department of engineers, one worked as topographer and at the engineering office, one worked as drawer, one worked as assistant chief chemist, two worked at the chemical laboratory, one as operator, one was in charge of analyses at the general laboratory and two worked with samples. At the Andes Copper Company and the Potrerillos plant two worked as assistants, two worked as chief chemist and one as chemist at the laboratory, one worked at the leveler engineering office and two worked as drawers.[1221]

However, even though there were more mining technicians than mining engineers, the industry did not consider the supply to be enough. There was a continuous lack of mining technicians. Engineers, professors and members of the National Mining Society were constantly complaining about a scarce number of students at the Mining Schools (see appendix 21 of articles published in the Mining Bulletin). In 1891, mining engineer Augusto Orrego Cortés argued that the Mining School in Santiago should double or triple the number of students. The School had thirty-two students at the time.[1222] In

[1220] C. C de bon Urrutia, *La Escuela de Minas de La Serena Derroto de sus Orígenes* (La Serena, 1992), p. 95
[1221] Escuela de Minas de Copiapó, *Boletin Centenario Escuela de Minas de Copiapó 1857-1957* (Santiago, 1957)*; Prospecto de admision de alumnos para la Escuela de Minas de Copiapó* (Santiago, 1935)
[1222] *Boletin de la Sociedad Nacional de Minería* (Santiago, 1891), p. 18

the early twentieth century the engineer Carlos Schulze explained that "(t)he three schools of mining that currently exist in Santiago, Copiapó and La Serena, are not in a position to satisfy the needs…"[1223] De Bon Urrutia confirms that the Mining School of La Serena received requests constantly asking for more mining technicians.[1224] There are few, if any, examples of people arguing that there were enough mining technicians. One exception, perhaps, is Jorge Kuntz who in 1923 affirmed that the "…Mining School of Copiapó provides sufficient practical technicians." [1225] This suggests that by this date the demand was met to a greater extent than before. On the other hand, it is possible that the mining areas around the Mining Schools were able to recruit more graduates than other mining areas. Kuntz was referring to the copper production in Copiapó, and not the whole country. In 1934, eleven years later, the industry still asked for more mining technicians. One of the conclusions of the Mining Congress of Copiapó in 1934 was that educational authorities should "…stimulate and develop interest for mining among students in mining regions."[1226] The National Mining Society, representing mining company leaders, mine owners and engineers, constantly published articles about the scarce number of mining technicians (see appendix 21). In 1934, it was argued that "…there is not enough technical personnel to carry out [scientific exploitation] and guide the miner."[1227] The North American companies too, although they did hire mining technicians, demanded more. The magazine published monthly by the Braden Copper Company wrote in 1917 that the Mining Schools provided a "…limited supply of suitably trained men."[1228] For this reason, it was argued: "…it has been thought necessary to import men – to contract them from the United States."[1229] Additionally, there was a particular demand for mining technicians specialised in coal. In 1919, the Chilean and Belgian coal industries were compared in the Mining Bulletin. Javier Gandarillos published an open letter in the Mining

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1223 *Boletin de la Sociedad Nacional de Minería* (Santiago, 1910), p. 330
1224 C. C de bon Urrutia, *La Escuela de Minas de La Serena Derroto de sus Orígenes* (La Serena, 1992), p. 95
1225 *Boletin de la Sociedad Nacional de Minería* (Santiago, 1923), p. 174
1226 *Boletin de la Sociedad Nacional de Minería* (Santiago, 1934), p. 197
1227 *Boletin de la Sociedad Nacional de Minería* (Santiago, 1934), p. 306
1228 *Topicos del Teniente Periodico quincenal dedicado a los intereses del personal de la Braden Copper Co*, vol. 2, No. 6 (August 1917), p. 23
1229 *Topicos del Teniente Periodico quincenal dedicado a los intereses del personal de la Braden Copper Co*, vol. 2, No. 6 (August 1917), p. 23

Bulletin to the Ministry that a mining school directed towards the coal industry should be developed. According to him, there was one foreman for every fifty workers in Belgium, more or less, while in Chile there was one for every 150 to 200, and sometimes 250. His conclusion was that "(t)he companies complain that they cannot obtain a sufficient number of trained foremen..."[1230] In 1940, the National Mining Society discussed, again, the needs for mining technicians and argued that the Mining Schools "… did not fulfil satisfactorily the purpose for which they were created."[1231] Overall, there seems to have been a greater demand for mining technicians in the sector than the domestic Mining Schools were able to provide.

11.2.2 Few professional workers

There were some mining engineers and technicians from domestic educational institutions in the mining sector, but they there was a great shortage of both. Moreover, we have already seen that illiteracy was a problem in Chile. This was confirmed in a description of the work at Braden Copper Company at El Teniente: "Our miners may perhaps never rightly understand English, when so many of them are entirely illiterate."[1232] The increased use of written texts, plans and calculations made this large share of illiterate workers complicated for companies. On the other hand, if some workers were able to read and write and did the work, which required these skills, perhaps it was not vital for the rest of the workers to be literate.

On the other hand, the industry demanded a broad spectre of skilled workers, not only mining engineers and technicians (see chapter of complex knowledge in mining). The demand for professionals with varied theoretic and scientific background gradually increased, especially after 1900 with the initiation of the large-scale copper production. Professionals of different kind, such as chemists, mechanics, electricians, economists, and others, were used in different operational

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[1230] *Boletin de la Sociedad Nacional de Minería* (Santiago, 1919), p. 843
[1231] *Boletin de la Sociedad Nacional de Minería* (Santiago, 1940), p. 142
[1232] A. Fuenzalida Grandón, *El trabajo y la vida en El Teniente* (Santiago, 1918), p. 619

activities in mining and for different purposes. Were there any other skilled workers or specialists to be found in the Chilean mining sector? In the late nineteenth century, a couple of lawyers made a career in mining. Manuel Echeverría Blanco, graduated lawyer in 1876 from the University of Chile, developed and operated the silver mining company Elisa de Bordos, which he owned. He was also one of the founders of the National Mining Society.[1233] After the turn of the century a couple of civil engineers, with formal education in bridge construction, roads, railways and other structures, were found working in the mining sector. C. Soza Bruna, for example, worked at the Mining Company of Collahuasi around 1906 with properties and construction.[1234] Augusto Millán Urzúa, had experience from the mining sector and wrote reports and books about several branches of the industry.[1235] Felix Federico Corona was the initiator of Mining Company of Aconcagua in the early twentieth century and became manager of the company.[1236] Later, in the late 1930s, the civil engineer Rodolfo Jaramillo B., wrote a study on the development of mining in the areas of Coquimbo and Atacama in the Mining Bulletin.[1237] After 1900, there are few, if any, traces of lawyers administrating companies, although some lawyers were involved in legal cases with regard to properties. Rafael González, for instance, represented Felix Federico Corona in the creation of the Mining Company of Aconcagua in the early twentieth century.[1238] The lawyer Emilio Tagle Rodríguez was member of the National Mining Society, member of the board of directors, functioned as an advisor for the industry and published several reports about the mining legislation.[1239] Some chemists were also recruited to the mining sector, especially to metallurgical plants. The chemical engineers Moises Arellano C., for instance, was involved in the coal industry and wrote an article about how to produce coal of good quality.[1240] Additionally, there were some other workers with intermediate technical education. At the Braden

[1233] *Boletin de la Sociedad Nacional de Minería* (Santiago, 1932), p. 429
[1234] Prospecto de la Sociedad Anónima Minera Riqueza de Collahuasi, *Informe,* (Santiago, 1907)
[1235] Augusto Millán U, *Historia de la Minería del Hierro en Chile*, Santiago: Impresos Universitaria, 1999; A. Millán Urzúa, *La minería metalica en Chile en el siglo XIX* (Chile, 2004)
[1236] E. Muñoz Maluschka, *Andina Historia del nacimiento de una mina* (Chile, 1987)
[1237] *Boletin de la Sociedad Nacional de Minería* (Santiago, 1938), p. 11.
[1238] E. Muñoz Maluschka, *Andina Historia del nacimiento de una mina* (Chile, 1987), p. 42
[1239] *Boletin de la Sociedad Nacional de Minería* (Santiago, 1939), p. 1006
[1240] *Boletin de la Sociedad Nacional de Minería* (Santiago, 1931), p. 154

Copper Company, there are traces of a couple of graduates from the School of Arts and Crafts.[1241] The graduates from the Industrial School of Concepción and the Industrial School of Temuco were close to the coal mining district of Lota and Coronel and probably some of these worked at mining companies in the area. Even so, the examples of skilled workers from domestic educational institutions were few.

Was there another alternative for mining companies to get a hold of professionals and specialists? For some companies, notably the advanced foreign companies, an option was to employ skilled workers from other countries. Many Foreign professionals were found in the Chilean mining sector throughout the period. The Engineer Carlos Schulze affirmed in the Mining Bulletin in 1910 that, with rare exceptions, foreign engineers filled both high and intermediate positions at all the "important mining companies".[1242] In 1924, a Norwegian mining engineer who went to Chile for a period to work confirmed the large share of foreigners in the mining sector. He argued that North American, English, German and Scandinavian engineers worked at a number of mining companies, notably at the North American corporations. As the Norwegian mining industry was not able to absorb all the mining engineers, he pointed out that Chile was probably one of the best working markets for Norwegian engineers at the time.[1243] In fact, sixty-five Norwegian engineers, mining engineers and others, travelled to Chile and worked for a while at mining companies from the late nineteenth century to 1940.[1244] These engineers worked mostly at foreign saltpetre and copper companies. Twenty-one of

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[1241] *Topicos del Teniente Periodico quincenal dedicado a los intereses del personal de la Braden Copper Co*, 1st of January (1919), nr. 12, p. 12-13

[1242] *Boletin de la Sociedad Nacional de Minería* (Santiago, 1910), p. 330

[1243] *Tidsskrift for kemi og bergvæsen* (Oslo, 1924), pp. 50-51

[1244] O. Alstad (red.) *Trondhjemsteknikernes Matrikel Biologiske meddelelser om samtlige faste og hospiterende elever av Trondhjems Tekniske Læreanstalt 1870-1915*, (Trondhjem, 1916); *Artiummatrikler studentene* [student yearbooks] (Kristiania/Oslo, 1855-1940); H. O. Christiansen et al. *25-års jubileumsberetning 1912-1937 Bergen Tekniske Skole Oslo Tekniske Skole Trondheim Tekniske Skole* (Norway, 1937); *Festskrift i anledning af Kristiania Tekniske Skoles 25 aars jubilæum* (Kristiania, 1898); R. Baggethun, *Horten Ingeniørhøgskole Horten tekniske skole En beretning om landets eldste tekniske skole gjennom 125 år* (Horten, 1980); S. Heier, *100 års biografisk Jubileums-festskrift, Horten Tekniske Skole 1855-1955* (Horten, 1955); KTS, *50 årsberetning om ingeniørkullet fra Kristiania Tekniske Skole 1896* (Oslo, 1946); Kristiania tekniske skole, *Ingeniørene fra KTS 1897-1947* (Oslo, 1947); *Ingeniører fra Kr.a Tekniske Skole 1897* (Kristiania, 1922); *K.T.S. ingeniørene av 1909: matrikkel utarbeidet til 25-års jubileet 1934* (Oslo, 1934); Oslo Tekniske Skole, *Skrift ved 50 års jubileet for ingeniørene fra K.T.S. 1894,* (Oslo, 1894), *KTS til Ingeniørkullet av 1910: 20 årsjubileum år 1910-1930* (Oslo, 1930); *Trondhjems Tekniske Mellomskoles virksomhet i de 3 første læseaar 1912-1915* (Trondhjem, 1916); *Skrift* the engineers worked at saltpetre companies, such as the Anglo-Chilean Consolidated Nitrate Corporation, Saltpetre Company Pedro de Valdivia or other companies.[1245] For instance, Fr. Will Arnet graduated as chemist at Christiania Technical School in 1908 and worked at saltpetre works in Chile between 1908 and 1917 before moving back to Norway.[1246] Per Bratt graduated as chemical engineer from the Technical University in Darmstadt in 1920 and worked in the United States before starting to work as a chief chemist at Anglo-Chilean Consolidated Nitrate Company in 1926.[1247] Asbjørn Danielsen graduated as construction engineer from the NIT in 1920 and worked at the same company from 1926 to 1932, first as an assistant and then the three last years as manager of works.[1248] Forty-one worked in the copper industry, whereof eighteen worked at Braden Copper Company and twenty worked at Chile Exploration Company. Ragnar Brygfjeld, for instance, graduated as electro-engineer from the NIT in 1925 and worked as an engineer at the laboratory at Chile Exploration Company from 1927.[1249]

Engineers and other professionals from other countries met to some degree the large demand of skilled workers at the foreign companies, which the domestic educational institutions were not able to provide. A revision of the organisation and management of foreign companies reveals that the managers, board of directors and engineers came largely from abroad. First of all, the British saltpetre companies acquired engineers to a large extent from other countries.[1250] But, it was the large North

ved 50 års jubileet for ingeniørene fra K.T.S. 1894 (Oslo, 1944); L. Eskedal, *BTS-matrikkelen Ingeniører uteksaminert ved Bergen Tekniske Skole 1875-1975* (Bergen, 1975); TTL, *1897-1922* (Kristiania, 1922); Trondhjem tekniske læreanstalt, *Festskrift ved Afslutningen av Trondhjems Tekniske Læreanstalts 25de Læseaar* (Trondhjem, 1895); B. Bassøe, *Ingeniørmatrikkelen Norske Sivilingeniører 1901-55 med tillegg* (Oslo, 1961)

[1245] *Studentene fra… (1831-1943);* Den Norske Ingeniørforening, *Biografiske Oplysninger om Kandidater med eksamen fra Bergseminaret på Kongsberg*, 1932; G. Brochmann (red.), *Vi fra NTH de første 10 kull: 1910-1919* (Stavanger, 1934); Amundsen, *Vi fra NTH de neste 10 kull 1920-1929*, 1950; L. Eskedal, *BTS-matrikkelen Ingeniører uteksaminert ved Bergen Tekniske Skole 1875-1975* (Bergen, 1975); B. Bassøe, *Ingeniørmatrikkelen Norske Sivilingeniører 1901-55 med tillegg* (Oslo, 1961)

[1246] B. Bassøe, *Ingeniørmatrikkelen Norske Sivilingeniører 1901-55 med tillegg* (Oslo, 1961), p. 16

[1247] B. Bassøe, *Ingeniørmatrikkelen Norske Sivilingeniører 1901-55 med tillegg* (Oslo, 1961), p. 58

[1248] *Studentene fra 1915* (Oslo, 1965), p. 48

[1249] C. L. Bommen, *Studentene fra 1920* (Oslo, 1970), pp. 37-38

[1250] The Guggenheim process, on which the operations at the North American saltpetre companies were based, was developed by the Norwegian engineer E. A. Cappelen Smith. In the annual reports of the Anglo-Chilean Saltpetre Company the majority of the members of the Directory were foreign; Medley G. B. Whelpley was the

American copper companies from the early twentieth century which indeed started a recruitment of foreign skilled workers and other professionals from abroad. These companies, operating some of the largest mines in the world, El Teniente, Potrerillos and Chuquicamata, had a steady flow of hundreds of engineers, technicians, mechanics, electricians and others from abroad. Correspondence between engineers at Andes Copper Company provides an example. In July 1925, the mineral metallurgical manager Frederick Laist wrote to Mr. William Wraith about the recommendations of hiring of workers to the Potrerillos plant. It was recommended to send twenty to twenty-four electricians, seven to nine machinists, ten to twelve ironworkers and boilermakers, two to four carpenters, two to three brick masons and four to five pipefitters from the United States. One of the leaders had recommended "(all) of the above men to be American mechanics of good grade and tested ability."[1251] The same company decided to build a Sulphide Plant. In this regard the mechanical engineer Wilbur Jurden wrote to Frederick Laist in July 1925 that:

> "(i)t is in my opinion that quite a number of Americans should be sent down as soon as possible to augment the construction force during the last three months of this year and that the construction force should be recruited to full strength and practically all the men on the ground by January 1st 1926… […]Mr. Topping told us that there was about 300 American employees at Chuquicamata and that this number would probably increase. This, of course, is probably more than will ever be required at Potrerillos, but it gives some idea of the number of Americans that will eventually be required there."[1252]

Foreign workers were also hired to the large Chuquicamata plant. Around 700 North Americans and

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president of the company; Horace R. Graham was Executive Vice-President; E. A. Cappelen Smith, R. P. Miller, Paul E. Kruger, Kenneth H. Rockey and R. Worh Vaughan were members. At the Saltpetre Company of Tarapacá and Antofagasta David Blair, Paul Joachim Crasemann, Owen Lewis Potts and Jorge H. Jones were members of the Directory: Compañía Salitrera Anglo-Chilena, *Memoras del directorio* (1933-1936); Compañía Salitrera de Tarapacá y Antofagasta, *Memorias* (1934-1941)

1251 Montana Historical Society Archives, Collection No. 169, Box No. 73, *Anaconda Copper Mining Company Records*, General Office, Subject File 6.4c, Folder No. 78-6 1925-1928 Staff

1252 Montana Historical Society Archives, Collection No. 169, Box No. 73, *Anaconda Copper Mining Company Records*, General Office, Subject File 6.4c, Folder No. 78-6 1925-1928 Staff

Europeans were working at this plant in 1920 (see table below):

Census: the two camps at Chuquicamata

	Men	Women	Children	Total
Mine				
North Americans and Europeans	107	34	33	174
Chileans and others	550	107	325	1072
Plant				
North Americans and europeans	411	64	48	523
Chileans and others	1532	599	892	3023
Total	2600	894	1298	4792

Source: Boletin de la Sociedad Nacional de Minería (Santiago, 1920), p. 277

Practically all the leaders of company departments, management and directories at Braden Copper Company and Andes Copper Company were foreigners.[1253] The only Chilean professionals who were

[1253] At the Braden Copper Company the North American engineer William Braden was the manager of the company in Chile. Furthermore, the leaders and chiefs of all the departments were brought from the United States. In general, the personnel were foreign, generally North American, and with a lot of experience. In 1915 Bradley was in charge of the personnel and superintendent of the mine and had an assistant, J. D. Tallant. W. E. Bradley had been hired especially to set up the mill. The survey work was led by the specialist S. B. Gordy and the preparation and extraction work was administered and directed by the specialist G. L. Helmrich. The surveying and leveling work was led by the engineer T.W. Skinmer. The laboratory, working with research and samples for calculation and analysis, was managed by R. Welsch. In 1911 the chief constructor was Mr. Nowell. The company had been taken over by the Guggenheim Brothers in 1911 and Pope Yeatman, a North American engineer, carried out new plans and amplified the capacity of concentration of minerals. John Chadwick was another North American engineer who came to Chile around 1915 and started to work at Braden Copper Company as chemist and later as chief of laboratory. And, North American mining engineers, metallurgists and mechanical engineers were assigned as consultants, such as Pope Yeatman, representing the Guggenheims, E. S. Berry, J. P. Bartholomew, E. A. Cappelen Smith and Herbert York. In 1920 the "superiors" were; S. S. Sørensen, general manager; L. E. Grand, sub-general manager; G. L. Helmreich, mining superintendent; R. E. Douglas, general milling superintendent; W. L. Stevens, smelting superintendent; A. J. Noerager, chief electrical engineer; G. Chambers, railway superintendent; Lewis, chief chemist; Richardson, chief doctor; Jones, local controller; Graig, auditor; Brulé, construction engineer; Pearce, superintendent of the material department; Walker, superintendent of welfare. Other North American engineers were Tom Hamilton, in charge of the installation of construction; W. E. Bradley, in charge of installing the mill. P. E. Doolittle was in charge of building the power plant. Thomas Graham was in charge of the lifts: La Braden Copper Company Mineral de "El Teniente" (Rancagua, 1942); L. Hiliart, *Braden Historia de una mina* (Chile, 1964).

The Chilean mining engineer Francisco Solano Vega made a report about the Andes Copper Company and the Potrerillo plant in 1918. He listed up the men in charge of the company between 1916 and 1918, and they were, with few exceptions all foreigners. In 1916 the North American Mr. Hamilton was the chief and manager, the North American S. C. Rundle was superintendent, the North American Mr. W. A. Burtin was chief of mine. The mechanics and drillers were North American or English. Moreover, the mechanics and perforators were North American or English. Cremer, a North American metallurgist, was in charge of the metallurgical research plant where the leaching and flotation took place. Later, the North American metallurgist manager Frederick mentioned at these companies, in addition to the mining technicians already revised, were the practical engineer Manuel Droguett as second assistant and the engineer Hermójenes Pizarro as chief of railway and water at the Andes Copper Company in 1918.[1254] The Chilean lawyer Javier Díaz Lira, specialist in mining law, worked at this company after having worked at El Teniente.[1255] In the second half of the nineteenth century, domestic companies also acquired engineers and technicians from abroad, mainly Britain, but also Germany and other countries.[1256] Gatico Mining Company acquired a couple of foreign engineers in the early twentieth century. Christopher Budde Dahll, graduated as a chemist from Trondhjem Technical School in 1908, worked as chief chemist at Braden Copper Company before working as an engineer at Mining Company of Gatico from 1914.[1257]

What about the small and medium-sized companies? Pirquen work dominated these companies. This

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Laist and chief engineer Wilbur Jurden were sent to Potrerillos from Anaconda Copper Mining in Montana to continue engineering projects after WWI. They implemented metallurgical research and experiments at a testing plant that had been constructed. In 1925 new chiefs of staff were sent to the plant; William Wraith became the executive in charge, Oscar M. Kuchs was general manager, A. A. Hoffman remained in charge of contruction, L. A. Callaway had supervised the experimental metallurgical work and became general metallurgical superintendent, I. L. Greninger was mining superintendent before becoming general sub-manager and W. B. Saunders became chief engineers for hydraulic development and tube construction. Laist and Jurden with C. E. Arnold as Wraith's assistant were in charge of metallurgical operations: F. Solano Vega, *El Mineral de Potrerillos 1916-1918* (Copiapó, 1918); M. C. Baros Mansilla, *Una historia de pioneros* (Santiago, 2006)

[1254] F. Solano Vega, *El Mineral de Potrerillos 1916-1918* (Copiapó, 1918), pp. 12-14

[1255] M. C. Baros Mansilla, *Una historia de pioneros* (Santiago, 2006), pp. 39-40

[1256] At José Tomás Urmeneta's company from the mid-19th century nearly all leading positions were filled by foreigners and there was a strong influence of German and English engineers. In 1859 he hired the North American Carlos Collins Greene to administrate the work at the mines. Other engineers were Adolfo Eastman, Emilio Keller, Zimmermann and Franz Arnemann. Additionally, the majority of the workers who worked with furnaces and smelting processes were English, mostly from the Swansea area. The Lota Industrial Coal Company from the mid-19th century found skilled personnel for leading positions in Europe, first and foremost in England. Technicians from England, and other countries, cooperated with the industrial leader Matías Cousiño, both in the start-up phase and after. In 1853 122 Englishmen worked in Lota and Coronel, while at the end of 1854 there were more than 900. Scottish miners in the coal mines were a "vital contribution to the development of the exploitation", according to Mazzei de Gracia. 60 years later, in 1910, the engineer Carlos Schulze confirmed that the "high and intermediate technical positions" in the coal industry were still filled by foreigners. The demand for engineers in the saltpetre industry was to a large extent met by foreign engineers, notably British: A. Millán Urzúa, *La minería metalica en Chile en el siglo XIX* (Chile, 2004), pp. 80-81; S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990); Ahumada, *Jose Tomas Urmeneta, empresario*, 1993 pp. 78-79; L. Mazzei de Grazia, *Los británicos y el carbon en Chile* (Concepción, 1924), p. 146. See Mazzei de Gracia for description of English engineers in the coal industry in the mid-19th century; O. Astorquiza, *Compania Carbonifera e industrial de Lota 1852-1942* (Valparaíso, 1942), p. 35; *Boletin de la Sociedad Nacional de Minería* (1910), p. 334; A. Soto Cardenas, *Influencia británica en el salitre: origen, naturaleza y decadencia* (Santiago, 1998), p. 73

[1257] O. Alstad (red.) *Trondhjemsteknikernes Matrikel Biologiske meddelelser om samtlige faste og hospiterende elever av Trondhjems Tekniske Læreanstalt 1870-1915*, (Trondhjem, 1916) way of organising mining work did not require mining engineers and scientifically trained mine and processing plant leaders. Instead, workers removed and extracted ores without the organised structure of a modern mining company. A relevant question is, then, with easier access to professional workers, would these companies have used them? Statements from professors, industrial leaders, engineers and the National Mining society suggest this. Looking to saltpetre it seems like this industry, in particular, had problems with finding professionals. In 1927, it was stated in a memorandum from the industry that "…the main technical advisor of the entire industry was a man who had no professional training except the one he had acquired in the prairie (pampa) or elsewhere in Chile." The Laurato Nitrate Company, the most important producer, had only one qualified engineer, and his office was in Valparaíso, located miles away from the saltpetre production.[1258] F. G. Donnan, professor in chemistry at the University of London, wrote a report on the saltpetre industry in Chile in the 1920s and declared that the control of the industry was in the hands of men who had no knowledge of chemistry or engineering and who lived far away from the centres of production.[1259] He suggested that a higher number of qualified personnel should be employed, both scientific and technical.[1260] A revision of annual reports of domestic mining companies indicates that technical problems were present also in other productions and were difficult to solve due to the lack of expertise. With regard to the installation of a machine in 1905 at Taltal Mining Company, the manager complained about a: "…shortage of competent workers and artisans."[1261] The scarce number of skilled workers and professionals was also documented in the Mining Bulletin. In an article by the engineer Carlos Schulze in 1910, directors and managers at "unimportant mines" (meaning small and medium-sized companies) were without training and lower positions in mining were filled by "simple practitioners" without technical instruction and in many

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[1258] Memorandum from 1927, cuote taken from A. Soto Cardenas, *Influencia británica en el salitre: origen, naturaleza y decadencia* (Santiago, 1998), pp. 328-329

[1259] A. Soto Cardenas, *Influencia británica en el salitre: origen, naturaleza y decadencia* (Santiago, 1998), p. 162

[1260] A. Soto Cardenas, *Influencia británica en el salitre: origen, naturaleza y decadencia* (Santiago, 1998), p. 162

[1261] Compañía de Minas Beneficiadora de Taltal, *memoria 1905* (Valparaíso, 1905), p. 8

cases without primary school.[1262] In 1922 the administrator of Las Vacas argued that "…in the country there are no personnel with practice in [machines]."[1263] Statements by engineers and managers of mining companies of the time suggest that the problem remained for decades. Eight years later the mining engineer Jorge Muñoz Cristi argued in in the Mining Bulletin in 1935 that the mining engineer "…cannot expect efficient help from other professional specialists." This was primarily "…because they are scarce in the country".[1264] In 1940 it was claimed that in order to improve its efficiency, the sector needed to have access to "truly competent" chemists, topographs, mine leaders, shift foremen, ore dressers, leaders of processing plants etc."[1265] According to these statements, despite the large flow of foreign skilled workers, the total demand of skilled workers and professionals was not met, especially not for the less advanced domestic industry. The mineral and metal industries demanded more professional workers, but they were nowhere to be found.

11.3 Comparisons

A review of the careers of mining engineers and technicians indicates that in the cases of both Chile and Norway, the majority of them worked in activities related to mining. They were meant to work with all sorts of metal and mineral ores, and that is what they did. Mining engineers and technicians worked in all types of metal and mineral productions, such as copper, silver, iron, pyrite, saltpetre, aluminium etc. The mining engineers and technicians thus acquired practice and experience in different areas within mining. Typically, in both countries, mining engineers and technicians obtained positions they were meant for at mining companies, namely engineering, managing, leading or intermediate technical positions. Some engineers had a career at research centres and academia with scientific research and consulting or as teachers at mining schools. A number of mining engineers became managers of whole companies, which work involved administration of mines, processing

[1262] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1910), p.. 330
[1263] La Compañía Minera "Las Vacas", *Informe 1922, segundo semestre* (Valparaíso, 1923)
[1264] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1935), p. 403-404
[1265] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1940), p. 142

plants, research centres, construction plants and other working sections. Therefore, it was not with regard to the functions, or quality, of the mining engineers and technicians in the sectors that the two countries differed.

Differences appear, however, when it came to working practice. Chilean mining engineers almost exclusively worked at domestic companies and there were only a couple of mining technicians at the foreign companies. In Norway, on the other hand, a large number of mining engineers worked at foreign companies and often obtained valuable work experience there. They often moved around, changed jobs several times and worked at different mining companies during their career. The fact that they moved around so much, enabled a spread of experience and know-how between companies and institutions.

More importantly, perhaps, it seems like the supply of engineers and other professionals relevant for mining was met to a much larger degree in Norway than in Chile. The striking difference between the two countries is related to the number of mining engineers, technicians and other professionals, which the domestic institutions provided. The mining sector in Norway had access to plenty of mining engineers, technicians and other relevant professionals. This has been demonstrated in two ways. First of all, there was a steady flow of professional graduates, such as mechanics, technicians, construction engineers, chemists and economists, and there were mining engineers and technicians working in a large number of mining companies. Second, the debate in the press was about whether there were too many, not too few engineers in Norway. In Chile, on the other hand, institutions did not provide nearly enough mining engineers, technicians and other professionals for the many mines and mining companies that existed. It was clearly not possible to reach across all thousands of positions at companies, educational institutions and research institutions with the small number of mining engineers. Engineers, company managers, professors and other members of the National Mining Society explicitly requested more professional workers, especially mining engineers. Civil engineers, mining technicians and others functioned as relatively good substitutes for the mining engineers, but also they were scarce. The difference between the two countries in the extent to which professional workers reached across the mining sectors, is summarised as follows:

Discrepancies in extent of professional workers in the two mining sectors

<table>
<tr><th></th><th>The extent of professional workers</th><th>Implications</th><th>Comments</th></tr>
<tr><td>Norway</td><td>A large number of professionals reached across the mining sector (maybe too many)</td><td>Mining engineers, other engineers and professionals managed companies and led operations at the mines and processing plants</td><td rowspan="2">Mining management and administration at modern technologically advanced companies, required scientifically trained engineers and other professionals to operate efficiently</td></tr>
<tr><td>Chile</td><td>Small number of professionals in the mining sector (probably far too few, considering the large number of companies)</td><td>Mining engineers, other engineers and professionals managed companies and led operations at only a small number of mines and processing plants</td></tr>
</table>

The foreign companies in Chile had an alternative, namely to hire foreigners. The large copper companies recruited hundreds of engineers, as well as technicians, mechanics, chemists, electricians and other skilled workers from abroad. Foreign engineers, with very few exceptions, almost exclusively held the leading and managing positions at these companies. The exclusive use of foreign professionals and the absence of domestic professional workers at these companies had a major negative effect. At a lower technical level training of mining workers, and also of some local technicians, perhaps occurred. However, it seems unlikely that training and transfer of knowledge happened at engineering and management level. This probably did not occur for two reasons. First, the absence of Chilean mining engineers excluded them from absorbing valuable knowledge from these countries and use it other part of the sector, as in Norway. Second, foreign professionals were normally hired for a specific task or job and did not settle down in Chile. They normally worked at the foreign company for a while, before returning to their home country, as seen with the Norwegian engineers, which meant that this knowledge remained within the enclaves. This is in sharp contrast to Norway where engineers were heavily involved in ore surveys, the start-up, operations and management in both domestic and foreign companies.

The way small and medium-sized companies organised operations were not optimal. It was an inefficient method based on unpredictable results and small productions of impure metals and minerals. The capacity to operate companies with up-to-date technology became increasingly complex and demanded specialists in a number of knowledge fields. Was the backward mining sector linked to a scarce number of professional workers with in-depth scientific experience? Would more professional workers have meant a modernisation of the small and medium-sized companies? It cannot alone explain this underdevelopment. That would have required a deeper analysis of the companies, their investments, workers and trade patterns. However, the lack of professional workers is part of the story. An important argument in this thesis is that the technology used to carry out efficient and technologically advanced mining productions became increasingly complex (see chapter about complex technology in mining). In order to build, direct and organise production, as the large North American companies did, professionals, especially mining engineers, were required. If new working techniques, organisation and rationalisation of operations were to be implemented at the small and medium-sized companies, mining engineers, professionals and specialists would be essential. The main problem in Chile was that there were no skilled workers to manage, organise and develop the inefficient and unorganised domestic mining companies. Leaders and managers at the traditional and technologically backward domestic companies were normally without formal education. The absence of scientifically trained and experienced workers made technological changes, which characterised technologically up-to-date companies very challenging.

12 Institutions for knowledge transfer in Chile and Norway: discrepancy in extent

New technology often had origin in other countries, notably large industrial countries, which meant that innovation largely involved technology transfers from abroad. In order to transfer knowledge from other countries, it was important to have contacts and direct, hands-on experience of the technology in question. This chapter explores institutions aimed to support and encourage technology transfer from abroad, namely technical magazines, industrial exhibitions, study travels and work experience in other countries. Which specific functions did these institutions have? Did they contribute to knowledge transfer? Were institutions developed to facilitate knowledge transfers, such as scholarships and grants? Were there any differences between Chile and Norway in this respect?

12.1 Functions of institutions for knowledge transfers

As seen in the chapter, which sets a framework for mining, technology transfers were complex practises, which required long processes of acquiring contacts, information and hands-on practical knowledge of the technique in question, summed up as know-what, know-who, know-how and know-why. These knowledges were acquired in different ways, namely through mining journals, industrial exhibitions and visits to and work experience at mining plants.

Magazines and Journals published and diffused up-to-date information and news about mining industries. Articles often included advertisements about new and relevant technology and were a good starting point for mining companies to acquire updated information about new machinery, processing techniques and so on. In Norway, the mining journal "Miner" was published in 1846 and 1847, once a month, and included some descriptions about mining techniques.[1266] A permanent journal every month came in 1913 with the Mining Journal, published by the Norwegian Mining

[1266] *Tidsskrift for Bergvæsen* (Oslo, 1913), p. 2

Engineer Association. Some articles included detailed descriptions about techniques and functions of specific machines. In September 1913 an article about "setz machines" explained in detail how these were used in separation processes, how the machines were used in operation, which minerals to use and so on.[1267] In Chile, the National Mining Society published the Mining Bulletin Magazine monthly from 1883. It was a local publication, financed by the state, with on-going updates and information about foreign mining technology. The National Mining Society affirmed that it reached all the members of the Society and was even distributed abroad.[1268] Many of the articles included descriptions of machinery, devices, furnaces etc. and their uses. An article about ball mills from 1892 described different types of ball mills, their advantages and in which mines they were adopted. Pictures and drawings showed their composition and general usage.[1269]

However, reading about new technology in magazines was not enough to transfer and adopt technology. Key to select and find the right technology, was to have comprehensive knowledge of how the different techniques functioned in practice, their strengths and weaknesses and how it could be transferred, installed and modified to the mine or plant in question (see examples of knowledge transfers in the chapter which sets a framework for mining). As the majority of innovations originated from other countries, it was normally necessary to go abroad. International exhibitions fulfilled some of the functions in a knowledge transfer process. They were primarily important sources of information for up-to-date techniques. Engineers, technicians, managers and workers visited exhibitions to discover, observe and to some degree test the new technology on the market. Theodor Wilhelm Holmsen, for instance, went to the Universal Exposition in Paris in 1900 with the aim of studying modern mining, especially modern pumps and lifting machinery.[1270] Vogt participated in numerous foreign exhibitions, such as the Universal Expositions in Paris in 1889 and 1900, as well as

[1267] *Tidsskrift for Bergvæsen* (Oslo, 1913), pp. 102-104
[1268] FINN: G. Dodino, *Sociedad Nacional de Minería Crónica de Tres Siglos* (Santiago, 2001)
[1269] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1892), pp. 75-77
[1270] *Studenterne fra 1889* (Trondhjem, 1914), pp. 103-104

the International Exhibition of Mining and Metallurgy in London in 1890. He sat in the jury in the Liverpool International Exhibition in 1886.[1271] Travelogues from exhibitions were sometimes published in magazines. Mining engineer Holm Holmsen participated at the General Art and Industrial Exposition in Stockholm in 1897 and made a report about the mining section in the Technical Magazine, including descriptions and drawings of Swedish mines, drilling machines, hydraulic lifts, other lifts, safety facilities, tools etc.[1272] This way the knowledge acquired at these exhibitions were diffused.

Then again, observing models at industrial exhibitions alone could not enable transfer and use technology. As seen, the tacit dimension was high in mining, and to understand all dimensions of technology, how to select, transfer, adopt and modify it to local conditions, it was crucial to become familiar with it by acquire hands-on practical experience with it. Travels to mining plants served to acquire such practical hands-on knowledge and were an important element in technology transfer processes. The overall purpose of such trips was to learn about mining, either to acquire general practical experience or knowledge of a specific method (see appendix 22 for descriptions). A couple of examples show how the engineers observed, analysed and used technology during these trips. Emil Bertrand Münster, for instance, was given a public scholarship in 1843 and went to Freiberg to study smelting and amalgamation processes before going to Mansfeldt, Clausthal and other cities to study mines and plants, chemical factories, laboratories and mineral collections.[1273] In 1879, Olaf Aabel Cornelissen was given a scholarship to go to Wales, Cornwall, Belgium and Harzen to find out about ore dressing and motorised man lifts. Later, in 1889 he visited several ore dressing plants in Germany and transport plants in Luxembourg.[1274] Julius Helverschou also acquired a scholarship for technicians and went to Scottish, German and Norwegian mining districts around 1911 to study

[1271] *Studenterne fra 1876* (Kristiania, 1901), pp. 266-275
[1272] *Teknisk Ukeblad* (Kristiania, 26 August 1898), p. 465
[1273] G. A. Blom, *Fra bergseminar til teknisk høyskole* (Oslo, 1958), p. 134
[1274] *Studenterne fra 1868* (Kristiania, 1919), pp. 65-68

drilling methods and how water was supplied during deep drilling.[1275] Fredrik Sebastian Nannestad acquired a scholarship from the Mining Fund in 1910 and travelled within Norway and to Germany and Sweden to learn about modern techniques and ore processing. He also went to Canada to study nickel ores.[1276] Steinulf Smith-Meyer first studied coal mining in Germany in 1924 and then flotation techniques at mining works in Canada and the United States in 1931 with money from the Orkla Fund.[1277] In 1898, the mechanical technician Theodor Wilhelm Holmsen even published a travelogue in Technical Magazine of his trip to five Swedish ore dressing and metallurgical plants. He had observed how operations were carried out and described detailed of the stages in the extraction process, machinery and furnaces.[1278] There are also examples of mining technicians going on study trips. Anders Kokvoll went on a study trip to Sweden in 1939, even before graduating. Later, in the 1950s, he travelled abroad again to England, Finland, Belgium and Germany.[1279] Scholarships were fundamental to facilitate such travels for practical knowledge acquisition. In 1883, Technical Magazine strongly recommended the establishment of scholarships to acquire business contacts and to continuously be informed of foreign technology:[1280]

> "The desirability of granting the country's technicians the opportunity of traveling to catch up and thoroughly study the progress of their subject, is obvious, and the funds, which may be used for this purpose, must be said to be well spent…[…] By studying the new methods and advancements in technology on-site and by discussing the details with specialists one would much faster and in a more complete way acquire the necessary thorough knowledge of the relevant matter than by being referred only to books and journals …[…] [This] can hardly be described clear enough."[1281]

Another way of transferring foreign knowledge was to go abroad and work for a period at a mining

[1275] *Studentene fra 1904* (Oslo, 1929), pp. 170-171
[1276] *Studentene fra 1903*, pp. 294-296
[1277] *Studentene fra 1909* (Oslo, 1934), pp. 378-379
[1278] *Teknisk Ukeblad* (Kristiania, 1898), pp. 585-621
[1279] *Studentene fra 1933* (Oslo, 1958), p. 206
[1280] *Teknisk Ukeblad* (Kristiania, 30 November, 1883), pp. 133-134
[1281] My translation: *Teknisk Ukeblad* (Kristiania, 30 November, 1883), p. 133-134

plant and then use this experience in innovation processes back home. Some of the engineers who travelled abroad acquired contacts and were allowed to work short or long periods at a foreign company. Working abroad over a period of time meant acquiring crucial practical experience with how foreign plants operated, i.e. their routines, techniques and productions. We have already seen that working experience and travels to mining plants in other countries were used directly in innovation processes after their return. The case of Olav Steen and the use of his valuable working experience to change working methods at Stavanger Electrical Steel Works is a good example (see examples of knowledge transfers in the chapter, which sets a framework for mining). Henrik Kristian Borchgrevink went to the United States in 1893 and worked as a mechanical engineer at Anaconda Copper Company in Montana. He travelled around in the United States, Canada and Europe before returning to Norway in 1899 to become director of Hadeland Mining Works and Norway Mining Company Ltd.[1282] Carl Elieson Stabell was hired as a chemist for two years, from 1892 to 1894, at the Anaconda Copper Works and Butte plant in the United States. In 1894, he returned to Norway and started to work in mining and as a part time teacher at the Technical Day School and Christiania Machine Schools during winters.[1283] Another illustrating example is Harald Dahl. Dahl became mining engineer in 1906 and worked at different Norwegian mines after studies. After his work experience in Norway, he went to France and worked at different mining companies and in Northern-Africa. In 1917, he went back to Norway and became Director of operations at Ofoten ore field where he could draw on his experiences. In 1923, he obtained a similar position at A/S Bjørkåsen Mines, Ballangen, also in Ofoten. From 1927 to 1930, he became Director for Eisenerzgruve Fortuna in Harz, Germany. In 1935, he became professor in mining at the Norwegian Institute of Technology and later Dr. Engineer at the Mining Academy in Clausthal.[1284] In his analysis of Swedish engineers from 1880 to 1930, Per-Olof Grönberg shows how practical learning experiences from abroad was used, and highly valued. He examines the continuous flow of engineers going abroad, normally to other European

[1282] *Studenterne fra 1884* (Kristiania, 1909), p. 44
[1283] *Studenterne fra 1883* (Kristiania, 1908), pp. 365-366
[1284] *Studentene fra 1901* (Oslo, 1926)

countries or the United States, how they acquired relevant skills and knowledge about techniques, before returning to Sweden. In strategic positions at Swedish companies, they used the knowledge that they had acquired abroad.[1285] Working experience from abroad also seems to have been valued in the case of mining companies in Norway. Correspondence between Skandia Copper Works and professor Johan Herman Lie Vogt suggests this. He was contacted in January 1907, just after this firm had been established, and asked if he could recommend a mining engineer as manager at the copper mine at Lillebotten and Narvik. One important criteria was that "(t)he man should have practiced at copper mines, and preferably abroad."[1286] Companies in Chile also preferred engineers with working experience from abroad, which indicates that know-how of foreign technology was appreciated. In the mid-nineteenth century, the only two Chilean engineers registered at the Chilean Urmeneta's Company were Teodisio Cuadros and Antonio Alfonso, two mining technicians who had went to Europe to study on the recommendation of the principal of the University of Chile, Ignacio Domeyko. They both worked in the administration of the company.[1287] This trend seems to have continued. Decades later, in the beginning of the twentieth century, the large North American companies preferred engineers with education and work experience from other countries. One of the few Chilean engineers mentioned working at Andes Copper Company was Hermójenes Pizarro, chief of railway and water in 1918, who had an engineering degree from the United States.[1288] These cases indicate that experience from abroad was highly valued among companies.

The functions of technical magazines, industrial exhibitions, study travels and work experience in Chile and Norway are summed up as follows:

[1285] P-O. Grönberg, *Learning and Returning. Return Migration of Swedish Engineers from the United States, 1880–1940* (Sweden, 2003), p. 1

[1286] Brev fra Aktieselskabet Skandia Kobberverk til Professor J. H. L. Vogt, Luleå 16. jan. 1907, Privatarkiv nr. Tek 4, *Johan Herman Lie Vogt*, Eske 70

[1287] R. Nazer Ahumada, *José Tomás Urmeneta. Un empresario del siglo XIX* (Chile, 1993), p. 63

[1288] F. Solano Vega, *El Mineral de Potrerillos 1916-1918* (Copiapó, 1918), pp. 12-14

Institutions for knowledge transfers

Institution	Functions	Facilitating institutions
Technical magazines	Diffused codified knowledge of new technology and other information regarding mining **(know-what)**	Mining Societies
Industrial exhibitions	Presented new technology for observation and testing **(know-what and to some degree know-how)**	Private and public scholarships
Study trips to foreign mining plants and research institutions	Key channels to acquire contacts **(know-who)**	Private and public scholarships
	Key channels for general and practical hands-on experience of foreign technology **(know-how)**	
	Key channels for practical experience with specific mining techniques **(know-how and know-why)**	
Work experience abroad	Key channels for contacts (know-who)	Indirectly through private and public scholarships
	Key channels for practical experience with specific mining techniques **(know-how and know-why)**	
	Key channels for long practical experience with routines, techniques and operation at foreign companies **(know-how and know-why)**	

12.2 Plenty of facilitating institutions for knowledge transfer in Norway

Mining journals, industrial exhibitions, study travels and work experience abroad had certainly important functions in knowledge transfer processes. Were these channels facilitated in Norway? In terms of written information, all members of the Norwegian Mining Engineer Association and

Norwegian Mining Industry Association had access to the Mining Journal. Additionally, according to the Mining Journal, foreign magazines were widespread among engineers in Norway.[1289]

Yet, going abroad was more important to transfer technology than just reading about it, and this was facilitated by establishing a large number of annual scholarships. From early on, public scholarships, such as "royal scholarships", were given to engineers with the purpose of studying at a foreign institution or to study techniques at foreign mines. There are traces of Norwegian miners travelling abroad from the seventeenth century with scholarships and from the 1730s, the scholarships increased.[1290] The mining engineer Rolf Falck-Muus listed a number of miners and mining engineers who went to Sweden on study trips from the late seventeenth century, often with scholarships from companies, notably Røros Copper Works.[1291] The majority of the mining engineers who graduated from the Kongsberg Mining Seminar obtained public scholarships to travel, either from the Mining Fund or the Fund "ad usus publicus". Grethe Authén Blom explained that "(p)ractically all (except two) received scholarships for long study trips at home and abroad."[1292] This tradition continued into the nineteenth century. In the regulations of the mining engineering program 1st March 1819, it was confirmed that:

> "(t)he mining engineers, who…[…]… have demonstrated the capability and skills in this subject, could hope to be provided public support to make journeys, not only in the realms of Norway and Sweden, but even in the foreign country, where mining has reached preferable perfection."[1293]

Falck-Muus explained that "…the majority [of the mining engineers] took the opportunity to travel

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[1289] *Tidsskrift for Bergvæsen* (Oslo, 1913), p. 1

[1290] A. K. Børresen and J. T. Kobberrød (red.), *Bergingeniørutdanning i Norge gjennom 250 år* (Trondheim, 2007), p. 18

[1291] R. Falck-Muus, *Bergmannsutdannelsen i gamle dager, norske bergmenn til Sverige som ledd i utdannelsen* (Oslo, 1949), pp. 114-129

[1292] G. A. Blom, *Fra bergseminar til teknisk høyskole* (Oslo, 1958), p. 111

[1293] My translation, R. Falck-Muus, *Bergmannsutdannelsen i gamle dager, norske bergmenn til Sverige som ledd i utdannelsen* (Oslo, 1949), p. 101

with a scholarship to Swedish or German plants."[1294] Both public and private institutions encouraged foreign study trips. Scholarships were normally provided either to study at a foreign institution, to visit foreign mining companies, international exhibitions or to do practice at a foreign plant. A public scholarship directed towards technical development was the "state technical scholarship" or "scholarship for technicians" and was provided several times from the second half of the nineteenth century (see appendix 22 for list of study trips). Other public scholarships, university scholarships, state scholarships, bequests and other funds were continuously provided during the nineteenth and twentieth centuries. The University, and later the NIT, managed many of these funds.[1295] Public scholarships specifically directed towards mining engineers also existed, such as the "Mining Fund" or the Fund "ad usus publicus".[1296] Another public Mining Fund was established in 1908 with the purpose of promoting mining.[1297] Mining companies also established private funds for mining purposes. From the end of the nineteenth century and during the twentieth century, companies provided grants with the purpose of studying specific techniques abroad. The Orkla Fund was established in 1914 for "graduated skilled mining engineers" with the aim of travelling within Norway or abroad.[1298] In addition, Kongsberg Silver Works, Sulitjelma Mining Company Ltd. and Vigsnes Works had their private funds.[1299] The engineer Hybinette established a scholarship in 1917 for the famous mining engineer and professor Johan Herman Lie Vogt, which he was entitled to spend from "…as long as he live[d]." [1300] From 1850 to 1940, ninety-nine public and private scholarships and funds were provided to mining engineers for foreign travels. Thus, the recommendation of Technical Journal from 1883 was taken into account. The list below shows some of the public and private scholarships, which were used to travel to foreign companies and institutions to learn about mining:

[1294] R. Falck-Muus, *Bergmannsutdannelsen i gamle dager, norske bergmenn til Sverige som ledd i utdannelsen* (Oslo, 1949), p. 101
[1295] *Universitets- og skoleannaler* (Kristiania, 1834-1910)
[1296] G. A. Blom, *Fra bergseminar til teknisk høyskole* (Oslo, 1958), p. 111
[1297] *Tidsskrift for bergvæsen* (Oslo, 1921), p. 190; *Tidsskrift for bergvæsen* (Oslo, 1930), p. 32
[1298] Den tekniske høiskole i Trondhjem, *Program for studieåret 1916-1917* (Trondhjem, 1917), p. 58
[1299] *Tidsskrift for bergvæsen* (Oslo, 1917), p. 71
[1300] Den tekniske høiskole i Trondhjem, *Program for studieåret 1917-1918* (Trondhjem, 1918), p. 57

Norwegian scholarships for study trips used by mining engineers

Year of establishment	Name of scholarship
Eighteenth century	Mining Fund
Eighteenth century	Fund “ad usus publicus”
From 1811? (The establishment of the University of Oslo)	Fund “scientific travels within Norway”
1811	University scholarship
Before 1830	Scholarship from Kongsberg Silver Works
Before 1830	Scholarship from Røros Copper Works
Before 1885	Scholarship from Vigsnes Works
Before 1880	Rathke scholarship
Before 1880	Summer travel scholarship
Before 1890?	Scholarship for technicians
Before 1906	Hjelmstjerne Rosencrone scholarship
1908	Mining Fund (different from the one above)
Before 1910	The American-Scandinavian Society Scholarship
1914	Orkla Fund
Before 1924	C. Sundt’s scholarship
Before 1924	Norway-America Fund
Before 1924	Norwegian Military Goods Insurance-Fund
Before 1937	Norwegian Technical Institute scholarship
Before 1935	Hs Fund

Based on the appendix 22 of travelling mining engineers

This list is not extensive. In many cases, the engineers did not specify which type of scholarship they acquired, only that it was a “scholarship” or a “public scholarship”. This variety of scholarships and funds suggests that studying abroad was understood as very useful. The continuous provision of state scholarships and company funds to go abroad contributed to a particularly outward-looking institutional setting.

The scholarships should be seen in connection with the fact that Norwegian mining engineers had a long tradition of travelling abroad. After formal studies, it was common to travel within Norway or to foreign mining districts, mining plants or industrial exhibitions, either to practice, do surveys or learn about mining techniques. A review of the student yearbooks, the Mining Journal and other documents, reveals that 256 of 341 Norwegian mining engineers (seventy-five per cent) between 1787 and 1940 went abroad to 1) study at a foreign institution, 2) do geological surveys or to acquire information about specific techniques, including industrial exhibitions,[1301] or 3) work at a foreign company (see appendix 22 for list of engineers travelling abroad). The Norwegian mining industry, in particular, organised trips for Norwegians to attend industrial exhibitions presenting new mining machinery and equipment. There are traces of at least nine engineers going to industrial exhibitions in Norway or abroad between 1881 and 1914 with the purpose of learning about mining techniques.

148 of these mining engineers travelled with the purpose of visiting mines, metallurgical plants and study specific mining techniques. They either went on behalf of a company, with a public scholarship or at their own expense. Learning about foreign mining and techniques must have been regarded as so important that foreign trips should be undertaken even without scholarships. Others were given more than one scholarship. Travelling was thus very common among the mining engineers.

Where did they go? There was a continuous flow of mining engineers going to other European countries, notably German, Sweden, France and England. Seventy-eight of the engineers travelled to different places in Germany, fifty-six to Sweden, thirty-one to Britain and twenty to France. In addition, other European countries with important mining industries were common destinations, such as Italy, Austria, Belgium, Holland, Spain and Switzerland. Some went abroad many times during their career and to many countries. From the 1880s, mining engineers also started to travel to the United States. This country gradually developed a significant mining sector, one of the most advanced in the world, and adopted many new techniques, which rationalised and improved mining operations.[1302] Twenty-nine engineers travelled to the United States. Additionally, sometimes in the extension of study trips, 127 of the mining engineers went abroad to work at some point during their career. The most common place to work abroad was the United States. Forty-six of the mining engineers went to this country to work at some point. Forteen mining engineers worked in Sweden

[1301] Some engineers travelled within Norway (see appendix of study trips)
[1302] P. David, G. and Wright, "Increasing Returns and the Genesis of American Resource Abundance", *Oxford Journals*, vol. 6, issue 2 (1997)

and twelve in Britain. Germany was also a natural destination to go to and work for a period. Gunnar Schjelderup was one of twelve mining engineers who worked there. He worked first at several mining companies in Norway before leaving for Canada. He worked as a chemist at British American Nickel Corp. in 1920, Crucible Steel of America in 1921 and Rheinmetall in Düsseldorf, Germany the same year. Later he returned to Norway to work in the iron and steel and aluminium production.[1303] Another popular destination was Chile. Fifteen mining engineers went there to work. For instance, the mining engineers Kristian Lerche Bøckman, Hans Nicolai Ellefsen, Leonard Ervik Holmboe and Arne Utne travelled together to Chile and started to work at Braden Copper Company in 1911-12.[1304] Other popular countries were Denmark, Spain, France, Australia and South Africa, all countries with long traditions with mining.

What did the large amount of travels and work experiences abroad mean? It meant that the broader spectre of the mining sector had easy access to mining engineers with practical experience with technology that was used abroad. Mining engineers used these experiences in their work at mining companies in Norway and contributed directly to the continuous innovation processes that were happening in the sector.

12.3 Few institutions for knowledge transfer in Chile

Were channels for knowledge transfers facilitated in Chile? The most important organisation aimed to promote mining development was the National Mining Society, established in 1883. The Society was involved in a variety of activities, such as publishing the Mining Bulletin, organising expositions, improving mining education, discussing conditions for mining, mining laws and so on. The Society held meetings and presentations concerning different subjects several times during the year.[1305] Perhaps one of the most recognised initiatives of the Society was the National Exposition of Mining

[1303] G. Brochmann, *Studentene fra 1913* (Oslo, 1938), p. 227
[1304] K. L. Bøckman, "In Memorandum", in Ivar Leveraas (red.) *Bergmanns-Jul 1958* (Orkanger, 1958), pp. 5-10
[1305] See monthly publications of *Boletín de la Sociedad Nacional de Minería*

and Metallurgy, held in Santiago in 1894 and supported by the Government.[1306] The idea behind the Exhibition was to persuade foreign mining to come to Chile and demonstrate new and updated mining technology. Embassies, consulates and chambers of commerce abroad acted as intermediaries and invited companies to participate in the exhibition.[1307] A number of countries participated, such as Germany, the United States, England, Belgium and Brazil, with products, machinery and mining equipment.[1308] This Exhibition was a good way for companies to acquire information and observe new and existing technology. Some Chilean engineers also went to European and American exhibitions. Chilean delegations were present at the Universal Exposition in Paris in 1867 and 1889, the Pan-American Exposition in New York in 1901, Brussels International Exposition in 1897, The Centennial International Exhibition in Philadelphia of 1876 and others.[1309] A delegation of seventeen persons from the National Mining Society was sent to the Exposition in Paris in 1889.[1310] An engineer was sent by the government specifically to study "…modern methods for coke fabrication, production of sulphuric acid …[…]… focusing especially on the electro-metallurgy and power transport…[…]…, used to provide power to the drills, pumps and tools used in mining."[1311] Chilean mining companies were also represented at international expositions. To the Universal Exposition in Paris in 1867, for instance, Ignacio Domeyko brought minerals and machinery from a variety of Chilean companies.[1312] In 1901 the mining engineer Guillermo Yunge was sent by the government to the Pan-American Exposition in New York.[1313] Several countries were represented and a variety of machinery and mining

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[1306] FINN: G. Dodino, *Sociedad Nacional de Minería Crónica de Tres Siglos* (Santiago, 2001)
[1307] FINN: G. Dodino, *Sociedad Nacional de Minería Crónica de Tres Siglos* (Santiago, 2001)
[1308] S. M. Basurco, *La exposicion de mineria y metalurgia de 1894 por Santiago M. Basurco* (Santiago, 1895)
[1309] *Chile en la Esposicion universal de Paris en 1867, Catalogo De los objetos remitidos por la Comision nombrada con este fin* (Santiago, 1867); *Boletín de la Sociedad Nacional de Minería* (Santiago, 1890), p. 96; *Exposicion universal de 1889 en Paris Comision directiva chilena nombrada por decreto supremo* (Santiago, 1887); G. Yunge, *Memoria presentada por Guillermo Yunge Delegado del Gobierno de Chile a la Exposicion de Buffalo, N.Y.* (Santiago, 1905); Ministerio de Industria i Obras Publicas, *Memoria* (Santiago, 1898), p. 40; *Catalogue of the Chilean Exhibition of the centenary of Philadelphia* (Valparaíso, 1876), p. 38
[1310] *Exposicion universal de 1889 en Paris Comision directiva chilena nombrada por decreto supremo* (Santiago, 1887)
[1311] My translation: *Boletín de la Sociedad Nacional de Minería* (Santiago, 1890), p. 96
[1312] *Chile en la Esposicion universal de Paris en 1867, Catalogo De los objetos remitidos por la Comision nombrada con este fin* (Santiago, 1867)
[1313] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1902), p. 18

equipment for mineralogy were exhibited. After participating at the exhibition, Yunge visited mines and mining companies around the country. [1314] He made a detailed report about his experience after his return, which was published in the Mining Bulletin.[1315]

One thing was participation at industrial exhibitions, but another was facilitating study trips. Were scholarships for travels abroad encouraged in Chile? An engineer who had visited Europe in the mid-nineteenth century insisted on sending two or three distinguished engineering students from the University of Chile to European countries to improve their skills. The purpose of these trips would be to return to Chile and teach relevant subjects at the University or mining schools.[1316] Ignacio Domeyko, the famous Polish mining engineer and principal of the University of Chile from 1867, agreed with him in that it was crucial for the University to send students from all the engineering programs to improve their scientific capabilities.[1317] According to Domeyko this idea was met with "…the strongest cooperation in the Government."[1318] The mining engineer Juan Blanquier Teilecht represents an interesting case, which indicates that public institutions were interested in acquiring knowledge of foreign technology. He was sent years later, in 1912, by the Chilean government to Europe with the following purposes: (1) carry out a complete study of the applications of electricity in the chemical and metallurgical industry, especially the electro-technical procedures for the processing of minerals in electric furnaces; (2) analyse electrolysis of minerals, especially applied to copper and silver; (3) visit and examine the best ore dressing plants, with specific focus on the best machinery used for the concentration of copper and tin ores; (4) carry out a geologic map of Spain and places where there is evidence of underground water currents; (5) find out about processing of ores in

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[1314] G. Yunge, *Memoria presentada por Guillermo Yunge Delegado del Gobierno de Chile a la Exposicion de Buffalo, N.Y.* (Santiago, 1905)
[1315] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1902), pp. 18-95
[1316] I. Domeyko, "Reseña de los trabajos de la Universidad desde 1855 hasta el presente", in *Anales de la Universidad de Chile* (October 1872), p. 22
[1317] I. Domeyko, "Reseña de los trabajos de la Universidad desde 1855 hasta el presente", in *Anales de la Universidad de Chile* (October 1872), p. 22
[1318] I. Domeyko, "Reseña de los trabajos de la Universidad desde 1855 hasta el presente", in *Anales de la Universidad de Chile* (October 1872), p. 22

electric furnaces in Norway, especially copper processing; (6) analyse the fabrication of artificial saltpetre and its importance in connection with the Chilean saltpetre industry.[1319] Blanquier Teilecht's experiences and knowledge of European mining techniques served to select the proper technology for the mining sector. He published articles in the Mining Bulletin about his experiences in Europe. For instance, a description of the fabrication of synthetic saltpetre in Norway was published in 1912 based on his visits to factories in Notodden and Saaheim.[1320] He started to work in a gas company in Santiago and functioned also as a consultant for the Saltpetre and Mining Department and the Corps of Mining Engineers.[1321]

Nevertheless, even though study trips abroad were highly useful to transfer knowledge and public institutions seemed to appreciate the value of them, there are no traces of continuous public or private scholarship programs with such purposes. Only sporadic arrangements were established. The three students who went to Europe in the mid-nineteenth century to study, Manuel A. Osorio, Teodisio Cuadros and Antonio Alfonso, were actually paid for by Ignacio Domeyko. He used his own salary to provide for scholarships to send students to Europe because of a lack of funds.[1322] Later, in 1903, the engineer Eleazar Lezaeta A. claimed in an open letter to the Minister that it was necessary to send mining engineers to mining schools in Europe to become acquainted with "the recent advances in the field". He found it remarkable that "…of the around 10 or more Chilean engineers who are currently studying abroad, there is not one mining engineer…". He recommended to create a permanent arrangement which guaranteed a continuous flow of mining engineering students to distinguished mining schools in Europe.[1323] However, the situation does not seem to have changed. A couple of years later, in 1910, professors at the University of Chile expressed their opinions about sending students or graduates abroad. It was argued that it an arrangement should be made to send

[1319] *Anales de la Universidad de Chile* (Santiago, 1911), pp. 176-177
[1320] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1912), pp. 323-338
[1321] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1931), p. 258
[1322] C. C de bon Urrutia, *La Escuela de Minas de La Serena Derroto de sus Orígenes* (La Serena, 1992), p. 34
[1323] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1903), pp. 420-421

at least one or two graduated mining engineers with public scholarships to travel and take specialising courses:[1324]

> "(T)heir stay abroad and the conditions under which the benefits of their education must show, will be grounds for a special regulation, which would be issued in due course by the Faculty if the plan that we have the honour to propose, comes to have the acceptance that we expect."[1325]

However, their requirements do not appear to have been met. Although the government showed willingness to subsidise study trips occasionally the funding did not become permanent. In 1935, the Institute of Mining Engineers still complained about the lack funds. In an article in the Mining Bulletin, the same argument about the necessity to send graduated capable mining engineers abroad to learn about technological and scientific advances was repeated.[1326] In total, as few as six public and private scholarships were provided to mining engineers between 1850 and 1940.

The scarce funds for study travels abroad meant that very few Chilean engineers travelled abroad after finishing formal studies. A review of University reports, the Mining Bulletin, literature and other relevant documents shows traces of eighteen engineers going abroad between the 1850s and 1940, notably to study at a foreign institution. Only one case is found of a Chilean engineer travelling on behalf of a mining company to study foreign technology. Fidel Cabrera was sent by the Carboniferous Company of Lota and Coronel to the major coal centres in England, Germany, and Belgium to study the most modern coal mining in practices (see appendix 23 of Chilean engineers abroad).[1327] Likewise, few Chilean mining engineers acquired working experience abroad. There is information about three mining engineers and two mining technician working abroad; two in Bolivia, two in Argentina and one in Bolivia and Argentina. However, only two of these certainly returned to Chile after working

[1324] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1910), p. 120
[1325] My translation: *Boletín de la Sociedad Nacional de Minería* (Santiago, 1910), p. 120
[1326] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1935), p. 286
[1327] O. Astorquiza, *Compania Carbonifera e industrial de Lota 1852-1942* (Valparaíso, 1942), p. 61

abroad.[1328]

What did the lack of scholarships and the limited study trips and work experience abroad mean for the mining sector? They meant that very few mining engineers in Chile had hands-on practical experience with foreign technology. This, in turn, functioned as an obstacle for practical knowledge and experience being transferred to Chile. First, technology transfers could hardly occur without this practice. Although there were, of course, other factors, which should be in place for technology transfers to occur, absence of in-depth practical experience of how up-to-date mining techniques were used, blocked important knowledge from being transmitted to the technologically backward small and medium-sized companies. Second, it meant that the Chilean engineers were less prepared to work at the large technologically advanced multinational companies in the country. Mining projects of this size were new in Chile and relevant knowledge was important to handle complex technology. As Chilean mining engineers rarely travelled to other countries, they hardly acquire such experience. Internal correspondence between engineers suggests that these companies doubted the technical capability of the Chilean engineers. Internal letters between the mineral metallurgical manager Frederick Laist and Mr. Williams Wraith at Andes Copper Company from December 1925 reveal that the management questioned whether local workers had the relevant practice they required. With regard to the hiring of “good practical men to act as reverberatory, roaster and converter shift-foremen” Laist argued that it would be preferable to hire men from South America “who have had experience with the operation of roasters, reverberatories and converters… […]…, provided that their experience has really been with equipment of the size and design of that being

[1328] Casimiro Domeyko Alamos graduated from the Mining School in Freiberg in 1892. He worked as manager at Mining Company in Oruro, Bolivia, as well as other Bolivian and Argentinian companies before returning to Chile. He then worked at silver and gold companies in Chañaral and became director of Las Vacas Mining Company; *Album Histórico de la Escuela Univ. de Minas de Copiapó 1857-1950* (Santiago, 1950), p. 10; La Compañía Minera “Las Vacas”, *Informe 1934,* (Valparaíso, 1935): Nicolas Puelma Quevedo, mining technician in 1904 from the Mining School of Copiapó went to Argentina before 1912 for two years before returning to Chile. He started to work as an inspector and professor in mathematics until 1924 and as an administrator at mining companies: *Album Histórico de la Escuela Univ. de Minas de Copiapó 1857-1950* (Santiago, 1950) initiated."[1329] He continued claiming that:

> "…I doubt whether a man accustomed to operating the little converter that Gore used to run at [the Chilean company] Gatico would be the right man for foreman in a converter plant such as ours, although such a man with a little training under the right kind of foreman would, no doubt, prove valuable in time."[1330]

The doubt was whether engineers with only work experience from small-scale domestic companies would have the skills to work with foreign technology and large-scale production. Frederick Laist was clear in his opinion about the use of reverberatory furnaces:

> "With unskilled men, we are not only likely to have much costly delay and annoyance with runaways and spills but the equipment is comparatively easy to ruin. It is not difficult to burn out a reverberatory furnace in a few months and we know from our own experience that a converter lining can be utterly destroyed in a few days if improperly handled."[1331]

This comes close to admit that Chilean workers were not capable of handling the highly complex technology at this company. Therefore, during the start-up of the Potrerillos plant, organised by the Andes Copper Mining Company, preference was given to North American engineers, who were considered better skilled than Chileans. Internal correspondence suggests the company wanted trusted men who were acquainted with the technology that was used the company. The assistant chief engineer at the company who wrote to the metallurgical manager Frederick Laist in October 1915, argued this:

[1329] Montana Historical Society Archives, Collection No. 169, Box No. 73, *Anaconda Copper Mining Company Records*, General Office, Subject File 6.4c, Folder No. 78-6 1925-1928 Staff
[1330] Montana Historical Society Archives, Collection No. 169, Box No. 73, *Anaconda Copper Mining Company Records,* General Office, Subject File 6.4c, Folder No. 78-6 1925-1928 Staff
[1331] Montana Historical Society Archives, Collection No. 169, Box No. 73, *Anaconda Copper Mining Company Records,* General Office, Subject File 6.4c, Folder No. 78-6 1925-1928 Staff

> "Information in regard to the labor situation in Chili should be obtained soon, that is, can we take any labor from here or not; if so, can we take any kind or quality of labor we wish; if not, where will the division be made. I sincerely hope that we can take expert mechanics in the various trades with us, as to have enough of this class of men who are familiar with the various parts of the work would save lots of time, grief, and consequently money."[1332]

Thus, according to these evaluations, in addition to the blockage of knowledge transfers the lack of hands-on experience with up-to-date foreign technology also probably functioned as an obstacle for Chilean engineers to be hired at multinational companies. I argue, therefore, that the few measures that were undertaken in Chile to send mining engineers abroad, contributed to the enclave tendencies and the technological gap within the mining sector.

12.4 Comparisons

Small catching-up economies often based their innovation processes on foreign technology. Examples from Chile and Norway show that mining journals, industrial exhibitions, study travels and work experience abroad had important functions in knowledge transfer processes. Consequently, efforts were made in both Chile and Norway to facilitate knowledge transfers for mining. Technical magazines with information about up-to-date technology was published in both countries. Additionally, engineers and workers participated at industrial exhibitions to acquire information about and observe new and up-to-date technology of the time. Thus, having information about, or being aware of, new technology was not the aspect that separated Chile and Norway.

Differences between the two countries appear when taking a closer look at the institutions, which supported acquisition of practical experience with foreign technology. Reading about new technology in magazines and observing new technology at industrial exhibitions was not enough to transfer and

[1332] Montana Historical Society Archives, Collection No. 169, *Anaconda Copper Mining Company Records,* Box No. 73, Folder No 75-13, 1914-1921, subsidiaries: Andes Copper Co use it. Tacit knowledge was perhaps particularly present in mining and hands-on experience was crucial to select, use and modify technology. Visits to the plants where relevant technology was used in operation, was therefore key enable technology transfers. During trips abroad engineers, technicians and workers acquired contacts, information of, practical knowledge and experience with foreign technology. Technology transfers were extremely difficult to conduct without acquiring such contacts and hands-on practical knowledge. The functions and importance of these trips were clear in both countries.

It was argued by both professors, engineers and politicians that grants were an important initiative to transfer technology. Nevertheless, in spite of being vital for technology transfers, only institutions in Norway implemented measures to encourage travels. The difference between the two countries is related to the number of private and public scholarships that were established. This became apparent in different ways. First of all, continuous programs for travel scholarships were established in Norway, but not in Chile. Permanent arrangements for scholarships, stipends and grants enabled Norwegian engineers to travel abroad. Public and private institutions in Norway provided ninety-nine scholarships, grants and funds between 1850 and 1940 for mining engineers to travel to foreign destinations to learn. In addition, many travelled at their own expense. Over seventy per cent of the mining engineers went abroad either to work, visit plants, industrial exhibitions or on field trips. In contrast, during the same period there are traces of only six public and private scholarships provided by institutions in Chile. There are no traces of mining engineers systematically going on study trips to explore new advances in mining or to work abroad, as the Norwegians did from an early stage. There are examples in Norway back to the eighteenth century of workers and formally trained engineers travelling abroad with such funds, which suggest that this was rooted in an old tradition.

What did these differences mean? Technology transfers and innovation required enormous efforts and took a long time. The companies in question should find it profitable and make the decision to change their technology. It may possibly be that mining companies in Chile did not see the benefits of adopting new and advanced technology. Alternatively, they did not have the funds. Nevertheless, I argue first and foremost that hands-on learning of the technology was an important ingredient in the innovation processes. Hands-on practice and experience with the machinery and techniques were necessary to do that, which the Chilean engineers lacked. Few travels abroad meant that the Chilean mining engineers had much less hands-on knowledge about how new technology functioned and used than the Norwegian engineers. The small number of scholarships for these purposes hindered a free flow of practical knowledge to the mining sector in Chile. This lack of foreign knowledge and experience put the Chilean mining engineers in a disadvantage. Although the lack of this knowledge does not fully explain why companies did not innovate, I argue that relevant hands-on practical knowledge and experience with foreign technology was indispensable to transfer technology. Second, the lack of experience from abroad probably prevented the Chilean mining engineers from working at technologically advanced foreign companies. Evaluations by North American companies about the domestic level of engineering and competence suggest that they preferred workers with experience from other countries (see the implications of these discrepancies summarised in the table on the next page).

The discrepancies in institutions were linked to the different developments of the two sectors. Mining engineers used experiences from abroad directly in their work at mining companies in Norway after their return and contributed to the continuous innovation processes that characterised the sector. In contrast, the few measures that were undertaken in Chile to send mining engineers abroad strengthened the enclave tendencies and the technological gap within the mining sector. Institutions in Chile did not carry out the necessary efforts to transfer knowledge to the mining sector – a sector that required continuous technological changes, in terms of energy sources, machinery and processing techniques, to become technologically advanced.

Discrepancies in institutions for technology transfers in Chile and Norway

	The extent of scholarships, study travels and work experience abroad	Implications	Comments
Norway	Large number	Transfer of practical knowledge to the larger part of the mining sector	1.Travels and visits were crucial for the acquisition of contacts, experience and use of technology, notably foreign 2. Experience and work practice with foreign technology were considered positive in both countries
		Employment of engineers at all companies (also foreign)	
Chile	Small number	Transfer of knowledge only to a small part of the mining sector	
		Exclusion of engineers from foreign companies	

One can wonder why there were so few travel scholarships in Chile. Engineers, professors and politicians clearly saw the importance of them. Was Chile too far away from industrial powers for engineers to continuously travel and work there? Norway was situated in Europe, and much closer to industrial centres in Germany, England and France than Chile, which made it easier, cheaper and faster for people from this country to travel. On the other hand, many Norwegians travelled to the United States, Chile, South Africa and Australia, which probably implied long and complicated travels. If the only problem was travelling distance, this challenge has been overcome many times in history. Alternatively, even though knowledge transfers were valued, maybe supporting foreign travels and work experience in other countries were simply given lower priority by the broader set of political decision-makers. This was then part of a deeper political and cultural issue of a downgrading of the mining sector, which will be discussed further in the last chapter.

13 Geological mapping and ore surveys: discrepancy in extent

The aim of this chapter is to explore the institutions, which aimed to carry out geological maps and ore surveys in Norway and Chile. National geological surveys were essential for advancement of mining industries, as they were in charge of making geological maps, examine contents and grade ore mineral ores and estimate potential economic profits. Mining sectors based their progress on this type of work. David and Wright emphasise the importance of mineral prospecting in relation to the start-up of mining operation. In the case of the United States they find that: "(p)rovision of geological information was perhaps the most important initial step in the collective enterprise of resource discovery and exploitation."[1333] The utilisation of gradually lower grade mineral and metal ores from the late nineteenth century, increased the even more the importance of detailed information about possible economic returns.

13.1 Systematic and organised geological mapping and ore surveys in Norway

From early on, initiatives were made to promote mining in Norway. Public grants, such as "scholarship for scientific trips within the Fatherland" and "Royal travel grant", as well as the "Rathke bequest", after the professor Jens Rathke, and the "Greve Hjelmstjerne-Rosencrone bequest", were provided by the University especially for mining engineers to do geological excursions, map and to search for ores within Norway.[1334] Ole Sandstad was given a scholarship from the Rathke Fund to study Norwegian nickel, copper and gold deposits.[1335] In 1870 assistant professor Hjortdal was given 50 spesidaler from the "scholarship for scientific trips within the Fatherland" to analyse the minerals in the tunnels at Kongsberg Silver Works.[1336] The geologist, mining engineers and professor Theodor Kjerulf went to Hardangervidda immediately after studies in 1849 to carry out a geological survey with a University scholarship.[1337] Scholarships were also provided to travel abroad. Kjerulf went on

[1333] P. David, G. and Wright, "Increasing Returns and the Genesis of American Resource Abundance", *Oxford Journals*, vol. 6, issue 2 (1997), p. 223
[1334] *Universitets- og skoleannaler* (Kristiania, 1834-1910)
[1335] *Studenterne fra 1883* (Kristiania, 1908), pp. 335-338
[1336] *Universitets- og skoleannaler* (Kristiania, 1870), p. 49
[1337] A. K. Børresen and A. Wale, *Kartleggerne* (Trondheim, 2008). 52

field trips to Iceland, France, Harz and Erzgebirde, Germany and Tirol in Austria and collaborated with researchers in Bonn and Heidelberg. In 1862, he went to Berlin, Breslau and Vienna to inquire with specialists with regard to geological mapping.[1338] Amund Theodor Helland did several trips abroad between 1871 and 1913. In 1875, he went to Greenland and studied microscopic petrography in Leipzig in 1876-77. Later he went to the lakes in northern Italy before analysing Norwegian glacial erratic in England, Holland, northern Germany and Denmark. In 1879, he conducted geological surveys in the Orkney Islands, Shetland Islands and Faeroe Islands before going to in Iceland in 1881.[1339] Carl Olaf Bernhard Damm obtained a Rathke scholarship and at least two other scholarships during the 1890s. He studied removal and transport of ore at Norwegian mining works and carried out geological surveys and analyses of rocks in Sweden, Germany and Austria.[1340] In 1917, Sulitjelma Mining Company Ltd. created a fund to promote Norwegian geological knowledge. The fund paid for a stay at Sulitjelma for geologists to do geological surveys.[1341]

Scholarships largely encouraged geological surveys, but the main institution for this work was Norwegian Geological Survey (NGS), a public research centre, was established in 1858. Geologists and mining engineers started immediately to organise mapping and implementat geological maps and ore surveys. The Survey had in principle two main tasks. On one hand, it was to contribute to new knowledge about geological features, their scope and potential utility. On the other hand, it sought to contribute to new and more systematic surveys of the country's geological formations and deposits.[1342] In 1891, the Survey established a publication series, including yearbooks, academic reports and map descriptions of Norwegian geology and engineers and geologists made gradually more detailed maps during the late nineteenth century and early twentieth century.[1343] Twenty-six

[1338] A. K. Børresen and A. Wale, *Kartleggerne* (Trondheim, 2008). 52
[1339] J. A. Schneider, *Studenterne fra 1864* (Skien, 1916), pp. 95-99
[1340] *Studenterne fra 1886* (Kristiania, 1911), p. 86-87
[1341] *Tidsskrift for bergvæsen* (Oslo, 1917), p. 71
[1342] See A. K. Børresen and A. Wale, *Kartleggerne* (Trondheim, 2008) for the history of Norwegian Geological Survey
[1343] A. K. Børresen and A. Wale, *Kartleggerne* (Trondheim, 2008), p. 96

mining engineers worked a period at Norwegian Geological Survey from its start-up in 1858 to 1940. They either conducted geological excursions on behalf of the Survey during summers or worked there as “state geologists”. Some politicians criticised the institution for working to slow, but by 1920, geological and laboratory work had resulted in overview maps of the country, including Svalbard, detailed maps of mineral deposits and ore analyses. More detailed maps were added later.[1344] Other research institutions with the purpose of doing research on minerals were the Public Laboratory for Raw Materials, established in 1917, aimed to do research of the country’s geological resources through chemical analysis, and the Institution for Geophysical Ore Exploration, founded in 1934, which used geophysical methods.[1345] In addition, the University of Oslo and the Norwegian Institute of Technology (NIT) created a number of laboratories for scientific research in chemistry, metallurgy and ore dressing.[1346]

Børresen and Wale describe the vital role of these institutions in the start-up and development of the mining sector:

> “The know-how the geologists at the university and NGS managed, and the rocks, ore deposits and mineral raw materials that systematically had been examined, explored and mapped, even during the difficult years for the mining industry from the 1870s, was an essential prerequisite for the market opportunities to be utilised to such an extent to quickly revive the Norwegian mining industry.”[1347]

Large-scale electro-metallurgical productions started in Norway in the early twentieth century with large foreign investments and were directly linked to the geological work and ore analyses

[1344] A. K. Børresen and A. Wale, *Kartleggerne* (Trondheim, 2008), p. 124
[1345] H. Carstens, *…Bygger i Berge* (Trondheim, 2000), pp. 72-73
[1346] For collaboration between professors and mining companies See A. K. Børresen, *Bergtatt: Johan H. L. Vogt – professor, rådgiver og familiemann* (Trondheim, 2011); A. K. Børresen and Kobberrød, J. T. (red.) *Bergingeniørutdanning i Norge gjennom 250 år* (Trondheim, 2007); A. K. Børresen and A. Wale, *Kartleggerne* (Trondheim, 2008); A. K. Børresen and A. Wale (red.), *Vitenskap og teknologi for samfunnet? Bergfagene som kunnskapsfelt* (Trondheim, 2005)
[1347] My translation: A. K. Børresen and A. Wale, *Kartleggerne* (Trondheim, 2008), p. 107

implemented by the geologists at Norwegian Geological Survey. Organised mapping and geological surveys contributed to discoveries of new resources and the establishment of new large-scale companies. The mining engineer and professor Johan Herman Lie Vogt played a big part in the mapping of Norwegian mineral deposits. From 1889 he continued mapping Nordland, a region in the northern part of Norway, work which had started in the 1860s by the mining engineer T. Dahll. Vogt published his surveys and analyses of the Dunderland Valley iron ore fields, including a general description of how the minerals were formed and their geological structure. It also included a detailed review of the deposits. Subsequently, the foreign companies Dunderland Iron Ore Company and Sydvaranger Mines Ltd were founded in 1902 and 1906. A similar story can be told of the marble industry. Vogt reported of several marble ores which represented a good foundation for a marble industry. Together with Professor Waldemar Chr. Brøgger he contributed to the start-up of Ankerske Marble Business in 1895.[1348]

13.2 A lack of systematic mapping and ore analyses in Chile

Information about the content of ores and the possibilities for economic profit were vital for the start-up of mining operations. Mining engineers and geologists played a crucial part in the carrying out of such mineralogical analyses in laboratories. During the nineteenth century, a number of countries with important mining industries created national geological surveys to carry out systematic and detailed geological maps of mineral deposits:

[1348]: see A. K. Børresen and A. Wale, *Kartleggerne* (Trondheim, 2008), pp. 101-106 and A. K. Børresen, *Bergtatt: Johan H. L. Vogt – professor, rådgiver og familiemann* (Trondheim, 2011)

Selected National Geological Surveys

Year	Country	Institution
1835	Britain	British Geological Survey
1842	Canada	Geological Survey of Canada
1849	Austria	Federal Geological Office
1849	Spain	Commission for Geological Map of Madrid and the Realm
1851	India	Geological Survey of India
1858	Sweden	Geological Survey of Sweden
1858	Norway	Geological Survey of Norway
1867	Italy	Geological Committee
1873	Germany	Royal Prussian State Geological Institute
1877	Finland	Geological Survey of Finland
1879	The United States	The United States Geological Survey
1896	Belgium	Geological Survey of Belgium
1910	Australia	Ausralian Survey Office

Geological surveys in Chile, on the other hand, were traditionally carried out irregularly through sporadic studies of terrain.[1349] They were either sponsored by the state or financed privately by local or foreign engineers and geologists, but were not part of an organised institution.[1350] A lack of systematic geological maps and detailed ore surveys was a continuous problem and has been used as a direct cause for the unutilised ore deposits in Chile. This problem was recognised from early on. At a mining conference in 1894, it was argued that one of the reasons of the underdeveloped mining sector was the lack of organisation to carry out scientific and industrial work.[1351] Four years earlier, in 1890, the mining engineer Augusto Orrego Cortés stressed that:

> "(i)t seems incredible to Europeans, that a country like Chile, where export of minerals reaches 80 per cent of its total exports, has not been concerned with ensuring through permanent research and fixed data, the regularity and continuity of utilisation of industries which constitute its main assets…[…]… Gold, copper, lead, coal, salt, sulphur, manganese, limestone and even silver could be the object of

[1349] Pedro José Amadeo Pissis, a French geologist, published a number of books in the mid-19th century about Chilean geology with topographic maps about different regions of the country. He started a preparation of a Chilean map in 1848 on behalf of the Government. He was the first to make geologic maps of Chile. In "Geografía fisica de Chile", published in 1875, he gave an orographic, geological, meteorological and hydrographic description. The Government sent Rudolfo A. Philippi in 1854 to the Atacama Desert to implement scientific analyses of nitrate deposits: S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 100

[1350] A. Orrego Cortés, *La Industria del oro en Chile, memoria excrita por encargo de la Sociedad Nacional de Minería* (Santiago, 1890), p. 49

[1351] S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 174

> this work, which should not be limited to simple scientific observations and topographic and geognostic data, but the detailed knowledge and as complete as possible of all existing deposits in the country, their market value and economic conditions in which they find themselves."[1352]

Gandarillos Matta confirmed that without such geological studies the mining sector would not be able to "…acquire any precision or accuracy of geological data."[1353] Members of the National Mining Society wrote in the Mining Bulletin every year about a lack of maps, surveys and scientific analyses. The Society published articles continuously about the lack of detailed topographic studies of each of the Chilean regions and geological analyses of the nature of the mines.[1354]

It is important to underline that during the first part of the twentieth century efforts were made to make detailed topographic studies and national geological maps. Long and detailed reports were made of the Chilean geology and mineralogical grounds in the Mining Bulletin and the annual reports of the University, notably by professor Ignacio Domeyko. They often included descriptions of copper, iron, iron and silver deposits. In addition, some mining engineers did consulting work in the form of ore analyses and economic panning for companies or institutions. Their reports included information about geological setting, mineral ores, production, technology and economic development of companies. There are traces of seventeen mining engineers doing evaluation work of this type (see appendix 19 of mining engineers and consultant work). Then, in 1914 the public Temporary Service for Geological Studies was created and the Department of Mines and Geography in 1919.[1355]

[1352] My translation: A. Orrego Cortés, *La Industria del oro en Chile, memoria excrita por encargo de la Sociedad Nacional de Minería* (Santiago, 1890), pp. x-xi

[1353] J. Gandarillas Matta, *Estado actual de la industrial minera del cobre en el extranjero y en Chile* (Santiago, 1915), p. 79

[1354] See *Boletin de la Sociedad Nacional de Minería* publications: for instance *Boletin de la Sociedad Nacional de Minería* (Santiago, 1891), p. 159; *Boletin de la Sociedad Nacional de Minería* (Santiago, 1931), p. 355; *Boletin de la Sociedad Nacional de Minería* (Santiago, 1934), p. 122; *Boletin de la Sociedad Nacional de Minería* (Santiago, 1939), p. 88; *Boletin de la Sociedad Nacional de Minería* (Santiago, 1939), p. 300; *Boletin de la Sociedad Nacional de Minería* (Santiago, 1939), p. 310

[1355] S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 198

Nevertheless, although some analyses and reports of this kind were made, they were obviously too few to cover the enormous demand for detailed ore analyses of the content of ores, yields and information about economic returns. Members of the National Mining Society, the Institute of Mining Engineers and the Credit Bank of Mining continued to complain about the lack of scientific analyses of mineral deposits and the scarce number of necessary scientifically trained mining engineers to carry out such mineralogical analyses in laboratories. In 1923, the Chilean politician and lawyer Santiago Macchiavello Varas pointed out that:

> "(t)he utilisation of the mines, which has long done without any scientific principle, has evolved so much…[…]… that it can now be said that it is completely impossible to carry it out in an economically productive way, without complying with principles of physics, chemistry, geology and mineralogy."[1356]

The many ore deposits in Chile remained unutilised, he explained, "…due to ignorance."[1357] He even argued that many owners of mines paid the patents to maintain ownership of the concession and waited for foreigners to start operators. In the northern provinces "…thousands are awaiting for the arrival of the foreigners..."[1358] The solution of the problem, according to him, was to establish:

> "…a body to come and fill these countless voids which today are felt in the national mining in general, a Corp which with the necessary scientific capacity can store our mining potential, with appropriate authority inspect and acquire all necessary data for the proper control, and without capital interests can orient the miner in his operation…"[1359]

[1356] My Translation: S. Macchiavello Varas, *El problema de la industria del cobre en Chile y sus proyecciones económicas y sociales* (Santiago, 2010), p. 260

[1357] S. Macchiavello Varas, *El problema de la industria del cobre en Chile y sus proyecciones económicas y sociales* (Santiago, 2010), p. 121

[1358] S. Macchiavello Varas, *El problema de la industria del cobre en Chile y sus proyecciones económicas y sociales* (Santiago, 2010), p. 189

[1359] My translation: S. Macchiavello Varas, *El problema de la industria del cobre en Chile y sus proyecciones económicas y sociales* (Santiago, 2010), pp. 111-112

Two years later, in 1925, a Corps of Mining Engineers was formed with the aim of forming a national geological map. Five years after, in 1930, the Mining and Petroleum Department continued the originally assigned functions of the Corps.[1360] The government hired a group of geophysicists to do examinations of petroleum deposits in Magallanes in the 1930s.[1361] However, the mapping and surveying continued to be sporadic and unorganised. In 1931, the Society wrote that:

> "(i)n all countries that have geological services and firmly established mines, the skeleton of these geological-economic studies constitutes the general geological map. Unfortunately in our country it has not been possible to carry out the preparation of this map and the only overall [map] is the one raised by Pissis commissioned by the Government of Chile [from the mid-nineteenth century]."[1362]

In 1934, it was stated in the Mining Bulletin that the enormous non-metallic deposits had not given rise to productive industries "…due to the lack of scientific studies".[1363] The Geological Research Institute was another geological institution established after 1939 by CORFO (Corporation for Promotion of Production), with the intention of making analyses of mineral deposits in the country.[1364] Yet, the implementation of a geological map was still "in its initial stage", compared to other countries with smaller and less important mining industries.[1365] The National Mining Society affirmed in 1939 that the lack of scientific studies to exploit natural resources "…is leading us to a dead end situation."[1366] In the same line of argument the Credit Bank of Mining explained that a "lack of scientific guidance in the study of these deposits causes us to make mistakes [which are] fatal for these industries."[1367] This problem continued for decades. An illustrating example from recent times is La Escondida, one of the largest ore deposits in Chile, and in the world, which was not discovered

1360 S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 198
1361 *Boletin de la Sociedad Nacional de Minería* (Santiago, 1931), p. 361
1362 *Boletin de la Sociedad Nacional de Minería* (Santiago, 1931), p. 355
1363 *Boletin de la Sociedad Nacional de Minería* (Santiago, 1934), p. 122
1364 S. Villalobos et al. *Historia de la ingenieria en Chile* (Santiago, 1990), p. 306
1365 *Boletin de la Sociedad Nacional de Minería* (Santiago, 1939), p. 88
1366 *Boletin de la Sociedad Nacional de Minería* (Santiago, 1939), p. 300
1367 *Boletin de la Sociedad Nacional de Minería* (Santiago, 1939), p. 310

until 1981, by the North American J. David Lowell.[1368]

13.3 Comparisons

The most remarkable difference between the two sectors was geological mapping, ore surveys and economic planning, which was the basis and starting point of mining operations. Without proper ore analyses and knowledge about existing mineral deposits, mining could hardly advance. In Chile, one of the main problems was the lack of such geological surveys and ore analyses of the country's existing mineral deposits. Sporadic work was carried out in the field, but they were not nearly enough to obtain a complete picture of the ore deposits in the country, their grade and possible profits. The result was that several thousand mines were abandoned and mineral deposits remained unknown. This situation endured and large mineral deposits were not found up until recent time. In short, it is argued here that the lack of geological maps and ore surveys in Chile had huge implications for the progress of the mining sector by blocking the start-up of mining projects.

Discrepancies in geological mapping and ore surveys in Chile and Norway

<table>
<tr><th></th><th>Geological mapping and ore surveys</th><th>Implications</th><th>Comments</th></tr>
<tr><td>Norway</td><td>The Norwegian Geological Survey mapped the larger part of the country by 1920 and continuously carried out analyses of ores</td><td>Led directly to start-up and continuation of mining projects</td><td rowspan="2">Geological maps and detailed scientific analyses of the ground and ores were vital to begin and continue efficient and profitable mining. Mining could not take place without knowledge about the ground, detailed information about the ore that was being utilised and potential economic profit</td></tr>
<tr><td>Chile</td><td>Sporadic geological mapping and surveys organised publicly or by private companies</td><td>Blocked start-up of mining projects and continuation of abandoned mines</td></tr>
</table>

[1368] D. De Ferranti et al. *From Natural Resources to the Knowledge Economy* (Washington D. C., 2002), p. 6

Norway, on the other hand, started early with a systematic geological mapping and surveys of the mineral and metal ores in the country. The Norwegian Geological Survey was established in the mid-nineteenth century, while Chile lacked such an institution. In Norway, copper, silver and nickel production was modernised and a new large-scale electro-metallurgical industry based on hydroelectric capacity developed after extensive systematic geological mappings of regions rich in minerals. The implications of these discrepancies are summarised in the table above.

In Chile, many engineers, industrialists, mining leaders and others expressed the need for a national institution for geological mapping and surveys. Why, then, was not a national geological survey established in this country? Geological mapping, ore analyses and prospecting required scientific and detailed knowledge of the ground, of mineral compositions, of how minerals and metals behaved and of how to profit from them economically. Formally trained and experienced mining engineers were essential because they had in-depth knowledge of how to carry out such work. Therefore, I argue, the lack of geological maps and ore surveys were linked to the few mining engineers in the country. This was particularly serious because it prevented start-up of mining companies and advancement of industries. The contrast to other countries is striking. The early implementation of detailed geological maps and ore surveys in mining countries, such as the United States, the Scandinavian countries etc. were gradually carried out by geologists and mining engineers. The Norwegian Geological Survey, for instance, based its detailed geological mapping and surveys of mineral deposits in the country on the organised work of mining engineers, geologists and other scientists from its foundation in 1858.

14 Returning to the role of the state

Why were knowledge institutions for mining in Chile not developed to the same degree as in Norway? Members of the National Mining Society, professors and engineers expressed the need for transfer of foreign knowledge and many more scientifically trained engineers and professionals. Initiatives were made on behalf of the state and private actors to establish mining education, scholarships, industrial exhibitions etc. but they were clearly not enough to encourage continuous innovation processes in the sector. It is, perhaps, strange that not more was done to develop knowledge for mining in Chile; a country with one of the largest mining sectors in the world and large amounts of unutilised mineral and metal ores. The underlying reasons for the unfavourable development of these knowledge institutions in Chile was rooted in more structural problems, which seems to be linked to the role of the state.

The lack of engineers and technicians in the mining sector was related to a too small number of students at the engineering programs, Mining Schools and technical schools. This lack of students was much due to a social problem of limited primary and secondary education. As seen in the chapter about the diverging gap between Chile and Norway, a large share of the cohorts did not attend primary school and many did not finish. This created a bottleneck in the education system, which made it difficult to recruit students to the Mining Schools and other technical schools. To be admitted to the University the students needed to have finished secondary school and to pass an admission test. Even fewer students finished secondary school, which meant that there were few students with the proper qualifications to enter higher studies. The few engineering students, thus, is explained to a large degree by a restricted number of qualified students to begin higher engineering studies.

At first glance, it would seem strange that illiteracy and a weak education system would be a problem for so long in Chile. From early on, politicians, industrialists and members of the elite, influenced by the Enlightenment and liberal way of thinking, expressed the importance of education for the whole population and argued that it was crucial for economic development and progress. During the nineteenth century, liberal sectors, intellectuals and labour organisations supported obligatory teaching. The brothers Gregorio and Miguel Luis Amunátegui, both historians, argued that education should cover the broader part of the population. Domingo Faustino Sarmiento was an Argentine intellectual, member of the liberal party in Chile, and president in Argentina from 1868 to 1874. He also became involved in promoting education in Chile. He stressed education for the whole population, including women, and the same rights for all citizens of the Republic. Education gave people the possibility to use their rights and searching for knowledge, which would encourage progress and industrial development. According to him, the public education system was responsible for creating these capacities. He looked to France and England and stressed that primary education should be valued because it assured a more efficient industrial performance. Such ideas maintained. In the late nineteenth century philosopher Valentín Letelier and the educators Claudio Matte and José Abelardo Núñez sustained that general primary education should be covered for the whole population. Letelier promoted free public education and argued that mandatory education was a democratic principle.[1369] As these intellectuals argued for basic education, more public schools were created and public spending on primary education increased gradually.[1370] Moreover, the government supported travels abroad, for example to Germany and Sweden, to learn about primary education systems in other countries.[1371] Even though there were discussions and some initiatives, covering basic education for the whole population would imply much more measures. The initiatives that were undertaken were not nearly enough to reduce illiteracy to a minimum. Latin American countries did not develop basic education for the general population during the Colonial times and, as argued, the

[1369] M. L. Egaña Baraona, *La Educación Primaria Popular en el Siglo XIX en Chile* (Santiago, 2000), pp. 27-32 and pp. 136-139
[1370] M. L. Egaña Baraona, *La Educación Primaria Popular en el Siglo XIX en Chile* (Santiago, 2000), pp. 63-64 and p. 88
[1371] M. L. Egaña Baraona, *La Educación Primaria Popular en el Siglo XIX en Chile* (Santiago, 2000), pp. 27-32 and pp. 136-139

political elite did not see the value of a literate working class. In comparison, in European countries, such as France, Germany, the Netherlands, the Nordic countries and the United States, education started long before the nineteenth century, often by members of the elite; the church, volunteers or industrialists. A public education system was gradually developed based on these initiatives.

It is important to mention that some public measures with the aim of fostering development in the mining sector were carried out. For instance, initiatives were conducted to recruit more mining engineer and technicians students. On the recommendation of the Faculty, around 1910 scholarships were established for young people from the province who wanted to start a career as mining engineer.[1372] 8000 pesos was used in 1920 to "…subsidise students in provincial schools to continue in Santiago the higher course of mining engineering."[1373] However, professors explained that scholarships were not enough to raise the number of students and were not applied as intended. A problem pointed out by professors was that this scholarship did not comply its purpose. The regulation did not oblige the students to finish mining engineering studies, and the result was that "a number of students" transferred to the civil engineering program instead.[1374] This leads to another question: why would students move over to civil engineering? One reason was perhaps that the mining engineering program had less status than other study programs because of lack of opportunities after graduation. A professor at the University of Chile stated that one of the reasons for the lack of mining engineering students was that there were too few jobs for them after they finished their studies.[1375] However, the problem was probably not a lack of work in the mining sector. As seen, almost all the mining engineers, only with a couple of exceptions, started to work in mining. Still, there were also other problems related to status. Professors at the University and mining engineers found that the title "practical mining engineer" that was given to the graduates from the

[1372] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1910), p. 119
[1373] *Anales de la Universidad de Chile* (Santiago, 1920), p. 319
[1374] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1910), p. 119
[1375] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1910), p. 115

Mining Schools was misleading. This involved "…misunderstandings and confusion" for the industry with regard to the definition of an engineer.[1376] It reduced the status of the engineers, who had a long scientific education behind them and prevented more students from choosing the mining engineering study at the University.[1377] For these reasons, it was requested to eliminate "engineer" from their title.[1378] Their wishes were taken into account and in 1916, the word "engineer" was removed from the graduate title at all the Mining Schools.[1379] The number of students increased to some degree after this, but it was clearly not enough. With an overall lack of students with the necessary requirements to enter the University, some student scholarships and motivation to start the mining engineering program, would probably not help that much.

In Chile, although the state received huge incomes from mineral and metal productions, the state did not give priority to the mining sector. The marginalisation of the mining sector became apparent in different ways. As seen in previous chapters, property laws favoured the owner of the land and did not stimulate efficient and competitive large-scale mining. The few travel scholarships is another indication that mining was downgraded. Although professors and some politicians saw the importance of sending students and graduates abroad, this did not become a permanent arrangement. The downgrading of the mining sector is illustrated by the public measures to foster different industries. The Mining Bulletin from 1921 revealed information from the budget and shows that mining was not prioritised nearly as much as agriculture and manufacturing industries, even though the mining sector was clearly the largest sector for exports:

> "Education and fostering of agriculture 2 358 180
>
> Education and fostering of manufacturing industries 1 477 588

[1376] S. Macchiavello Varas, *El problema de la industria del cobre en Chile y sus proyecciones económicas y sociales* (Santiago, 2010), p. 261
[1377] *Anales de la Universidad de Chile* (Santiago, 1915), p. 176
[1378] *Anales de la Universidad de Chile* (Santiago, 1915), p. 176
[1379] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1918), p. 492

Education and fostering of mining (including mines and geology) 803 617"[1380]

A direct effect of this underfunding was that the Pontifical Catholic University of Chile initiated a mining engineering program in the early twentieth century, but had to close it down due to large expenses.[1381] The state as a promoter of knowledge development for mining was much clearer in Norway than in Chile. In Norway, the state was active in the establishment of a general education system for the whole population. The more developed primary and secondary school system and low illiteracy rates reduced the problem of recruiting students to technical schools, the University and the NIT. The more active state in Norway was also illustrated by the large a number of public programs for learning and travels abroad, which were established from the eighteenth century and onwards.

Why, then, was knowledge development for the mining sector not prioritised in Chile? The state gave the mining sector less priority compared to other sectors, notably agriculture. The reason for instead prioritising agriculture may lie in the agricultural elite, which dominated the political agenda in Chile. It is explained that in the late nineteenth century, "(t)he government was constituted of a minority from the oligarchic political elite, of landowner origin, in which characters from the intelectual and commercial world were incorporated…".[1382] This situation persisted. In the early twentieth century, "… the Chilean oligarchic elite, based in Santiago and Europe, had in their hands the total control of tthe different spheres of power."[1383] Although there were political decision-makers who saw the importance of fostering mining, the great majority of the political sphere had other interests, which possibly was in direct conflict with mining. Whether this actually was the case and whether institutions for the development of the agricultural sector in fact built an efficient and profitable

[1380] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1921), p. 457
[1381] *Boletín de la Sociedad Nacional de Minería* (Santiago, 1925), p. 663
[1382] "Partidos politicos chilenos del siglo XIX», article in Memoria Chilena, Biblioteca Nacional de Chile: http://www.memoriachilena.cl/602/w3-article-3572.html#presentacion [accessed 29th March 2015]
[1383] "La Guerra civil de 1891", article in Memoria Chilena, Biblioteca Nacional de Chile: http://www.memoriachilena.cl/602/w3-article-706.html [accessed 29th March 2015]

agricultural sector, requires further analyses.

15 Conclusions

Why have economies based on natural resources developed so differently? Some of the richest countries in the world, such as Australia, New Zealand, the Nordic countries, Canada and the United States, have largely based their economic growth on the utilisation of natural resources. Why have these economies become rich, while Latin American and African countries have not? Scholars have recently started to address this issue in more detail and have demonstrated that some countries have developed *because* of their natural resources, not in spite of them. Evidence suggests that industries in the rich resource-based economies have been highly knowledge intensive, innovative, created linkages to other industries within the economy and developed successful specialisations and new industries, often based on upstream and downstream linkages. At the same time, other resource-based economies, both large and small, have experienced lack of growth and trade difficulties. These questions have been explored here through a comparative analysis of institutions that aimed to create, transfer, adopt, modify and diffuse knowledge for mining development in Chile and Norway.

Scholars have constructed a number of general models of institutions and economic growth, which classify countries into broad categories, as they seek to explore these questions. Douglass North, for example, divides societies into “limited access societies” and “open access societies”: elites control political institutions and the economy in the former, and free competition rules in the latter. Acemoglu and Robinson make a distinction between extractive and inclusive institutions. They argue that there are societies in which institutions sustain the rule of a small elite, which exploits the broader population, while others include the greater part of the population in democratic processes. The foundation of these models are institutions, which motivate innovation or constrain economic agents. Some institutions are understood as “good”, while other are “bad” for economic activites. A democratic state system, secure proverty rights, efficient trade systems and education are some of the “good” institutions, which arguably support continuous learning and innovation. Authoritarian regimes, rent-seeking and insecure property rights are argued to be negative for economic growth.

However, incentives to innovate may be a precondition for economic growth, but do not explain how innovation actually occurs. Much research has been made on institutions and economic growth, but in-depth analyses of their aims, functions, impacts and links to innovation and economic growth are scarce. There are few analyses, which actually show the direct relationship between institutions, innovation and economic performance. There is a lack of evidence with regard to (1) which institutions in fact determine knowledge development and innovation, and (2) how particular institutions encourage and enable learning and innovation. Even the innovation systems approaches, which seek to examine innovation processes, can be criticised for making overly simple national models and for not capturing the complex sets of learning and knowledge institutions within and across countries. My claim in this thesis has been that these general models neglect variety and the possibility that regions, sectors and countries grow in different ways. When we go deeper into the institutions and analyse how they in fact interact with each other, how they develop knowledge and influence innovation, we can hope to understand more about economic growth.

Comparative studies of Scandinavia and Latin America have argued that some key factors ensured a positive development in the former, while these factors were absent, or certain elements constrained such positive development, in the latter. Among the features that have been proposed to explain the diverging economic paths of Latin America and Scandinavia, are, notably, the use of foreign technology, reforms in the agricultural sector, political regulations and education systems. However, when taking a closer look at these factors specifically for two of these countries, namely Chile and Norway, analyses appear to be too general, or to lack empirical evidence or support. To understand fully the factors which determined differences in social patterns and economic growth of these countries, general comparisons are not enough. To make solid conclusions, it is necessary to go deeper and make sure that the arguments reflect actual circumstances.

Perhaps the most striking findings of this analysis are the similarities between Chile and Norway, two countries that at first might not appear particularly similar. Yet, they share a number of geophysical, industrial and historical characteristics. First, the two countries have similar geophysical structures, in terms of big mountain areas, a long coast, waterfalls, huge mineral and metal deposits and forests. Second, Chile and Norway posess many of the same natural resources and have developed comparable natural resource industries, such as metal and mineral extraction, timber and timber-related industries and fishing. Third, both countries were under colonial rule for hundreds of years before becoming independent in 1810 and 1814 (when Norway entered into a union with Sweden, which ended in 1905). In this sense, they were both met with challenges when it came to form a self-governing state. The two countries had comparable economic growth until the 1930s. Thereafter, an economic gap started to emerge and from the late 1940s, after the Second World War, the gap was evident. Norway, some say against all odds, developed to become one of the richest countries in the world with a literate population from a very early stage and small social differences. Chile, on the other hand, had high illiteracy rates until the mid-twentieth century, has until recent decades had slow economic growth and still has poverty and large social differences. What determined failure and success in these two economies? Although the answer to this question is still unclear, I have sought to explore this further by focusing on one sector, namely mining, from the mid-nineteenth century to 1940, the period leading up to the economic gap between the two countries.

During the nineteenth century, industrialisation in many countries created larger markets for traditional metals, such as copper, iron and silver as well as new mineral products, such as steel and aluminium. In this context, mining faced major challenges in terms of finding, removing and processing ores, in particular due to a gradual exhaustion of valuable high-grade mines and the start-up of new mineral and metal productions. In order to maintain profitable production, new methods to find ores were developed and mining companies adopted new techniques for ore prospecting, removing ore, organisation of work and ore processing. New and more powerful machinery and power sources became common from the late nineteenth century. Steam, animal and manual power were gradually replaced by mechanical and electrical power and enabled deeper mines and larger scale production. New converters, furnaces, ore dressing and smelting techniques permitted the utilisation of lower grade ores.

A revision of the operational activities and innovation processes have demonstrated that profitable mining in Chile and Norway was based on complex knowledge and depended on a continuous adoption of new and more efficient technology. As mining diversified and operational processes became more complex, the relevant knowledge became increasingly specialised. This supports the argument made in the literature that natural resources can be knowledge intensive and that mining in many ways was compatible with "modern knowledge-based economies". A variety of knowledge categorisations has been used to identify different aspects of knowledge, such as scientific, theoretical and practical knowledge. Knowledge domains, in terms of natural sciences, i.e. geology, mathematics, metallurgy, mechanics and mineralogy, were developed at universities and technical schools. Operations at technologically advanced companies became increasingly dependent on scientifically trained mining engineers and mining technicians. Professionals with other educational backgrounds, such as electro-engineers, mechanical engineers, chemists, economists etc. also became increasingly important. Educational institutions turned out to be crucial because they provided mining industries with such professional workers. Without downplaying the signal effects of formal education in an employment situation, this analysis has shown that formal technical education, notably in terms of scientific and theoretical knowledge, was essential for certain procedures in mining and used directly in working operations. One of the obvious connections between education and innovation was the extensive use of geology, chemistry and mineralogy in the construction of geological maps and analyses of ore. Another obvious example is the use of mathematical calculations and knowledge of physics and mechanics in the design and measuring of mines. At the same time, mining operations were based on hands-on use of equipment and measurement tools, drawing and making of mines, removing, transporting and processing of ores etc.

The uniqueness of each geological ground and mine, and the continuous adaptation of new techniques, suggest that much of the work involved trying and failing. Practical knowledge and long experience were required to carry out mining successfully. Consequently, much learning happened through observing, doing and hands-on practice. As learning and innovation processes in Chile and Norway were to a large degree based on foreign technology, going to other countries to learn was essential. To select useful machinery, furnaces and techniques, transfer it and adapt it to local conditions managers, leaders, engineers, technicians and other workers went to institutions in other countries, notably mining companies and plants, research centers, universities and industrial exhibitions, to acquire work experience and practice. Bengt-Åke Lundvall's categorisation of knowledge into know-what, know-who, know-how and know-why, has been useful to identify the different aspects of knowledge in technology transfer processes. These involved information, contacts, knowledge of how to carry out a technique and the scientific principles for a technical problem. Technology transfer and innovation processes from both Chile and Norway show that trips and stays abroad were vital to learn about these aspects of knowledge.

The central features of the Norwegian and Chilean mining sectors that have been analysed here have been (1) the degree of utilisation of the natural resource potential in the two countries, (2) the technological level of the companies in the two sectors, (3) linkages between the two mining sectors and capital goods industries and (4) the role of multinational companies in the two economies. In Chile, the mining sector stood for the majority of exports and contributed to a major income for the state. The sector was huge and stood for eighty to ninety percent of exports, which means that mining was actually the largest economic activity in the country and the driving force of the economy. The concern was, however, that it did not contribute to strong economic growth, as natural resource industries did in Norway.

Did problems in the mining sector cause the slow and stagnant Chilean economy? I find that the diverging economic paths between Chile and Norway were linked to some repeating patterns within the mining sectors. In Chile, negative traits in the mining sector, were in turn linked to the country's slow growth. First, much of the mineral and metal deposits remained unutilised and thousands of mines were abandonded; second, the saltpetre industry found itself in crisis by the 1920s; third, there was an increasing technological gap between technologically backward domestic companies and technologically up-to-date multinational firms; and fourth, foreign companies functioned to a large degree as enclave economies, in which managers and technical leaders were exclusively foreign and nearly all technology, material and other inputs were imported from abroad. Although these companies paid taxes and employed thousands of workers, the Chilean state had little control over the utilisation of resources and did not manage to secure local participation in the management. All in all, the mining sector as a whole failed to undergo the technological changes that were required to become technologically advanced and begin large-scale mining. In this way, the negative traits of this huge sector, which stood for the largest part of the economy, functioned as an obstacle to growth.

In Norway, in contrast, the mining sector was not nearly as big as the Chilean mining sector. A number of relatively big, and growing, natural resource industries developed from an early stage, such as fishing, mining, timber and timber-related industries. In the mining sector, both domestic and multinational companies were innovative and continuously adopted new and common methods of the time to find, remove and process ores. The sector had an overall high level of technology, developed large-scale production of a number of minerals and branched out a large electro-metallurgical production based on the utilisation of hydroelectric power from the late nineteenth century. The multinational companies were integrated in the wider economy and linkages were created between the mining sector and the capital goods industry. State regulations contributed to a stronger national control over the natural resources and local participation in the direction and management of companies. The sharp increase in the economy from the 1930s and onwards was probably due to growth in several industries, such as chemicals and the large shipping industry. Yet, the mining sector, in particular the large-scale electro-metallurgical industry, added to this growth.

I have explored and compared the functions and outcomes of certain knowledge institutions in Chile and Norway, which aimed to create, transfer, adopt and diffuse knowledge for the mining sectors. Using primary sources, primarily mining engineering and technician study programs, company records, mining journals, student yearbooks, engineering reports and other historical documentation, this project has provided an empirical analysis of knowledge development and interactions and collaborations between institutions, which enabled innovation. The purpose, in turn, has been to explain differences in institutions between the two countries. At first glance, the institutional setting in the two countries did not seem so different. Institutions, which were directly involved in learning and innovation, were developed in both countries during the nineteenth and twentieth centuries. Innovation in the mining sectors in Chile and Norway rested on these key knowledge institutions:

Knowledge institutions and their functions in Chile and Norway

Institution/organisation	Function
Mining education at tertiary level	Provided scientifically and theoretically trained mining engineers for the mining sector.
Mining education at intermediate level	Provided practically oriented mining technicians for the mining sector.
Industrial exhibitions (participation)	Presented new and up to date technology.
Technical society for mining	Interest group, which published mining journals, held meetings and organised participation at industrial exhibitions.
Mining journals	Magazine with written news and information about up-to-date technology.
Study trips and work experience abroad	Contributed to transfer of practical knowledge of how to install, use, modify, repair and maintain technology.
Geological Surveys	Mapped metal and mineral ores in the country and implemented research, geological surveys, ore analyses, prospecting and economic estimations of ore deposits.

The establishment of these knowledge institutions suggests an interest in both countries for mining and an ambition to develop knowledge for the sector. These institutions survived long after the period analysed here.

Yet, the mining sector in Chile did not develop to the same degree as in Norway. Even though knowledge institutions were created, companies remained technologically backward, mineral and metal ores remained untouched, and multinational companies developed into enclave economies. This suggests that the mere establishment of a set of knowledge institutions did not guarantee innovation. It did not ensure a provision of useful knowledge, which would guarantee innovation and development of the sector. I find the story to be a more complex one. A closer examination of these knowledge institutions provides us with a deeper understanding of their outcomes and the impacts of innovation. It reveals that not all of the knowledge institutions in the two countries fully served their purposes. There were some differences between the two countries' institutions, which in turn were linked to the negative traits of the mining sector in Chile and the more positive development of the mining sector in Norway.

On the surface, all the knowledge institutions appear equal, and some of them also were. Mining educations in the two countries, both at intermediate and higher level, were similar in character, in the sense that the study programs included similar types of courses, covered a wide range of scientific and technical subjects and reforms were adopted according to technological changes in the sectors. This indicates that mining graduates at both the higher and intermediate level in the two countries acquired comparable formal education. Furthermore, engineers and other professionals interested in mining participated at industrial exhibitions and had access to up-to-date information about new technology through mining journals.

However, to actually transfer and use machines, furnaces, techniques, etc. it was not enough to read about them in magazines or observe them at exhibitions. To select, transfer, modify and use technology, considerable hands-on practice and experience with the technology were required. With regard to experience and practice with up-to-date foreign technology, there were important differences between the two countries. This can be observed as the Norwegian mining engineers, and the broader set of professionals, travelled and worked a lot more in other countries than the Chilean mining engineers. During these trips, they acquired valuable contacts, observed and learned about foreign technology, which in turn was transferred and used directly in operational activities in Norway. The large flow of engineers travelling from Norway to other countries to learn was a result of the large amount of public and private scholarships and funds in the country for such purposes. Private and public scholarships contributed to hundreds of travels and stays abroad. In Chile, scholarships were only provided sporadically. The small number of travels to other countries from Chile meant that less valuable practical knowledge and experience of this type was transferred to the country.

There were also variations between the two countries in terms of number of mining engineers, technicians and other professionals relevant for mining. From estimates of workers per mining engineers and technicians, and public debates about technical education, it seems like the supply of professionals in Chile was much lower than in Norway. In Norway, there was an abundance of mining engineers, technicians and other professionals, much like in other mining countries, such as the United States, Germany and Australia, and at times even a surplus. They worked in both domestic and foreign companies and were normally the initiators of mining projects. In Chile, there were generally too few professionals, and when it came specifically to mining engineers, the situation worsened from the 1880s. The alternative for the technologically advanced mutlinational companies in Chile was to hire foreign professionals. They recruited hudreds of engineers, technicians, chemists, mechanics, electricians, and other workers from Europe and North America, which in turn strengthened the enclave tendencies.

The reason why domestic companies in Chile did not use engineers is not clear-cut. These small and medium-sized technologically backward companies were organised in a very different way from the large multinational companies. Operational activities at these companies normally consisted of making superficial mines and the removal of high-grade ores. One could think that this type of simple mining did not require scientifically trained engineers. Following this line of thinking, there was no need for these mining companies to hire professionals. If this was the case, the small number of graduates from domestic institutions just reflected the small, or nonexistent, recruitment of professionals to these firms. The problem, however, was that this way of organising work was very unsystematic and inefficient. Companies extracted a very small share of the minerals and metals in the country and were hardly competitive. The building of technologically advanced large-scale mineral and metal productions by these companies would have required a much larger number of professionals with long practical experience. The discussions in the Mining Journal reflect this idea. Leaders of the industry in Chile, together with professors, students, engineers and politicians, found that there were clearly not enough trained workers in the country. The small number of professionals in the country made it very difficult for companies to get a hold of engineers, technicians, mechanics and others. Foreign companies had contacts abroad, which the domestic companies normally did not have. The far too few professionals with relevant education and experience in Chile, led to a low, and decreasing, absorptive capacity, as Cohen and Levintal understand it. As the technology that was used in technologically advanced mining became increasingly specialised and complex, the knowledge gap within the mining sector became more and more difficult to close. In Norway, the technical level was higher and more diverse. New knowledge diffused within the sector and was more easily absorbed.

Then again, the huge unutilised mineral ores and abanonded mines in Chile were an even greater problem. The most remarkable difference between the two countries was the extent to which geological maps, ore surveys and economic planning were implemented. Without detailed and deep understanding of the geological ground, proper ore analyses, knowledge about the existing mineral deposits and their potential profits, new mining projects could hardly take place and the mining industry could hardly advance. In this sense, it was probably the failure to facilitate the start-up of new mining projects, which was most severe in Chile. Start-up of new mining projects and extraction of all the unutilised ores and abanonded mines would have required a highly organised institution, with a high number of mining engineers and geologists systematically carrying out geological maps and ore surveys based on scientific and economic principles. Some temporary institutions were founded and sporadic maps and analyses were made, but a persistent organisation with this objective did not exist in Chile. The result was that mines remained abanonded and ores and hydroelectric capacity stayed unutilised. This situation endured and large mineral deposits were not found up until recent times. Norway, on the other hand, started early with organised systematic geological mapping and prospecting of mineral ores. The Norwegian Geological Survey was founded in the mid-nineteenth century, and had access to and hired mining engineers to map and analyse mineral ores in the country. Copper, silver and nickel productions were modernised and a new large-scale electro-metallurgical industry based on hydroelectric capacity developed from the late nineteenth century after systematic geological mappings and ore surveys had been carried out.

In sum, a knowledge gap emerged between the two sectors. This gap was directly linked to differences in the amount of knowledge that was provided by the knowledge institutions in the countries and the extent to which knowledge reached into the sectors. Knowledge institutions and their impacts are summarised as follows:

Knowledge institutions and the knowledge gap between the two mining sectors

Institution	Measurement	Comparison	Implications
Mining education	Character of mining instruction	Equivalent	Educational institutions in both countries provided mining education at intermediate and higher level
Mining engineers and technicians	The extent to which mining engineers and technicians reached across the sector	Discrepancy in amount	**Chile** had too few mining engineers and technicians to cover all the mining companies and geological surveys
			Norway had enough mining engineers and technicians, maybe too many, to fill leading positions across the mining sector and the National Geological Survey

Engineers and other relevant professionals educated locally	The extent to which other relevant professional workers reached across the sector	Discrepancy in amount	**Chile** had too few relevant professional workers to cover all companies and required work to develop an efficient and technologically advanced mining sector
			Norway had enough relevant professional workers, maybe too many, to use modern efficient technology and continuously innovate
Industrial exhibitions and technical journals	The extent to which companies acquired information about new technology	Equivalent	Mining companies and engineers in both countries had access to technical and mining journals with up-to-date information about new technology and industrial exhibitions where new techniques were demonstrated
Study travels and work abroad	The extent to which mining engineers travelled and worked abroad	Discrepancy in amount	The few study trips abroad by Chilean mining engineers hindered transfer of practical knowledge of foreign technology to **Chile**
			The many study trips and work experience abroad meant an abundance of practical knowledge of foreign technology to **Norway**
Geological mapping and ore surveys	The extent to which geological surveys and research institutions reached across the sector	Discrepancy in amount	The few sporadic geological surveys and ore analyses in **Chile** blocked start-up of new mining projects and advancement of the sector
			Geological mapping and ore surveys from early on encouraged new mining projects in **Norway**
Foreign consultants and expertise	Use of foreign professionals and consultants*	Discrepancy	In **Chile**, a large number of foreign professionals were part of foreign enclave companies and barely contributed to transfer of managerial knowledge
			In **Norway**, foreign consultants were employed sometimes, but worked and cooperated with Norwegian engineers and companies

*The many foreign engineers in Chile indicate a large flow of foreign knowledge to the country. Foreign engineers and industrialists were crucial for the development of Chilean mining and were normally the ones who initiated changes in technology. However, their dominance, as seen, was negative in the sense that the lack of collaboration with domestic engineers and leaders prevented knowledge spillovers, notably managerial knowledge.

The knowledge gap between the two sectors was linked to the role of the state in the two countries. The state was the overall institution, which ratified mining laws and managed taxes, which in turn could be used to invest in research, education, infrastructure etc. I argue that the state had a particular role, because it funded national geological surveys, formal schooling and universities, and managed many of the scholarships for study travels and exhibitions. The state in Norway was much more active to develop these institutions than the state in Chile. First, the basic education system was more developed in Norway than in Chile. A general public education system was created in Norway from the early nineteenth century on the basis of earlier teaching initiatives. This contributed to a highly literate population by the late nineteenth century. While primary and secondary education were provided to everyone in Norway, in Chile the basic school system did not cover all children and youth of appropriate age and illiteracy rates remained high. The large share of illiterate people and the inertia by the state to establish universal basic schooling for the whole population reduced the number of viable candidates for higher, mining and technical educational programs. The few students with proper qualifications functioned as a bottleneck for the admission of mining engineers and other professionals. Second, the Norwegian state supported transfer of knowledge through funding of scholarships for study trips. Development of such institutions was not nearly as encouraged by the Chilean state with the result that very few mining engineers went abroad to learn about foreign technology. Third, from the mid-nineteenth century the Norwegian state organised and funded the Norwegian Geological Survey, which facilitated and encouraged the start-up of mining operations. In Chile, the state only funded surveys sporadically.

Why did knowledge institutions develop more effectively in Norway than in Chile? How did the institutional settings develop so differently? In both countries, industrialists, engineers, politicians and professors expressed a desire to develop the mining sector further. Yet, in Chile, their proposals were not fully taken into account. Although institutions and organisations were established, they did not develop sufficiently to build a technologically advanced sector. The governing elite, following the argument of Acemoglu and Robinson, was perhaps satisfied with things as they were. Political decision-making worked in favour of groups with other interests. It is likely that the feudal elite, which dominated the political sphere, instead prioritised other parts of the economy, especially the agricultural sector. The broad political forces failed to see the value of these particular knowledge institutions and their importance for the development of the mining sector. In the 1930s, the import substitution policy for industrialisation began in Chile. These political measures were linked to a lack of conviction that natural resources could form the basis of dynamic, knowledge intensive, innovative sectors and strong economic growth. However, adopting an import substitution policy, which sought to move away from natural resource industries and encourage industries with little basis and tradition in the country, was, arguably, not the best alternative.

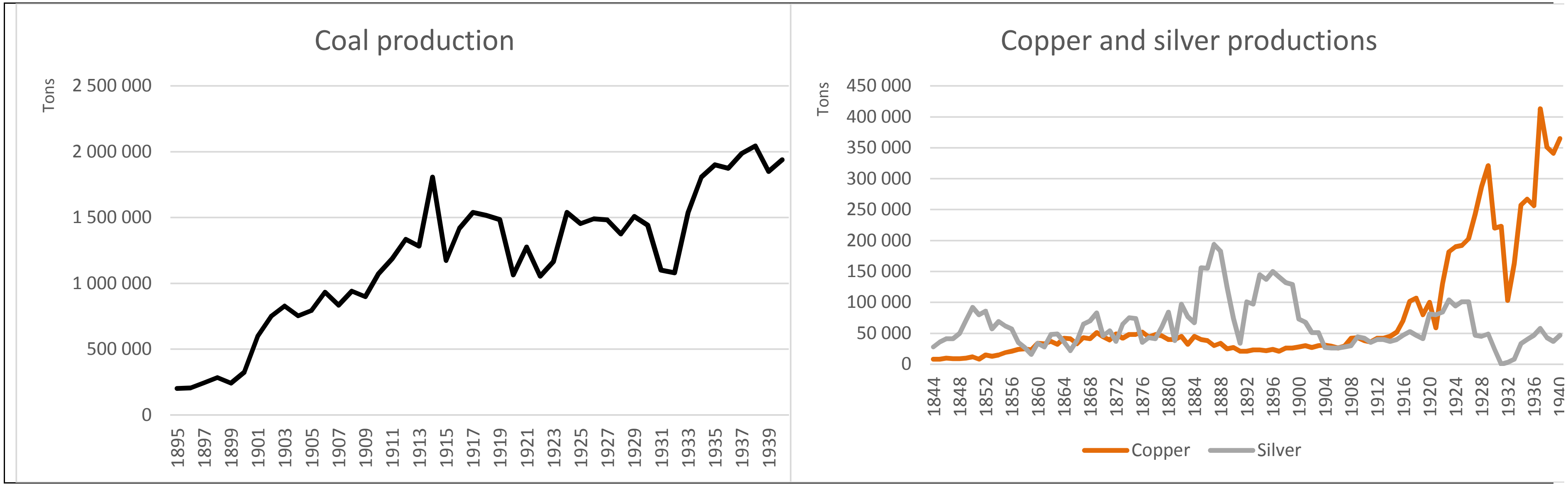
I have demonstrated that the set of knowledge institutions in Chile blocked transfer, use and diffusion of knowledge, while institutions facilitated knowledge development in Norway. Yet, to explain the different developments in the two mining sectors fully, and in the two countries more generally, other factors should be taken into account. Did external conditions influence development of the two mining sectors? The United States has often been given the blame for extracting natural resources from Latin American countries on disadvantageous terms. According to the dependency theory, large corporations extracted natural resources from the continent and transferred the larger share of profits abroad, without benefitting the host countries. Work on multinational companies by Alfred Chandler showed that North American companies from the turn of the century tended to be very large, with strong organisational capabilities, and to create oligopolistic competition. The large-scale companies in Chile, which took over most of the copper production and developed into enclave economies, fitted this description. Yet, Norway too had large shares of foreign investments in a number of industries. Multinational companies from a number of countries, such as the United States, Germany, France and Britain, also invested there. The difference was that while the foreign investments contributed in general to positive economic effects in Norway, the foreign investments did not contribute to anywhere near as many positive economic impacts, or even led to negative effects, in Chile. The question remains how foreign investments and multinationals have had such different, sometimes opposite, effects in different settings.

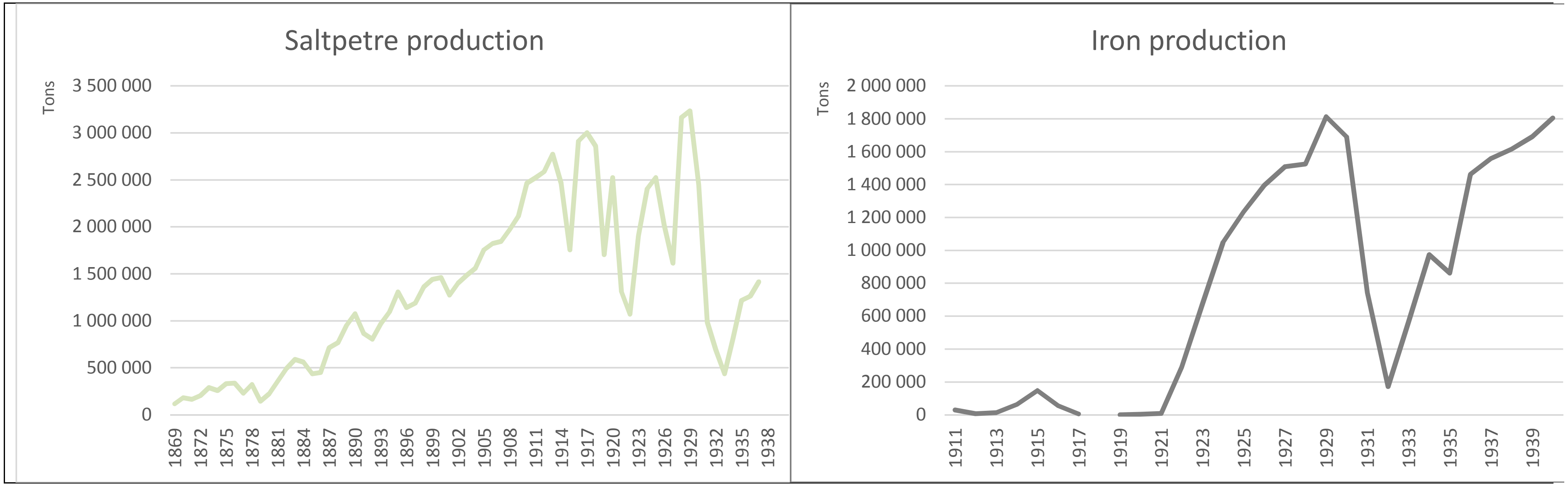
Multinational companies invested abroad with the aim of making profits, and were likely to be less worried about the industrial development of the host country. Naturally, they invested and operated in other countries for their own benefit. It was therefore essential for the host country to establish and develop institutions and organisations to actively interact with and benefit from the knowledge the multinational companies possessed. The different impacts of multinational companies in Chile and Norway suggests that the way they functioned and operated had less to do with the country of origin, and more to do with the institutional setting of the host country. Regardless of their organisational and operational characterstics, multinational companies would have in theory to relate and adapt to and comply with the regulations and institutions of the country in which they invest. Countries have sought to integrate companies in different ways. Through the development of regulations, education, infrastructure and suppliers, absorptive capacity can potentially increase and companies can be encouraged to hire domestic professionals and use domestic suppliers. The problem in the case of Chile, I argue, was an absent state and declining industries, which did not take advantage of the knowledge that the multinational companies provided or prevent the enclave economies from developing. In Norway, in contrast, the state actively encouraged integration, linkages and participation, which in turn prevented enclaves from emerging.

The account offered here plainly only takes us part of the way in explaining differences between Norway and Chile. To explain fully the developments of the two mining sectors and the diverging paths of the two countries, this comparative analysis of knowledge institutions in Chile and Norway would need to be placed into a wider domestic and global context. First of all, these knowledge institutions were only linked to a part of the production process, which was directly concerned with locating and extracting ores. Knowledge institutions should be analysed in connection with the larger institutional setting of access to capital, global markets, prices, transport systems and linked industries. Second, to fully understand the origins and developments of institutions in the two countries, it would be helpful to analyse a much longer period. Nevertheless, learning and knowledge are essential to successful resource-based growth, and therefore a key starting point.

16 Appendix

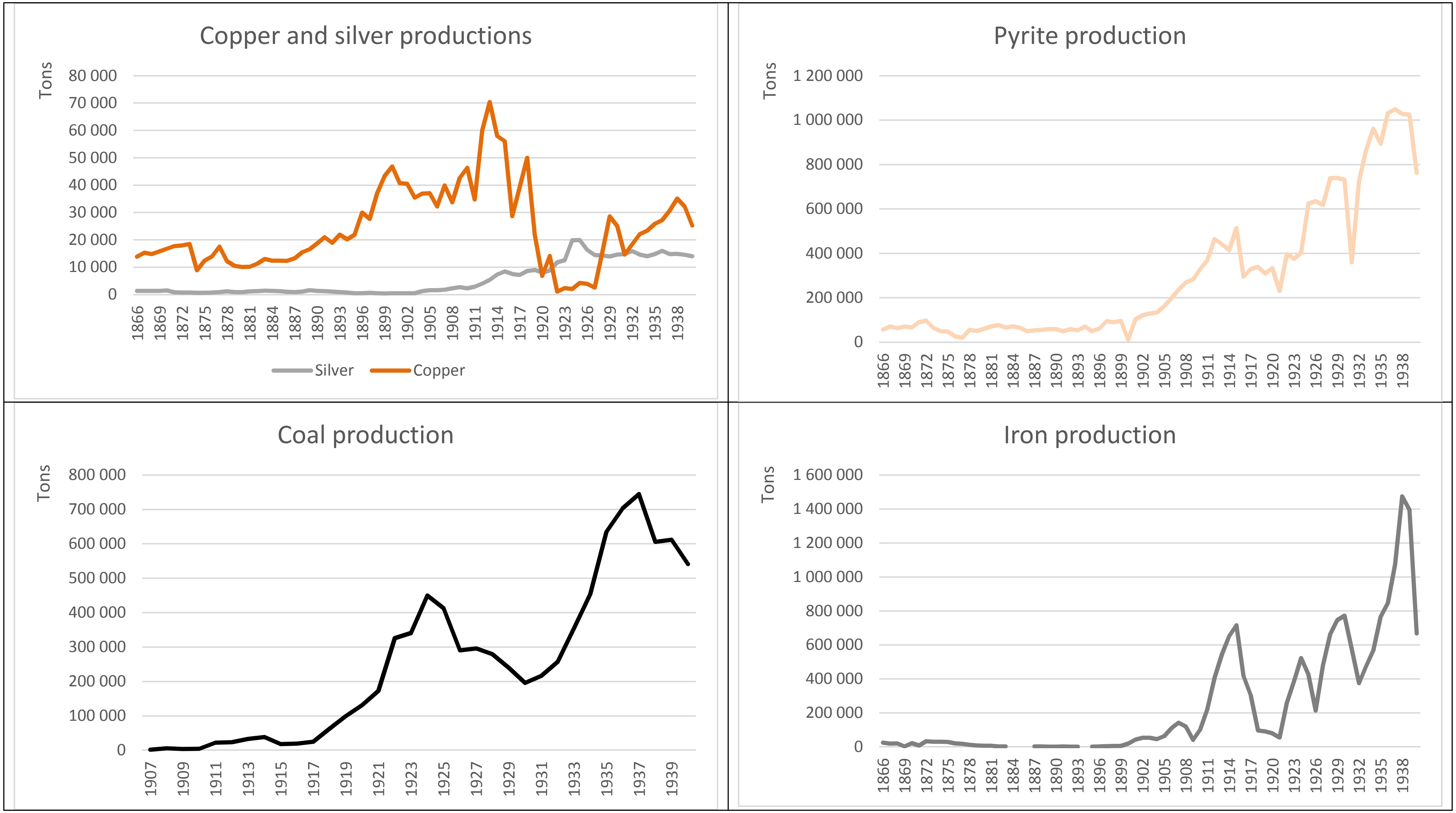
Appendix 1. Selected mineral and metal productions in Chile*





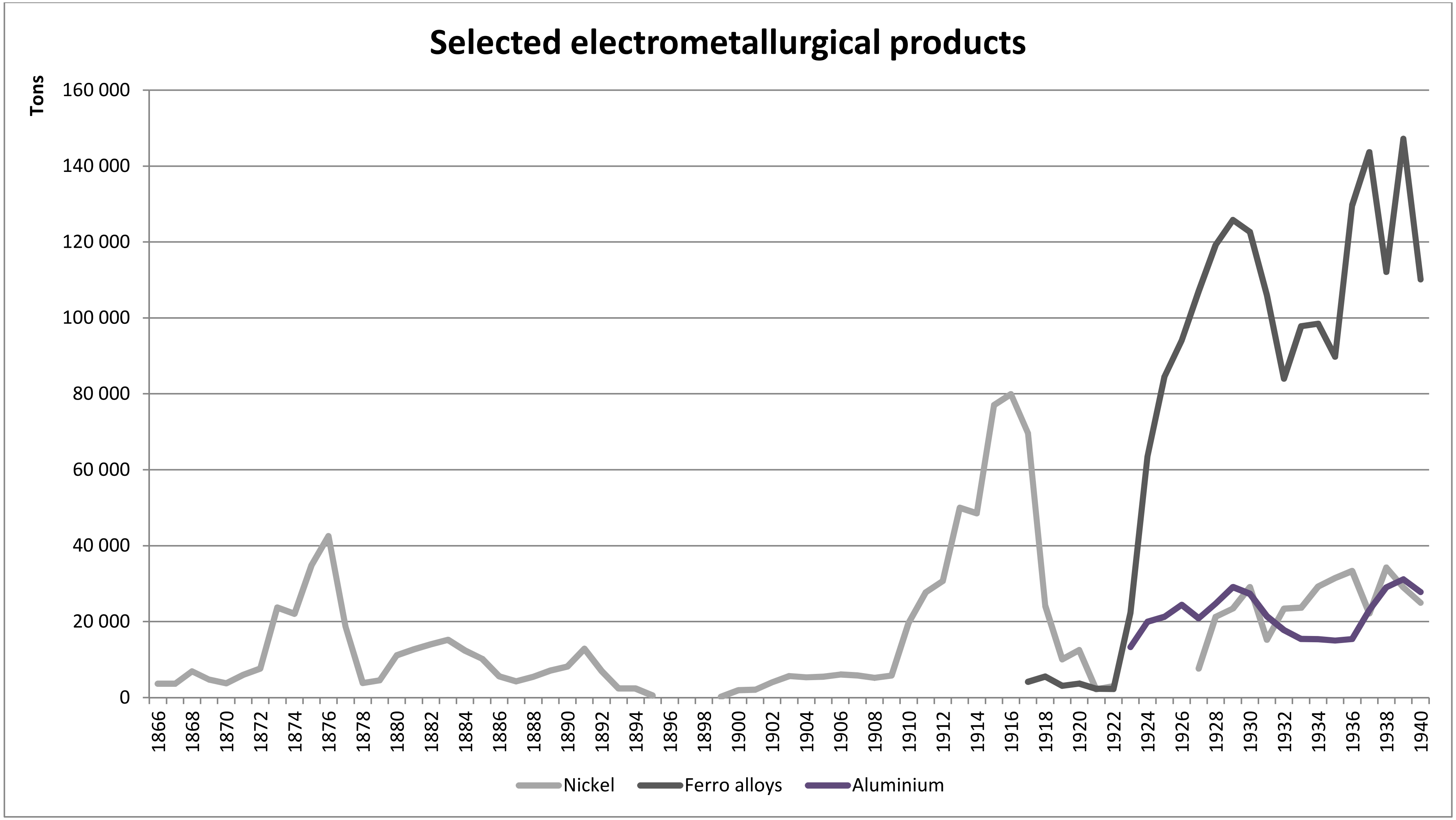
*Export of saltpetre until 1909.
Sources: B.R. Mitchell, *International Historical Statistics The Americas 1750-2005* and *International Historical Statistics Europe 1750-2005* (New York, 2007); Saltpetre production is taken from Oficina Central de Estadística, *Anuario Estadístico Minería y Metalurgia* (Santiago, 1909-1940).

Appendix 2. Selected mineral and metal productions in Norway



Source: Norges offisielle statistikk, *Norges Bergverksdrift* (Oslo, 1866-1940)

Appendix 3. Selected electrometallurgical productions in Norway



Source: Norges offisielle statistikk, *Norges Bergverksdrift* (Oslo, 1866-1940)

Appendix 4. Purchased equipment and technical services by Chilean companies

Arturo Prat Mining Company			
Year	**Technology**	**Geographical origin**	**Supplier**
1889	Condensor	Europe	?
1889	Steel boilers	Europe	?
1892	English boiler of steel with two flame tubes and 12 heater tubes Galloway	England	?
Around 1893	Big air compressor	Switzerland	?
Around 1893	Transport propeller for milled metal	Europe	?
1893	Electric light with 60 glowing lights	Germany	Siemens and Halske
1898	Compressor and pump	Germany	?
1898	2 boilers	Chile	A company in Santiago
Las Vacas Mining Company			
Year	**Technology**	**Geographical origin**	**Supplier**
1917	Jones Belmont machine	The United States	?
1921	Amalgamation plant	The United States	?
1921	Repair of a Crossley engine	Chile	The engine was dismantled and sent to Valparaíso
1934	Compressor	The United States	?
1935	Electric winch	Chile	Transferred from Saltpetre Company Tarapacá y Antofagasta: already mounted
Taltal Mining and Processing Company			
Year	**Technology**	**Geographical origin**	**Supplier**
1905	Parafine diesel engine	Switzerland	Sulzer Brothers
1907	Analysis of samples	England	Antony Gibbs & Son
1912	Exraction machine	England	?
1915	Beneficiary engine with spare parts and belts	Europe	?
1921	Diesel engine	Germany	Koerting Factory
1921	Generator and electric engines	Germany	Siemens-Schuckert
1921	Valve	Chile	Fundición Libertad Santiago
1923	Extraction machine, winches and electric engine	Germany	Demag and Siemens-Schuckert
1923	Cylindric ball mill	Germany	?

Sources: Gran Compañía Arturo Prat (1883-1921): *Memorias*. Santiago; La Compañía Minera "Las Vacas" (1914-1935): *Informes*. Valparaíso; Compañía de Minas Beneficiadora de Taltal (1903-1940): *Memorias*. Valparaíso.

Appendix 5. Purchased equipment and technical services by the Bede Metal & Chemical Company (Killingdal Mines), selected years*

Year	Technology	Country of origin	Supplier
1895-96	"window panes", "leather", "miners candles"	Norway	A.Haugan
	"20 m tape"	Norway	A.Motzfeldt
	"laboratory clothes", "dishes for laboratory"	Norway	C. Rönning
	"bar iron", "steel hammers", "tools"	Norway	Chr. Thaulow & Söns
	"stores and machinery"	Norway	Emil Grönning
	"construction"	Norway	Erik Schjölberg
	"various tools", "lamps and post bag"	Norway	G. A. Hartmann
	"brooms"	Norway	H. O. Grönli
	"hammer shafts"	Norway	J. Rönningen
	"hammer shafts"	Norway	Lars Josvold
	"lamp glasses"	Norway	Lars Skancke
	"hinges and screws"	Norway	M. Engzelius & Sön
	"new store buildings"	Norway	Ole Lundemo
	"materials"	Norway	P.I. Ramla
	"telephone poles"	Norway	P. Krokan
	"lamp glasses"	Norway	P. O. Rösten
	"materials"	Norway	Reitan
	"glass", "stores"	Norway	Aalens Övre Forbrugsforening
	"steam whistle (machinery)"	?	?
1900-01	"oils skins"	Norway	A.Kroglund
	"mine lamp"	Norway	A.Motzfeldt
	"9 boxes chalk"	Norway	A.Reitan
	"piping (steam) machinery", "crow bars", "hammers"	Norway	Chr. Thaulow & Söns
	"fuse"	Norway	Engzelius & Son
	"lamps", "50 brooms"	Norway	Emil Grönning
	"140 hammer shafts (large) 90 small"	Norway	Erik Grönli
	"lamp wick"	Norway	G. A. Hartmann
	"spikes kvs. 50", "kvs. 100 Rall spikes", "rail spikes"	Norway	Gustav Aspelin
	Not specified	Norway	H. & F. Bachke
	"lamp glass"	Norway	J. J. Siem
	"12 ladders"	?	John S. Öien
	"hammer shafts"	Norway	Lars Fosvold
	"Kvs 300 dynamite", "fuse"	Norway	M. Engzelius & Sön
	"500 rings fuse"	?	Nora Fuse Manufactory
	"36 mine lamps", "30 miner's lamps"	Norway	O. A. Moxness
	"hammer shafts" large and small	Norway	Ole J. Grönli
	"stoves: renewals"	Norway	P. O. Jenssen
	"ladders", "ladders-142 rungs"	Norway	Peder Kirkhus
	"India rubber packing"	Norway	W. Fischer & Sön
	"12 empty barrels"	Norway	Öien & Wahl

	"steam irons (?) machinery", "nails", "lamps", "iron lamps", "hammers", "dynamite", "fuses", "detonators", "steel rope", "tools", "shovels", "iron pails", "hammer shafts", "nitroglycerine", "krafsers", "trugs"	?	?
1909	"planed and grooved boards"	Norway	A.E. Gildseth
	"packing, dynamo, tubing", "driving belts, bends", "pulley", "screws, lead tubing", "brass lock"	Norway	Albert E. Olsen
	"spades", "spades and hammer handles"	Norway	Axel Nielsen
	"electric plant"	Norway	Annual government inspection
	"raw hide pinion (wheel) and copper wire", "cabel", "safety fuses", "bronze", "repair of motor", "repair of 2 telephones", "telephone effects", "telephone reserve pieces"	Switzerland (Norwegian subsidiary)	Brown Boveri
	"wire rope", "200 screws", "asphalt roof paper", "bolts", "asphalt paper", "roof paper", "nails", "rivets", "iron", "iron plades", "steel", "rivets"	Norway	Chr. Thaulor & Sön
	"2 sets wagon wheels", "ropeway pulleys", "saw blades", "3 oil cans", "files", "carborundum"	Norway	C. S. Christensen
	"ore trays", "cotton waste", "nails, asphalt roof paper", wire", "spades"	Norway	E. A. Smith
	"varnish"	Norway	E. D. Mogstad
	"100 m. electric wire and small isolators"	Norway	E. Fjeldseth
	"3 bar. Cement, 2 bar. tagpix", "ochre", "roof tar", "weighing machine", "wire rope"	Norway	Emil Grönning
	"ropeline renewals", "staples", "screws", "6 pump valves", "washers for ropeline tubs", "machinery pump-new body"	Norway	G. Hartmann
	"repair of house"	Norway	H. Kunig
	"painting house"	Norway	Ingebrigt Hansen
	"6 files", "50 flanges"	Norway	Gustaf Aspelin
	"repairs"	Norway	Jacob Digre
	"furniture"	Norway	Jacob Matteson
	"honorarium-electric engineer"	Norway	John Andersen
	"2 forks and 2 rakes"	Norway	John Rotan
	"double sleigh"	Norway	John Unsgaard
	"chains", "varnish, ochre, rope", "store"	Norway	John Öien
	"Guldal Mine-2nd installment"	Norway	John Östeng
	"repair of water, piping"	Norway	K. Lund
	"24 dry batteries"	Norway	Möller and Grönning
	"mining level-repair"	Norway	M. Svensen
	"repair of house"	Norway	N. Christensen
	"belting"	Norway	Norske Remfabrik
	"surveyor"	Norway	O. E. Aalen
	"store and printing and stationery", "store, household goods", "store, stationery, furniture", "store, kitchen".	Norway	Ola Hage

	"inspection of electric plant (government)"	Norway	Olaf Sandvold
	"tarpaulins"	Norway	Oure & Stene
	"cutting and crushing machine"	Norway	S. H. Lundh H.
	unknown	Norway	Sigurd Stave
	"oil cleaner and filter"	?	Storm Martens
	"grates (ovn)", "ovn door"	Norway	Trondhjems Værksteds Udsalg
	"machinery-spur wheel for pumps"	Norway	V. Lowener
	"200 isolators", "100 m. vulcanized wire"	Norway	Winger Elekt. Værksted
	"spur wheels"	Norway	Örens Mek. Værksted
	"vacuum oil: 2 bar, dynamo oil"	?	?
1914	"Construction", "ropeways"	Norway	A. E. Gildseth
	"tools, packing, files", "3 pulleys"	Norway	A. E. Olsen
	"writing paper"	Norway	A. Holbæk Eriksen & Co
	"planned and grooved boards"	Norway	A. J. Nilsson
	"copying paper"	Norway	A.H. Eriksen & Co
	"government inspection of electric plant"	Norway	A. Sandahl
	"soldering lamp"	Norway	Albert E. Olsen
	"fuse"	Norway	Andersen & Ødegaard
	"pulley and tools" "brass netting", "rack saus", "springs", "India rubber tubing", "block pulleys"	Norway	A/S Hynnes Maskinforretning
	"trugs and krafsere"	Norway	A/S Arthur Motzfeldt
	"electric materials", "glow lamp and shades"	Germany (Norwegian subsidiary)	A/S Siemens-Schuckert
	"belting"	Norway	A/S Den Norske Remfabrik
	"electric material", "motor repair"	Switzerland (Norwegian subsidiary)	Brown Boveri
	"krafsere"	Norway	Chr. Mynthe
	"glass", "screws", "washer", "iron", nails", "rail spikes"	Norway	Chr. Thaulor & Sön
	"bands for typewriter"	Norway	Chr. Johnsen
	"pulleys"	Norway	C. S Christensen
	"Belting"	Norway	Den Norske Remfabrik
	"asphalt paper", "pickaxes", "shafts" "paint", "sheet iron", "rail spikes", "spades", "nails", "iron sheets"	Norway	Emil Grönning
	"1 stolling"	Norway	E. Kroken
	"(construction) machinery"	Norway	Edward Kvam
	"fuse & nails"	Norway	E.A Smith
	"telephone"	Norway	Elektrisk Bureau
	"2 plumbobs"	Norway	Gundersen & Løken
	"pump valves" "dices"	Norway	G. Hartmann
	"ropeway erection"	Norway	Gustav Thorkildsen
	"chemical manuals"	Norway	Gunnar Birkeland
	"erecting ropeway"	Norway	Ing. Thorkildsen
	"building over ropeway-dressing plant", "construction-tubing over surface", "ropeway", "cutting"	Norway	Jens J. Grönli
	"repair of saw blades"	Norway	Jacob Digre
	"tubing"	Norway	K. Lund

	"erection of oil regulator"	Norway	Kværner Brug
	"electric lamps"	Norway	Möller & Grönning
	"2 nipper and 1 tap"	Norway	M. Engrelius & Sön
	"repair of wagons"	Norway	M. Hjelde
	"paint", "screws", "white lead and chalk", "emery paper"	Norway	M. Engzelius & Sön
	"2 stools and basket"	Norway	Norsk Husflids Venner
	"stove pipes"	Norway	O. A. Moxness
	"manilla rope"	Norway	P.O Jensen
	"photograph material"	Norway	S. Engan
	"wire netting", "rope hooks"	Norway	Sigurd Stave
	"horseshoes"	Norway	Ragnvald Lillevold
	"spur wheels and ovns" "repair (unknown)" "1 pulley and swings"	Norway	Trondhjems Mek. Værksted
	"2 form"	Norway	Trondhjems Landsfængsel Utsalg
	"sundry goods"	Norway	Ragnvold Lillevold
	"office goods"	Norway	Waldemar Janssen
	"2 spur wheels"	Norway	Ørens Værksted
	"china ink", "drawing paper", "pens", "paper plan", "copying paper", "6 books of 500 pages-timebooks"	Norway	Waldemar Janssen
	"fishplates", "iron", "bolts"	?	?
1919	"screws", "oil cans", "sundries"	Norway	A. E. Olsen
	"stationery"	Norway	A. Holbak Eriksen
	"board"	Norway	A/S Emil Grönning
	"boring tool", "sundry tools"	Norway	A/S E. A. Smith
	"pump-valves"	Norway	A/S G. Hartmann
	"gum-sales"	Norway	Andersen & Enger
	"one air-receiver for plant"	Norway	A/S Meraker Gruber
	"axel", "electric material", "erector (ropeway)"	Switzerland (Norwegian subsidiary)	A/S Norsk Elektrisk & Brown Boveri
	"belts"	Norway	A/S Viking Rem & Pakn. Fabr
	"stationery"	Norway	A/S Waldemar Janssen
	"soundries"	Norway	Aalens Øvdre Forbruksforening
	"forward machine from England in February"	England	Bachke & C.
	"stationery"	Norway	Bruns boghandel
	"repair typewriter"	Norway	Ch. Johnsen
	"carbide"	Norway	Ch. Engzelius & Sön
	"window-glass", "iron", "one iron-girder"	Norway	Chr. Thaulow & Sön
	"carbide", "sundry painting goods"	Norway	Emil Grönning
	"lac"	Norway	E. D. Mogstad
	"electric fittings", "stationery", "calculating tables", "rope", "leather"	Norway	E. Fjelseth
	"roofing"	Norway	E. Grönning
	"tools"	Norway	E. Olsen
	"tools"	Norway	Eidet Handelssamlag
	"board & sundries"	Norway	Engzelius & Sön

	"books for office"	Norway	F. Bruns Bokhandel
	"foundations, dam. wall"	Norway	Fjeldsjöen Dam. RO. Aune
	"sorting hammers"	Norway	Fr. Melbye & Co
	"sundries"	Norway	Grønning Emil
	"electrical inspection"	Norway	Government
	"repair of unknown"	Norway	Hamar Jernstøberi & Mek. Verksted
	"custom ovens", "transmission tubes", "transmission washing machinery", "cores", "transmission one case bolts"	Norway	H. F. Bachke
	"assays"	Norway	Hornhauer
	"sundry shop machinery"	Norway	Hviles el. Verksted A/S
	"dictionary", "letter files", "drawing material"	Norway	J. Brun
	"contract reconstruction mine"	Norway	J. Gaare
	"curtains for new office"	Norway	J. Matheson
	"office effects"	Norway	Janssen, Waldemar A/S
	"buildings"	Norway	Johan Gaare
	"sundries	Norway	Jongzelius & Søn
	"sundries"	Norway	Killingdal prov. Handel
	"nails"	Norway	Kvam & Gisvold
	"repair of typewriter"	Norway	Lorentz Syvertsen
	"screws", "sundries", "nails", "rope", "sundries"	Norway	M. Engzelius & Sön
	"sundry goods"	Norway	M. Gallus
	"electric materials", "electric battery", "electric sundries"	Norway	Møller & Grønning
	"electrical material"	Norway	Nicolay Beck
	"nitro-glycerine: explosives dynamite"	Norway	Nitroglycerincompagniet
	"caps"	Norway	Nordenfs. Sprængstof A/S
	"assays"	Norway	Norges Tekniske Høiskole
	"diesel motorer contract-pump"	Norway	Norsk HB
	"repair at Storvoldsen"	Norway	Norges statsbaner
	"belting"	Norway	Norske Remfabrik
	"sundries"	Norway	Olsen Alb
	"surveying mine"	Norway	Ole A. Aalen
	"wheels and axles"	Norway	Pay & Brick
	"sundry-building goods"	Norway	P. B. Paulsen & Co
	"sundry goods"	Norway	Ragnvald Lillevold
	"sundry"	Norway	R. E Carr's Ex. Kristiania & Trondheim
	"tubing", "tubes"	Norway	Sefsaas & Co.
	"cement", "tubing"	Norway	Trondhjems Cementsrøberi
	"washers for grizzlies", "cooking apparatus"	Norway	Trond. Mek. Verksted
	unknown	Norway	Trondhjems Elektricitetsverk
	"bolting store"	Norway	The Foldal Copper & Sulphur Co. Ltd
	"stationery"	Norway	Wald. Jansen
	"furniture for mine house", "sundry provisions for mine house", "sundry provisions for mine house", "sundry goods"	?	?

*The cash books after 1919 also show a large share of Norwegian suppliers, but the large amount of notes and comments makes it too difficult to include more years.

Sources: Bede Metal Killingdal, Privatarkiv 107, Statsarkivet in Trondheim: 10 kassabok sept. 1895.okt. 1906; 11 kassabok nov. 1906-okt.1919; 12 kassabok nov. 1919-des. 1919.

Appendix 6. Selected technologies adopted in the Chilean and Norwegian mining sectors

Technology	Origin and description of technology	Adopted in Norway/Chile	Sources
Amalgamation of silver	Invented by Bartolomé de Medina, a Mexican miner and used in Peru from 1570. In America the ore was stamped and then pulverized with water until a mud or soft paste was formed. The paste was then placed in pits to dry with salt. Roasted and pulverized copper ore was added. Mercury was sprinkled over the heap by straining it through coarse cloth. Salt and copper ore reacted to give copper chloride, which in turn acted on the silver ore to give silver chloride. Further quantities of mercury were added so as to form an amalgam with silver. Then the mineral was washed and the amalgam was strained through leather to remove excess of mercury, and the semi-solid amalgam was distilled to liberate the silver. The method was modified in the late eighteenth century with the use of reverberatory furnaces and mechanic casks. The system extended soon to gold, which is more solvable in mercury than silver.	**Chile** Used for centuries. Bernardo Kroehnke modified the amalgamation process in 1863 in Chile and used salt and copper, which reduced the losses of mercury and increased the silver recovery.	Gibbs, W. (1958): "part II. Extraction and production of metals: non-ferrous metals" in Singer, C. et al. (eds.). *A History of Technology, volume IV The Industrial Revolution The Industrial Revolution 1750 to 1850*. Oxford: The Claredon Press, p. 139-140 Orrego Cortés, A. (1890): *La Industria del oro en Chile, memoria excrita por encargo de la Sociedad Nacional de Minería*, Santiago: Imprenta Nacional, p. 9 Villalobos, S. et al. (1990): *Historia de la ingenieria en Chile*. Santiago: Editorial Universitaria, p. 101
Bessemer (Manhés) process	Invented by Henry Bessemer, English engineer in 1855. This technique was	**Norway**	Chadwick, R. (1958): "New extraction processes for metals" in Singer, C. et al.

	based on the North American William Kelly's experimental work with iron. In 1880 the process was adapted to copper by the French Pierre Manhès. The converter was charged directly with liquid matte, with a small amount of added coke in inverse proportion to the sulphur content. As the reaction proceeded, the sulphur was oxidized away and formed a fluid slag. Fresh matte was sometimes added, and the reaction usually took some 2 hours to complete, giving a result of up to 98,5 per cent copper.	The Manhès technique (after Pierre Manhès) was installed at Røros Copper Works in 1887. This was more efficient and simpler than the previous five-step method. Rocks were put directly from the melting oven over to the converter, where the iron was oxidized and converted to liquid slag. The clean white metal was blown to metallic copper, which was poured into big forms, and after into a refinery oven, where the oxygen was removed. The final metal was made into bars. **Chile** Introduced to Chile in 1884 in some places.	(eds.). *A History of Technoloy, volume V The Late Nineteenth Century 1850 to 1900*. Oxford: The Claredon Press, p. 82 Pinto Vallejos, J. and Ortega Martínez, L. (2004): *Expansión minera y desarrollo industrial: un caso de crecimiento asociado (Chile 1950-1914)*. Santiago: Universidad de Santiago de Chile, p. 27 *Røros Copper Works annual report 1887*, Trondheim: 1888, p. 8
Block caving method (in underground mining)	The block-caving method was used to mine massive steeply dipping brittle ore deposits bodies. Block caving removed all the ore body from the stope walls by undercutting and allowing the ore to fall down prepared cavities by gravity, shattering it in the process. It is uncertain where it was first used, but it was common in the copper mines of the Sdbury Basin in Canada and Central Africa by the 1930s.	**Chile** Used in Potrerillos and later in El Teniente from the early twentieth century.	Temple, J. (1978): "Metal mining", in Williams, T (ed.). *A History of Technology, volume VI The Twentieth Century 1900 to 1950*. Oxford: Claredon Press, p. 420 Villalobos, S. et al. (1990): *Historia de la ingenieria en Chile*. Santiago: Editorial Universitaria.
Board and pillar method	Used in coal mining. Consisted of advancing two or more horizontal parallel galleries and extracting all the coal pillar between the galleries and fill	**Chile** Introduced to Chile by English workers in Lota in the 1860s?	Ritson, J. A. S. (1958): "Metal and coal mining, 1750-1875", in Singer, C. et al. (eds.). *A History of Technology, volume IV The Industrial Revolution The Industrial Revolution*

	the hole with wood and rock barren. In England between 1750 and 1850 coal mining consisted of dividing the seams of coal into large pillars by roads and subsequently follow up by extracting the pillars. Later the technique was modified, making it safer, by dividing the area into small areas or panels by leaving solid ribs of coal.		*1750 to 1850*. Oxford: The Claredon Press, p. 86 Villalobos, S. et al. (1990): *Historia de la ingenieria en Chile*. Santiago: Editorial Universitaria.
Crushers	The first mechanical machine to crush the rock into smaller parts was called "jaw breaker" and invented by Eli. W. Blake in 1858 in New Haven, the United States. The next advance in crushing was the gyratory crusher, introduced by P. W. Gates in the United States in 1881. This machine had more capacity than the previous jaw breaker. The gyratory principle was also used in fine crushing, but not extensively used until after WWI. Disc crusher and cone crushers were other types of crushers.	**Norway** Jaw crusher machines were introduced at several mines at the turn of the century and later different types of mills and cone crushers. At Røros new equipment, such as stone crushers, rollers, rotating drums and "setz machines" (device for ore dressing) were installed after 1893. At Kongsberg new rock crushing equipment was introduced in 1894 with stone crushers and rollers driven by turbine instead of water wheels. **Chile** Used at Urmeneta's company in the mid-nineteenth century and at the coal mines in Lota.	Carstens, H. (2000): *…Bygger i Berge: en beretning om norsk bergverksdrift*. Trondheim: Norsk bergindustriforening Den norske bergingeniørforening Tapir, p. 109 Dennis, W. H. (1963): *A Hundred Years of Metallurgy*. London: Gerald Duckworth & Co. Ltd., pp. 22-23 Villalobos, S. et al. (1990): *Historia de la ingenieria en Chile*. Santiago: Editorial Universitaria.
Diggers/cutters in coal mining	A variety of machines for removing coal developed in the nineteenth century. **Coal cutter**: invented by Thomas Harrison in England in 1863. A toothed wheel fitted to the spindle of a compressed-air turbine, driving through	**Norway** In the beginning of the twentieth century coal production started in the archipelago Svalbard, with the use of electric drilling machines. **Chile**	Ritson, J. A. S. (1958): "Metal and coal mining, 1750-1875", in Singer, C. et al. (eds.). *A History of Technology, volume IV The Industrial Revolution The Industrial Revolution 1750 to 1850*. Oxford: The Claredon Press, pp. 82-83

	gearing. The machine exemplified the transition from reciprocating motion to the rotary motion which characterised all subsequent coal-cutting machinery. From this machine developed 3 well defined types of machines: a) **the disk**, whose cutting-member consisted of a disk or wheel armed at its periphery with cutters b) **the chain**, whose cutting-member consisted of a projecting arm or jib carrying an endless chain, the links of which were armed with cutters. Chain stripper, the “Hershey”, a machine used in coal mining invented in England in 1860 (for continuous mining). This machine had permanent problems by frequent breaking of the chains. In 1877 the American engineer Terry invented the “chain digger” which was more efficient. However, the machines needed frequent reparations, and in 1883 a more efficient version was introduced. c) **the bar**, whose cutting-member consisted of a projecting, rotating bar armed with cutters throughout its length. These machines were first driven by reciprocating compressed-air motors, and later by compressed-air turbines.	Hershey was used in coal mining in before 1900? Mechanical chopper was used in coal mining in Chile before 1900? Mechanical disc digger, made by the engineer Warring, which cut the coal by the “teeth” of a disc. **Chile** Used in Chile in the twentieth century.	*Tidsskrift for kemi og bergvæsen*, (1932): Oslo: Den norske ingeniørforeigning og Den polytekniske forening, p. 183 Villalobos, S. et al. (1990): *Historia de la ingenieria en Chile*. Santiago: Editorial Universitaria.
Drills	Mechanical rock-boring machine (the first) was invented by the Cornish engineer Richard Trevithick in 1813. Around 1850 the boring of shot holes by	**Norway** In 1898 Røros established a drill system with compressed air; later electric drilling machines were adopted.	Helleberg, O. A. (2000): *Kongsberg sølvverk 1623-1958: kongenes øyesten – rikenes pryd.* Kongsberg: Forlag Langs Lågen i samarbeid med Sølvverkets venner, p. 290

	machinery became possible with a steam rock-boring machine invented by Bartlett. Later, a similar machine was invented using compressed air. In the United States, J. W. Fowle produced a steam-operated drill, the Ingersoll drill, in 1871. The principle of these machines was to bore a hole either by the continuous motion of a rotating drill or by irregular beating of the rock by a pointed tool. A machine called "Low's machine", made by a firm in Ipswich in England introduced a combination of these operations. Two cylinders, one inside another rotated slightly but continuously between each blow of the drill. The machine was carried on a trolley and driven by compressed air. Later on, a light drill which could be held by one man was made. The first mineral extractor with an electric engine with direct current was applied in Germany in 1894. Engines with alternating current were developed before this.	Pneumatic drills were adopted at Kongsberg in 1912-15. **Chile** There are references of the use of compressed air machines for drilling in some Chilean mines In 1903.	Nissen, G. B. (1976): *Røros Kobberverk 1644-1974*. Trondheim. Ritson, J. A. S. (1958): "Metal and coal mining, 1750-1875", in Singer, C. et al. (eds.). *A History of Technology, volume IV The Industrial Revolution The Industrial Revolution 1750 to 1850*. Oxford: The Claredon Press, pp. 70-72 Villalobos, S. et al. (1990): *Historia de la ingenieria en Chile*. Santiago: Editorial Universitaria.
Dynamite	Invented by Alfred Nobel in 1867 in Sweden. A substitution for liquid nitro-glycerine.	**Norway** Was used in Norway from the late 1860s. Used at Kongsberg Sølvverk from 1868. **Chile** Used in the Panulcillo mine from the 1870s in and was commonly used in big mines from 1903.	Berg, B. I. (1998): *Gruveteknikk ved Kongsberg Sølvverk 1623-1914.* Trondheim: Senter for teknologi og samfunn, NTNU, p. 350 Villalobos, S. et al. (1990): *Historia de la ingenieria en Chile*. Santiago: Editorial Universitaria.
		Norway	

Electric power stations	The first power station erected for the supply of private consumers was the Holborn Viaduct station of the Edison Company in England in 1882, originally constructed for supplying street lightning, and later extended to serve private consumers in the vicinity.	The first power station in Norwegian mining was built at Røros Copper Works in 1896. Electric power was provided through a 24 km high voltage network to lifts, pumps, locomotives, crushing machines and other equipment. **Chile** A hydroelectric plant, Chivilingo, was built in 1897, and was the first installation of high-voltage electric power in Chile and South America. The power plant provided electric energy to equipment used in the mines.	Astorquiza, O. and Galleguillos, O. (1952): *Cien años del carbon de Lota 1852-1952*. Compañía Carbonífera e Industrial de Lota. Berg, B. I. (1998): *Gruveteknikk ved Kongsberg Sølvverk 1623-1914.* Trondheim: Senter for teknologi og samfunn, NTNU, p. 421 Jarvis, C. M. (1958): "The distribution and utilization of electricity", in Singer, C. et al. (eds.). *A History of Technoloy, volume V The Late Nineteenth Century 1850 to 1900*. Oxford: The Claredon Press, p. 198 Mazzei de Grazia, L. (1924): *Los británicos y el carbon en Chile*. Concepción: Atenea/Universidad de Concepción, p. 155 Nissen, G. B. (1976): *Røros Kobberverk 1644-1974*. Trondheim.
Electrolysis	James Belleny Elkington developed in Pembrey, near Swansea in Wales in Wales in the copper-smelting plant of Mason & Elkington, a method for extracting the copper through electrolysis. It was patented in 1865 and the first electrolytic refinery was made in 1869. Electricity was supplied by a magneto-electric machine. A saturated aqueous solution of copper sulphate was to be used as electrolyte and current was to be passed until the cathodes reached	**Norway** Through electrolysis of smelted metal compounds were also sodium and aluminium produced at Vigeland in 1900, Stangfjorden in 1906, the Norwegian Nitrid Aktieselskap in 1912 and Høyangfaldene in 1915.	Chadwick, R. (1958): "New extraction processes for metals", in Singer, C. et al. (eds.). *A History of Technoloy, volume V The Late Nineteenth Century 1850 to 1900*. Oxford: The Claredon Press, p. 85 Falck-Muus, R. (1924): *Bergverksdriften Dens historiske og tekniske utvikling i Norge samt dens betydning for landet*. Oslo: Norsk Næringslivs Boktrykkeri, p. 586

	¾-1 inch in thickness. The electrolyte was retained until the content of ferrous sulphate became excessive, when it was discarded and the copper contained in it recovered.		
Fahrkunst	Ludwig Wilhelm Dörell invented the fahrkunst lift in 1833 Zellerfeld, Germany. It was a mechanism of reciprocating ladders and stationary platforms installed in mines to assist the miners' journeys to and from the working levels.	**Norway** Used at Kongsberg from 1881.	Berg, B. I. (1998): *Gruveteknikk ved Kongsberg Sølvverk 1623-1914.* Trondheim: Senter for teknologi og samfunn, NTNU. p. 415
Fire-setting	Used since prehistoric times in traditional mining. Fires were set against a rock face to heat the stone, which was then doused with liquid, causing the stone to fracture by thermal shock. The technique was very dangerous in underground mining without adequate ventilation.	**Norway** Used until the end of nineteenth century.	Berg, B. I. (1998): *Gruveteknikk ved Kongsberg Sølvverk 1623-1914.* Trondheim: Senter for teknologi og samfunn, NTNU.
Flotation process	C. V. Potter and G. O. Delprat carried out the first modern flotation operation in 1901 in New South Wales, Australia for the production of zinc concentrates. Spread rapidly and used mostly in separation of copper. A process implied of separation of metallic minerals disseminated in a rock, which was implemented from its watery pulps through air bubbles. The method consisted of milling the mineral with water in ball mills, and then mixing in cells with different chemical reagents	**Norway** Flotation was used for the first time in Norway in Aamdal in 1908. Also at Røros and other places. **Chile** The flotation process in its industrial use was patented in Chile in 1905. Mining Company of Maipo used it in 1908. By that time the engineer Braden made experimental tests of flotation at El Teniente.	Chadwick, "New Extraction Processes for Metals" (1958) in Singer, C. et al. *A History of Technology*, *vol. 5 The late nineteenth century 1850 to 1900*. London: Oxford University Press, p. 75 Falck-Muus, R. (1924): *Bergverksdriften Dens historiske og tekniske utvikling i Norge samt dens betydning for landet*. Oslo: Norsk Næringslivs Boktrykkeri, p. 582

	and air to form bubbles. Sulfurized mineral particles adhered to the floating bubbles, forming a foam which were collected and dried. The crushed rock without metallic mineral, called tailings, was separated and deposited in dams		Villalobos, S. et al. (1990): *Historia de la ingenieria en Chile*. Santiago: Editorial Universitaria. Zauschquevich, A. and Sutulov, A. (1975): *El cobre chileno.* Santiago: Universitaria, p. 31
Furnaces and related equipment	The separation of metals from their ores was often accomplished by the use of furnaces. Smelting furnaces of various types were used for converting materials to the liquid state by heating them above their melting point. Based on the method of heating, a distinction was made of fired and electrical furnaces. Fired furnaces were heated by some type of fuel. They are divided into direct-heating and indirect-heating. In the former (continuous and shaft furnaces), fuel combustion products came into contact with the heated material. In the latter, heat from the combustion process is transferred to the heated material through a wall of radiant tubes of muffles or, in several cases, through liquids (tank furnace). **Furnaces:** **water-jacketed furnaces**: shaft furnace in steel construction with double walls where water circulated in the space for cooling of the walls in the shaft. **open-hearth furnaces**: Open-hearth furnaces were used in the smelting of	**Norway** Hot blast was adopted from the 1860s at a variety of mining works. With this method air was preheated and blown into a blast furnace for smelting the ore. Westly's smelting oven**,** an electric oven for smelting of copper ore, developed in 1913 by the engineer Jens Westly at Sulitjelma based on the electrode furnaces used in iron smelting. It was the world's biggest electric copper smelting oven of the time (ca. 1 000kW). Tysland-Hole furnace, invented by Georg Tysland became the most widely used electric iron smelting furnace in the world: used from 1924 at Christiania Spigerverk. Manhès copper convertor was installed at Røros Copper Works in 1887 (see Bessemer process) **Chile** Reverberatory furnaces introduced by Charles Lambert in 1831. It made it possible to process sulphuric minerals and lower grade minerals than previous. Bessemer convertors and water-jacket furnaces were used in Potrerillos and	Carstens, H. (2000): *…Bygger i Berge: en beretning om norsk bergverksdrift*. Trondheim: Norsk bergindustriforening Den norske bergingeniørforening Tapir, p. 109 Chadwick, "New Extraction Processes for Metals" (1958) in Singer, C. et al. *A History of Technology*, *vol. 5 The late nineteenth century 1850 to 1900*. London: Oxford University Press, p. 81 Gibbs, W. (1958): "part II. Extraction and production of metals: non-ferrous metals" in Singer, C. et al. (eds.). *A History of Technology, volume IV The Industrial Revolution The Industrial Revolution 1750 to 1850*. Oxford: The Claredon Press, p. 129 Pearl, M. L. (1978): "Iron and steel", in Williams, T (ed.). *A History of Technology, volume VI The Twentieth Century 1900 to 1950*. Oxford: Claredon Press, p. 489 Pinto Vallejos, J. and Ortega Martínez, L. (2004): *Expansión minera y desarrollo industrial: un caso de crecimiento asociado*

	steel and nonferrous metals in foundry production, and for fusing various materials. James Beaumont Neilson in Glasgow, Scotland, invented the system of preheating the blast for a furnace. He found that by increasing the temperature he could reduce fuel consumption. He, and partners, patented this in 1828. Open hearth furnaces, for making steel, was implemented through the Siemens-Martin process, which was a steelmaking technique that for the most of twentieth century accounted for most steel made in the world. . William Siemens made steel from pig iron in a reverberatory furnace of his design in 1867. The same year the French manufacturer Pierre-Émile Martin used the idea to produce steel by melting wrought iron with steel scrap. Siemens increased the temperature through preheated air. This process replaced the Bessemer process in iron smelting. Multi-hearth roasting furnace invented by A. Parkes in 1850. In this furnace the ore was loaded on to the top hearth and raked by rotating arms towards the centre, whence it droped though slots to the second hearth where it was worked to the outside. **Blast furnaces**: used in France and Germany, by 1861 the blast was being heated by waste gases. The ore was first	later in El Teniente in the early twentieth century (see Bessemer process).	*(Chile 1950-1914)*. Santiago: Universidad de Santiago de Chile, p. 24 Schubert, H. R. (1958): “The steel industry”, in Singer, C. et al. (eds.). *A History of Technoloy, volume V The Late Nineteenth Century 1850 to 1900*. Oxford: The Claredon Press, p. 66 Sogner, K. (2003): *Elkem gjennom 100 år Skaperkraft 1904-2004*. Oslo: Messel Forlag, p. 86 Villalobos, S. et al. (1990): *Historia de la ingenieria en Chile*. Santiago: Editorial Universitaria. “Furnaces” “Open-hearth furnace” “Reverberatory furnace”: The Free Dictionary (26th of November 2014) “Waterjacket-ovn”: Bergverkshistorie.no (26th of November 2014)

	roasted in kilns or heaps. It was then fused, after mixing it with slag rich in iron oxide. The coarse metal was roasted and fused to give black copper, 95 per cent, before refined in the blast-furnace to give 99,5 per cent copper. **Reverberatory furnaces**: indirect heating furnace. The structure of these furnaces makes possible a good control of temperature. Reverbatory furnaces were first applied to smelting metals in the late seventeenth century. Sir Clement Clerke and his son Talbot built cupolas or reverberatory furnaces in the Avon Gorge below Bristol in about 1678. Reverberatory furnaces were used some places in Europe before 1830. Ore was imported from South America and other places to Britain for further processing in such ovens. **Electric furnaces**: applied in melting iron-ores or metallic iron; for the application of electricity for metallurgical processes, and especially for the metallurgy of iron. A French chemist Pichou, demonstrator at the École de Chimie Pratique in Paris made one in 1853. Sir William Stevens made an Electric arc furnace for steelmaking in 1879.		
Gamboni process	A process used in the saltpetre industry and invented by the Chilean engineer Pedro Gamboni in 1852. With this process the old lixiviation method was	**Chile** Used in the saltpetre industry from 1852.	Villalobos, S. et al. (1990): *Historia de la ingenieria en Chile*. Santiago: Editorial Universitaria, p. 184

	modified. The old stoves were replaced with direct injection of hot steam on the crushed caliche and water. The operation was done in quadrangular tanks with high capacity. With this system heat was better benefitted and 40 to 50 per cent grade caliche could be processed. Steam engines were used in crushing. Gamboni also managed to separate the iodine from the salted waters which was left after the saltpetre extraction.		
Geophysical survey	Systematic collection of geophysical data for spatial studies. There were many methods and a number of different instrumentation were used, including magnetic and electric techniques. The analyses based on the fact that minerals and ores had different physical characteristics, and that they differed from the surrounding rocks. The landscape and bedrock were transformed into abstract numeric values. Experiments with geophysical surveys were done in Sweden in the nineteenth century. Iron ores are strongly magnetic, and is detected through magnetic methods, while different types of electrical methods were suited to detect sulphide ores, which have higher electrical conductivity than other rocks.	**Norway** Geophysical methods became important in the findings of ores in Norway from the 1920s. In Norway the electrical methods were extensively used to discover ores. One of the first systematic measures with electrical ore prospecting was done in 1923 by mining engineer Magne Mortensen. **Chile** Geophysical methods were used in Southern Chile from the 1930s.	*Boletin de la Sociedad Nacional de Minería* (1931): Santiago: Sociedad Nacional de Minería, p. 361 Børresen, A. K. and Wale, A. (2008): *Kartleggerne*, Trondheim: Tapir akademisk forlag, p. 132
Guggenheim process (used in	A method of chemical precipitation which employed ferric chloride and	**Chile**	Soto Cardenas, A. (1998): *Influencia británica en el salitre: origen, naturaleza y decadencia*.

copper and saltpetre)	aeration to prepare sludge for filtration. The Norwegian engineer Cappelen Smith improved the leaching technology and applied it to the low-grade copper ore deposits in the Chuquicamata mine in Chile on a large scale in 1915.	Used in Chuquicamata by Chile Exploration Company in 1915. Used also in saltpetre industry from the 1920s: the modification of the process implied milling, the lixiviation was done with a lower temperature and the crystallisation of the nitrate was obtained with artificial refrigeration. The final product was smelted and made into powder for use.	Santiago: Edit. Universidad de Santiago de Chile, p. 381 Sutulov, Antecedentes historicos in Zauschquevich, A. And Sutulov, A. (1975): *El cobre chileno.* Santiago: Universitaria.
Gunpowder	Invented in China in the 9th century. Black powder was used in mining as early as the fifteenth century. Used in Cornish mines from 1689.	**Norway** Used in Norway until around 1860s. **Chile** Used in Chile at least until the end of the nineteenth century.	McGrath, J. (1958): "Explosives", in Singer, C. et al. (eds.). *A History of Technoloy, volume V The Late Nineteenth Century 1850 to 1900*. Oxford: The Claredon Press, p. 284
Cyanide process	Lixiviation through cyanide process (gold and silver). Salts of potassium cyanide dissolved the gold and silver, and these were recovered by precipitating them with zinc metal. The system required fine milling of the ore. The process was invented by the Scottish chemists John S. MacArthur, Robert W. Forrest and Robert W. Forrest in 1887.	**Norway** Used at Kongsberg Silver Works after 1885. **Chile** In 1903 amalgamation methods were still used but the cyanide process was used for the first time in Mina Guanaco in Taltal; in 1907 other plants in Copiapó used the method.	Astorquiza, O. and Galleguillos, O. (1952): *Cien años del carbon de Lota 1852-1952*. Compañía Carbonínera e Industrial de Lota, p. 189 Helleberg, O. A. (2000): *Kongsberg sølvverk 1623-1958: kongenes øyesten – rikenes pryd.* Kongsberg: Forlag Langs Lågen i samarbeid med Sølvverkets venner, p. 306 Villalobos, S. et al. (1990): *Historia de la ingenieria en Chile*. Santiago: Editorial Universitaria.
Long wall system	"Long wall" system was used in the coal industry and employed first in the English coal mines in the late seventeenth century. The extraction occurred "by	**Chile** Introduced in Chilean coal mines before 1900? Replaced the board and pillar method.	Ritson, J. A. S. (1958): "metal and coal mining, 1750-1875", in Singer, C. et al. (eds.). *A History of Technology, volume IV The Industrial Revolution The Industrial Revolution*

	long fronts". This method consisted of progressive extractions of a panel of coal through galleries. One was used to extract coal and supply ventilation air; the other one was used for supply and return the contaminated air. The two galleries made contact in the front of production between 50 and 300 m; the front was extracted making it regress between 200 and 1000 m, until the panel was drained. Not common in England before after 1850. Mechanical coal cutters and conveyors were often used with this technique. The combination of heavy coal-cutter and conveyer on a longwall face became known as "conventional" machine mining.		*1750 to 1850*, Oxford: The Claredon Press, p. 87 Villalobos, S. et al. (1990): *Historia de la ingenieria en Chile*. Santiago: Editorial Universitaria.
Magnetic separation	Magnetic separation was a process in which magnetically susceptible material was extracted from a mixture using a magnetic force. This separation technique was useful in mining iron as it was attracted to a magnet. Magnetic separation was developed in the late nineteenth century. The finely crushed ore was carried on a belt between the poles of a powerful electromagnet. This method was first used to separate ferrous from non-ferrous constituents, but by the end of the century it was being used to separate minerals differing only slightly in magnetic susceptibility.	**Norway** Magnetic separation was used for the first time in Norway in 1910 at Sulitjelma Atiebolag and Salangen and at Dunderland Iron in 1910. Magnetic separation was also used at A/S Sydvaranger from the beginning of the twentieth century.	Carstens, H. (2000): *…Bygger i Berge: en beretning om norsk bergverksdrift*. Trondheim: Norsk bergindustriforening Den norske bergingeniørforening Tapir, pp. 124-125 Chadwick, "New Extraction Processes for Metals" (1958) in Singer, C. et al. *A History of Technology, vol. 5 The late nineteenth century 1850 to 1900*. London: Oxford University Press, p. 74

Mechanical unloaders	Used in iron works, a massive structure with huge buckets moving down into the hold of the ship. Invented by George H. Hulett in 1898.	**Chile** Used in the iron mine El Tofo near La Serena from 1913 by Betlehem Chile Iron Mines in the loading of iron.	Pearl, M. L. (1978): "Iron and steel", in Williams, T (ed.). *A History of Technology, volume VI The Twentieth Century 1900 to 1950*. Oxford: Claredon Press, p. 464 Schubert, H. R. (1958): "New extraction processes for metals", in Singer, C. et al. (eds.). *A History of Technoloy, volume V The Late Nineteenth Century 1850 to 1900*. Oxford: The Claredon Press, pp. 63-64 Villalobos, S. et al. (1990): *Historia de la ingenieria en Chile*. Santiago: Editorial Universitaria.
Mills/grinding machines	In 1862 the Englishman George Bedson of Manchester constructed a continuous-rolling mill. Gruson milling was designed by Sachsenberg brothers in Roblau-on-Elbe and W. Brucker in Ohrduf, and a mill was built in H. Gruson's workshop in Magdeburg, Germany in 1885.	**Norway** New types of milling machines and rollers were introduced at Røros and Kongsberg at the end of the nineteenth century. **Chile** Used in Chile at the end of the nineteenth century at Mining Company Arturo Prat in 1893.	*Gran Compañía Arturo Prat* (1893, primer semestre): *Memorias*: Santiago. Helleberg, O. A. (2000): *Kongsberg sølvverk 1623-1958: kongenes øyesten – rikenes pryd.* Kongsberg: Forlag Langs Lågen i samarbeid med Sølvverkets venner. Lynch, A. J. and Rowland, C. A, (2005): *The History of Grinding*, the USA: Society for Mining, Metallurgy, and Exploration, Inc., p. 101 Nissen, G. B. (1976): *Røros Kobberverk 1644-1974*. Norway: Aktietrykkeriet.
Napier system	Napier system was an English system of melting copper in smelting ovens. James Napier patented this process, used in Swansea, which followed the four stages	**Chile** Used in some copper foundries in Lota and Coquimbo at the end of the nineteenth century.	Aracena, F. M. And Sagredo Baeza, R. (2011): *Apuntes de viaje: la industria industria del cobre en las provincias de Atacama y Coquimbo, los grandes y valiosos despósitos*

	in the Cornish (Welsh copper method) method of assay. It involved adding saltcake in the melting-furnace and breaking up the mix in water to separate impurities such as tin and antimony.		*carboníferos de Lota y Coronel en la Provincia de Concepción*. Santiago: Cámara Chilena de la Construcción, Pontificia Universidad Católica de Chile, Dirección de Bibliotecas Archivos y Museos. Gibbs, W. (1958): “part II. Extraction and production of metals: non-ferrous metals” in Singer, C. et al. (eds.). *A History of Technology, volume IV The Industrial Revolution The Industrial Revolution 1750 to 1850*. Oxford: The Claredon Press, p. 128 Mazzei de Grazia, L. (1924): *Los británicos y el carbon en Chile*. Concepción: Atenea/Universidad de Concepción, p. 155
Nitroglycerine	Nitroglycerin was the first practical explosive ever produced that was stronger than black powder. Nitroglycerin was synthesized by the Italian chemist Ascanio Sobrero in 1847.	**Norway** Industrial production of nitroglycerin started in Norway in 1865 before the use of dynamite. **Chile** Used in Chile before dynamite.	
Open-pit mining (large-scale production)	Open cast mining, used on ores which lay near the surface. The technique was to remove the overburden with steam, shovel, having first loosened it with preliminary blasting if necessary, to reveal the ore beneath. This was then scooped out with steam shovels and dumped into nearby railway trucks for transportation to reduction plants. The North American engineer Daniel Jackling pioneered in exploitation of low-	**Chile** Copper production in low-grade and large-scale in El Teniente, Chuquicamata and Potrerillos: big volume production from the beginning of the twentieth century. In the early days of open-pit mining the companies stripped the ore with steam-driven shovels which dumped it into waiting railway wagons. Many mines, particularly copper mines in Chile and USA continued to use this	Sutulov, Antecedentes historicos in Zauschquevich, A. And Sutulov, A. (1975): *El cobre chileno.* Santiago: Universitaria, p. 413 Temple, J. (1978): “Metal mining”, in Williams, T (ed.). *A History of Technology, volume VI The Twentieth Century 1900 to 1950*. Oxford: Claredon Press, pp. 411-414

	grade copper mines in Utah in 1903. Based on technological developments of the late nineteenth century, such as fundamental drilling equipment, loading and transportation for large-scale operations for compensating the decreasing grade of minerals.	machinery except that electrically driven shovels replaced steam shovels. These were later replaced by bulldozers powered by diesel engines.	
Optical mineralogy	In 1815, the Scotsman William Nicol developed a method of preparing extremely thin sections of crystals and rocks for microscopical study. His technique (which involved cementing the specimen to a glass slide and then carefully grinding until it was extremely thin) made it possible to view mineral samples by transmitted rather than reflected light and therefore enabled the minerals' internal structures to be seen.	**Norway** Used in Norway from the 1870s.	Børresen, A. K. and Wale, A. (2008): *Kartleggerne*, Trondheim: Tapir akademisk forlag, p. 74
Orkla process	In 1929 the Norwegian company Orkla Grube Aktiebolag developed a method for separating pure sulphur and copper from pyrite. After a number of experiments the pyrite was separated without losing the sulphur.	**Norway** Based on the Orkla process the company established a smelting plant in Thamshavn in 1931. The company started to produce pyrite and sulphur as well as copper.	Bergh, T. et al. (2004): *Brytningstider: Orklas historie 1654-2004.* Oslo: Orion forlag, p. 51 "Orkla ASA": Det store norske leksikon, snl.no (27th of November 2014)
Pedersen process	Developed by professor Harald Pedersen and used for aluminium production from 1928. The process consisted of smelting bauxite with limestone and coke in electric shaft ovens. An important prerequisite for the process was the self-burning, continuous "Söderberg electrode", which was developed during WWI.	**Norway** The aluminium factory in Høyanger was finished in 1928 and based the production on the "Pedersen process".	"Harald Pedersen": Det store norske leksikon, snl.no (27th of November 2014)

Pumps (mechanical)	A continuous problem in mines was water. Before the introduction of the steam-power, many mines had to close down due to the water problem. The oldest way of draining mines, and still used in mining, is by the use of adits, tunnels going from the lowest spot possible and slightly rising. Adits can only drain mines above them, but they were also used in deeper mines to reduce pumping of water. Pumps were employed from the eighteenth century in Britain to drain water. When water-power was available, water-driven whims were used to draw water in barrels to the surface. Water wheels were applied to give power to the pumps. When water-power was not available, steam-engines were often used. Boulton and Watt steam-powered pumps and engines were common in the late nineteenth century in England. The rag-and-chain pumps, worked by manual labour, were also used. Water column engines was a water engine used for pumping purposes in different mining areas since the middle of the eighteenth century. A water column machine was built in France of Denisard and de la Dueille in 1731 and further developed in Germany. Later, in 1903 electrically driven centrifugal pumps were used for	**Norway** The first water column engine for drainage and rock hoisting at Kongsberg Silver Works was installed in 1869. In 1911 the electrical plant was expanded with an electric centrifugal pump for drainage. **Chile** Descubridoras de Caracoles Company probably used mechanical pumps in 1884. Mechanical pumps were probably used other places later, and at the large North American copper companies.	Berg, B. I. (1998): *Gruveteknikk ved Kongsberg Sølvverk 1623-1914.* Trondheim: Senter for teknologi og samfunn, NTNU, pp. 361 and 410 Helleberg, O. A. (2000): *Kongsberg sølvverk 1623-1958: kongenes øyesten – rikenes pryd.* Kongsberg: Forlag Langs Lågen i samarbeid med Sølvverkets venner, p. 292 Minas Descubridoras de Caracoles (segundo semestre 1884): *Memoria*. Valparaíso. Ritson, "Metal and Coal Mining, 1750-1875" (1958), in Singer, C. et al. (eds.) *A History of Technology, volume IV The Industrial Revolution The Industrial Revolution 1750 to 1850*. Oxford: The Claredon Press, pp. 77-79 Villalobos, S. et al. (1990): *Historia de la ingenieria en Chile*. Santiago: Editorial Universitaria, p. 169

	pumping for the first time in a Spanish mine.		
Railway (and locomotives)	The first railway used in mining was probably in Coalbrookdale in 1767. In 1777 were railways underground installed in the coal mines in Sheffield. Prior to locomotives, the motive force for railroads had been generated normally by human power, horses or other animals. The first successful locomotives were built by Richard Trevithick. In 1804 a steam locomotive hauled a train along the tramway of the Penydarren ironworks, near Merthyr Tydfil in Wales. Electric locomotive was invented by Werner Siemens in 1882 and made in Sachsen for the first time underground. The first electric mine railway in the world was built by Siemens & Halske mining in Saxon, Germany from 1882. Other types of locomotives, such as gasoline locomotives have been produced since the early 1900s.	**Norway** Railway in the mines was introduced at Kongsberg in the 1840s and was driven by horses. New tracks and other improvements were made in the 1860s. Røros railway was built in 1877 and Røros Copper Works used railway at the mines from 1886. Electric locomotives were introduced in the mines at Sulitjelma Aktiebolag in the 1890s. Gasoline locomotives were adopted at Kongsberg in 1912. **Chile** Electric locomotives to transport coal in Lota were introduced in 1897. In 1915 horses were replaced by electric locomotives at the coal mines.	Astorquiza, O. and Galleguillos, O. (1952): *Cien años del carbon de Lota 1852-1952*. Compañía Carbonínera e Industrial de Lota, p. 189 Berg, B. I. (1998): *Gruveteknikk ved Kongsberg Sølvverk 1623-1914.* Trondheim: Senter for teknologi og samfunn, NTNU, pp. 43-44, 423 and 443-444 Carstens, H. (2000): *…Bygger i Berge: en beretning om norsk bergverksdrift*. Trondheim: Norsk bergindustriforening, Den norske bergingeniørforening Tapir, p. 119 Villalobos, S. et al. (1990): *Historia de la ingenieria en Chile*. Santiago: Editorial Universitaria. Øisang, O. (1942): *Rørosboka: Røros bergstad, Røros landsogn, Brekken og Glåmos kommuner: 3-4: Røros Kobberverks historie,* 2. bind. Trondheim: Rørosbokkomiteen: kommisjon hos Globus-forlaget, p. 235
Shanks system	A British system used in saltpetre processing. With this mechanized method indirect heating through circulation of steam inside tanks was done to process the nitrate-rich mineral. This resulted in 5-8 per cent waste of saltpetre. Typically only the highest	**Chile** Used in the Chilean saltpetre industry, especially by the British investors in the nineteenth century This inefficient process could only be maintained as long as Chile had a near monopoly on production and the price of nitrate	Marr, P. (2007): "Ghosts of the Atacama: The abandonment of nitrate mining in the Tarapacá region of Chile", Middle States Geographer, 40: 22-31 Pinto Vallejos, J. and Ortega Martínez, L. (2004): *Expansión minera y desarrollo*

	grade of ore was mined, with moderate and low-grade ores left behind as spoils.	remained high. The Guggenheim method took over in the 1920s.	*industrial: un caso de crecimiento asociado (Chile 1950-1914)*. Santiago: Universidad de Santiago de Chile, p. 39 Soto Cardenas, A. (1998): *Influencia británica en el salitre: origen, naturaleza y decadencia*. Santiago: Edit. Universidad de Santiago de Chile.
Steam engines	James Watts invented the steam engine in 1774 in England. It is a heat engine that performs mechanical work using steam as its working fluid. Newcomen engines were used from 1778 in Cornwall (coal), but they were replaced by the more economic Boulton and Watt engines, which used much less coal: used in coal mines on the surface to pump water, transport and lifting.	**Norway** Used in Norwegian mining from 1840s for drainage, lifting and transport. **Chile** Used in Chile from the 1840s. The steam engines were used among others for removal of water, which was a big problem in Latin American mines.	Berg, B. I. (1998): *Gruveteknikk ved Kongsberg Sølvverk 1623-1914.* Trondheim: Senter for teknologi og samfunn, NTNU, p. 405 Ritson, J. A. S. (1958): "Metal and coal mining, 1750-1875", in Singer, C. et al. (eds.). *A History of Technology, volume IV The Industrial Revolution The Industrial Revolution 1750 to 1850*. Oxford: The Claredon Press, pp. 77-79
Theodolite	Jesse Ramsden invented a modern theodolite in 1787 in England. The device derives from older astronomical instruments and was used in geological surveys for measuring.	**Norway** Used at Kongsberg Silver Works in the measuring of ores, introduced in 1846. **Chile** Used in Chile by 1884.	Aracena, F. M. And Sagredo Baeza, R. (2011): *Apuntes de viaje: la industria del cobre en las provincias de Atacama y Coquimbo, los grandes y valiosos despósitos carboníferos de Lota y Coronel en la Provincia de Concepción*. Santiago: Cámara Chilena de la Construcción, Pontificia Universidad Católica de Chile, Dirección de Bibliotecas Archivos y Museos, p. 327 Berg, B. I. (1998): *Gruveteknikk ved Kongsberg Sølvverk 1623-1914.* Trondheim: Senter for teknologi og samfunn, NTNU, p. 429-431

Turbine	Benoit Fourneyron invented a turbine in 1827 in France. It was a rotary mechanical device that extracted energy from a fluid flow and converted it into useful work. Alternative turbines were developed after this. In England the reaction turbine was created and the impulsive turbine developed in Sweden.	**Norway** Used in Norway from the 1860s. **Chile** Used at the electric plant at Braden Copper Company from 1910.	Berg, B. I. (1998): *Gruveteknikk ved Kongsberg Sølvverk 1623-1914.* Trondheim: Senter for teknologi og samfunn, NTNU. *La Braden Copper Company Mineral de "El Teniente"* (1942): Rancagua: Es propiedad.
Water wheels	The ancient Greeks invented the water wheel and were, along with the Romans, the first to use it for irrigation and source of power. It was a hydraulic machine that drove technical devices to convert the energy of falling water into mechanical usable energy. There were different kinds of wheels depending on where the water passed.	**Norway** Water wheels were used for draining and other purposes in mining. At Kongsberg Silver Works it was used until 1900, and until later in other mines in Norway. **Chile** Used extensively in mining. Water wheels were applied to give power to pumps.	Berg, B. I. (1998): *Gruveteknikk ved Kongsberg Sølvverk 1623-1914.* Trondheim: Senter for teknologi og samfunn, NTNU, p. 403 Villalobos, S. et al. (1990): *Historia de la ingenieria en Chile*. Santiago: Editorial Universitaria, p. 169

Appendix 7. Import of machinery and equipment to the Chilean mining sector, selected years

Year	Technology		Unit of measure	Imported from country
1840	Machines for mining	8	packages	Great Britain
1860	Buckets for mines	6	dozen	Great Britain
	Coal mining machines	171	packages	?
	Foundry machine	1	machine	Great Britain
	Fuses for mining	465	quintals	Great Britain
		189	quintals	North America
	Gunpowder for mines	9 699	packages	?
	Mining pumps	36	dozen	Great Britain
		33	dozen	North America
	Milling machines for metals	7	packages	?
1880	Milling machines for metals	7	packages	Great Britain
	Mineral extraction machine	1	package	Great Britain
	Mining fuses	5 590	kilos	Germany
		102 291	kilos	Great Britain
		3 465	kilos	The United States
	Mining gunpowder	5 000	kilos	Germany
		194 695	kilos	Great Britain
		103 270	kilos	The United States
	Mining lamps	20	packages	?
	Mining pumps	15	packages	Great Britain
	Saltpetre processing machine	62	packages	Great Britain
1900	Mining fuses	13 939	kilos	Belgium
		747	kilos	France
		143 445	kilos	Germany
		54 690	kilos	Great Britain
		887	kilos	Italy
		1 774	kilos	The United States
	Saltpetre processing machine	4 994	kilos	Germany
		19 114	kilos	Great Britain
	Mining machines	12 622	kilos	France
		94 792	kilos	Germany
		244 565	kilos	Great Britain
		14	kilos	Italy
		92 963	kilos	The United States
1920	Iron and steel Crowbars	829	kilos	Great Britain
	Drills and perforators	948	kilos	Germany
		2 645	kilos	Great Britain
		5 184	kilos	The United States

	Air pumps	445	kilos	Argentina
		2 316	kilos	France
		6 530	kilos	Germany
		66 087	kilos	Great Britain
		93 626	kilos	The United States
	Crushers	610	kilos	Great Britain
		244	kilos	The United States
	Tools and spare parts	29 648	kilos	Great Britain
		501	kilos	Spain
		12 397	kilos	The United States
	Lamps for mines and spare parts	229	kilos	Germany
		5 151	kilos	Great Britain
		828	kilos	Spain
		1 084	kilos	Sweden
		2 324	kilos	the United States
	Machines, equipment and parts	2 430	kilos	Belgium
		422	kilos	Bolivia
		20 210	kilos	France
		264 698	kilos	Germany
		324 204	kilos	Great Britain
		19 510	kilos	Holland
		547	kilos	Sweden
		3 273 695	kilos	The United States
	Perforators for mines	55	kilos	Argentina
		830	kilos	Germany
		1 623	kilos	Great Britain
		35 583	kilos	The United States
1940	Iron or steel pans for mines	140 680	kilos	Germany
		219	kilos	Great Britain
	Lamps for mines and metallic spare parts	1 459	kilos	Belgium
		3 233	kilos	Spain
		3 717	kilos	the United States
	Not specified equipment for mining	593	kilos	Great Britain
		42 645	kilos	The United States
	Perforators, excavators, mechanical shovels and other machines for mining	43 511	kilos	Belgium
		694	kilos	Bolivia
		65 749	kilos	Germany
		13 230	kilos	Great Britain
		228	kilos	Japan
		275 003	kilos	The United States
	Spare parts and tools for machinery and equipment	549	kilos	Belgium
		2	kilos	Bolivia
		12 441	kilos	Germany
		55 824	kilos	Great Britain
		841 734	kilos	The United States

Sources: Oficina Central de Estadística (1840, 1860, 1880, 1920, 1940): *Anuario Estadístico de la República de Chile, Comercio exterior.* Valparaíso: Sociedad Imprenta y Litografía Universo.

Appendix 8. Power sources and equipment in Norwegian mining companies

Mineral and ore mines*

Year	Companies	Companies with engines	Engines (quantity)					Total horsepower	Steam boilers	Operational machines**	
			Water	Steam	Gas	Electricity	Other driving forces			With engine	Without engine
1895/96	90	26	31	32	1	18	14	3 067	37	202	7
1897	80	30	29	28	1	19	15	2 860	40	224	8
1898	102	28	28	30	2	23	10	2 918	40	223	7
1899	123	30	53	26	2	25	14	3 321	36	237	14

*Some of the terms used in the official statistics are difficult to translate to English.
**The Norwegian term is «arbeidsmaskiner».
Source: Rigsforsikringsanstalten. *Norges Officielle Statistik, Rigsforsikringsanstaltens Industristatistik for årene 1895-1899* (1904): Kristiania: H. Aschehoug.

Year	Companies	Companies with mechanical power	Primary force		Electricity			The applied mechanical power (self-produced and leased) HK. (horsepower)*
			Water, steam, gas etc. HK. (horsepower)	Thereof used for operation of dynamos. HK. (horsepower)	Used for smelting, electrolysis etc. (self-produced and leased) HK. (horsepower)	Electric engines	Power of the engines HK. (horsepower)*	
1916	178	89	50 666	22 872	45 277	1 250	27 704	36 250
1917	206	100	45 583	31 758	43 488	1 511	31 059	35 315
1918	234	109	48 966	48 966	48 691	1 654	33 255	36 947

* The Norwegian expression used is «motorens påstempelkraft».
**The Norwegian expression used is «den anvendte mekaniske drivkrafts størrelse (selvproducert og leiet)».
Source: Statistisk Sentralbyrå (1921): *Norges Officielle Statistik, Industristatistikk for året 1918*. Kristiania: H. Aschehoug & Co.

Ore, metal and mineral extraction and processing

Year	Companies		Thereof	Application of primary power	Total size of	Electro engines	Electricity for

			Total primary power HK. (horsepower)	Waterpower HK. (horsepower)	Steam power HK. (horsepower)	Other types of power HK. (horsepower)	For direct mechanical purposes HK. (horsepower)	For operation of generators	generators in kW.	Number	HK. (horsepower)	smelting, electrolysis etc. in kW
1938	Mines and smelting operations	36	41 903	26 245	13 516	2 142	3 713	38 190	28 995	2 744	67 393	2 000
	Electrical processing of metals	27	53 965	49 345	4 620	-	445	53 520	38 327	3 633	49 856	292 210
	Mineral mines	72	1 513	600	-	913	844	669	493	133	1 384	-
	Mineral mills	11	697	390	-	307	83	614	367	82	1 419	-
	Total	**146**	**98 078**	**76 580**	**18 136**	**3 362**	**5 085**	**92 993**	**68 182**	**6 592**	**120 052**	**294 210**

Source: Statistisk Sentralbyrå (1941): Norges Offisielle Statistikk, Norges Industri Produksjonsstatistikk 1939. Kristiania: H. Aschehoug.

Appendix 9. Power sources and equipment in Chilean mining companies

Machinery and power at copper smelting plants

1912																				
	Boilers		**Engines**																	
			Steam		**Gas**		**Hydraulic**		**Electric**		**Petroleum**									
	Number	**HP.**	**Number**	**HP.**	**Number**	**HP.**	**Number**	**HP.**	**Number**	**HP.**	**Number**	**HP.**	**Crushing and milling machines**	**Concentration machines**	**Compressors**	**Ventilators**	**Barrels and tons**	**Calcining furnace**	**Smelters**	**Converter**
Total	**53**	**4 600**	**44**	**2 776**	**7**	**1 100**	**13**	**984**	**54**	**13 050**	**8**	**1 032**	**105**	**197**	**18**	**34**	**5**	**22**	**54**	**59**

Source: Oficina Central de Estadística, *Anuario Estadístico Minería y Metalurgia 1912*, Santiago: Soc. Imp. y Lit. Universo, 1913.

Machinery and power at copper smelting plants

1925													
Companies	**Boilers**		**Engines**					**Crus hing and**	**Con cent :**	**Co mpr**	**Ven tilat**	**Calc inin**	**Sme lter**	**Con vert**
	Number	**HP.**	**Steam**	**Gas**	**Hydraulic**	**Electric**	**Petroleum**							

			Number	HP.	Number	HP.	Number	HP.	Number	HP.	Num ber	HP.							
Chuquicamata	4	500	1	120	-	-	-	-	156	80 000	-	-	14	-	17	2	1	4	1
El Teniente	21	1 141	14	506	-	-	8	37 625	775	48 000	6	48	78	19	82	7	8	3	3
The rest	43	7 570	39	5 203	3	320	4	572	118	2 532	1	80	28	16	13	22	3	33	21
Total	**68**	**9 231**	**54**	**5 829**	**3**	**320**	**12**	**38 197**	**1 049**	**130 532**	**7**	**128**	**120**	**35**	**112**	**31**	**12**	**40**	**25**

Source: Oficina Central de Estadística, *Anuario Estadístico Minería y Metalurgia 1925*, Santiago: Soc. Imp. y Lit. Universo, 1926.

Machinery and power at copper mines

1925																		
	Engines																	
	Boilers		**Steam**		**Gas**		**Hydraulic**		**Electric**		**Petroleum engine**		**Drills**			**Pumps**		**Extraction machines**
	Number	**HP.**	**Number**	**HP.**	**Number**	**HP.**	**Number**	**HP.**	**Number**	**HP.**	**Number**	**HP.**	**Hand**	**Compressed air**	**Electric**	**Hand**	**machine**	
Total	**32**	**2 413**	**28**	**1 772**	**4**	**80**	**5**	**455**	**55**	**1 064**	**21**	**683**	**12**	**404**	**20**	**22**	**87**	**47**

	Transport									
	Carriages		**Carts**		**Small carts**	**Cars**		**Traction engines**	**Horses**	**Mules**
	2 wheels	**4 wheels**	**2 wheels**	**4 wheels**		**Load**	**Passengers**			
Total	**3**	**9**	**68**	**8**	**19**	**27**	**17**	**3**	**305**	**667**

Source: Oficina Central de Estadística, *Anuario Estadístico Minería y Metalurgia 1925*, Santiago: Soc. Imp. y Lit. Universo, 1926.

Machinery and power at copper plants

1939																
Companies	**Type of engine (primary engines)**															
	Hydraulic turbines				**Steam piston engines**				**Steam turbines**				**Diesel engines and others**			
	Operating		**Standby**		**Operating**		**Standby**		**Operating**		**Standby**		**Operating**		**Standby**	
	Number	**HP.**	**Number**	**HP.**	**Number**	**HP.**	**Number**	**HP.**	**Number**	**HP.**	**Number**	**HP.**	**Number**	**HP.**	**Number**	**HP.**

Chuquicamata	-	-	-	-	-	-	-	-	3	55 000	6	97 168	-	-	-	-
El Teniente	9	62 500	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Potrerillos	2	5 425	-	-	-	-	-	-	4	34 000	3	15 350	2	120	-	-
The rest	1	100	-	-	3	1 110	3	520	-	-	-	-	1	10	1	10
Total	**12**	**68 025**	**-**	**-**	**3**	**1 110**	**3**	**520**	**7**	**89 000**	**9**	**112 518**	**3**	**130**	**1**	**10**

Companies	**Generators and electric generator engines**											
	Generators						**Generator engines**					
	Operating		**Standby**		**Total**		**Operating**		**Standby**		**Total**	
	Number	**HP.**	**Number**	**HP.**	**Number**	**HP.**	**Number**	**HP.**	**Number**	**HP.**	**Number**	**HP.**
Chuquicamata	3	55 000	6	97 168	9	152 168	78	106 505	6	1 500	84	108 005
El Teniente	9	56 949	-	-	9	56 948	184	7 898	16	34 242	200	42 140
Potrerillos	6	40 053	3	15 750	9	55 803	46	19 055	13	7 390	59	26 445
The rest	5	1 020	3	225	8	1 245	1	3	1	50	2	53
Total	**22**	**153 022**	**12**	**113 143**	**35**	**266 164**	**309**	**133 461**	**36**	**43 182**	**345**	**176 643**

Companies	**Electric engines**									
	Operating		**Standby**		**Total**		**Energy distribution**			
							Energy from:		**Energy supplied:**	
	Number	**HP.**	**Number**	**HP.**	**Number**	**HP.**	**Own plant kW. per hour**	**Other plant kW. per hour**	**To own plant kW. per hour**	**To other plants kW. per hour**
Chuquicamata	2 218	84 206	250	13 400	2 468	97 606	451 870 820	-	438 918 920	12 951 900
Potrerillos	1 232	48 342	155	3 921	1 387	52 263	168 966 980	-	168 130 094	836 886
El Teniente	1 549	88 671	166	9 193	1 715	97 864	269 883 119	-	269 883 119	-
The rest	182	3 883	40	915	222	4 798	4 854 844	8 844 204	13 699 048	-
Total	**5 181**	**225 102**	**611**	**27 429**	**5 792**	**252 531**	**895 575 763**	**8 884 204**	**890 631 181**	**13 788 786**

Companies	**Boilers and working machinery***												
	Steam boilers		**Machines**						**Furnaces**				
	Number	**Heating surface M²**	**Crushing and milling machines**	**Air compressors**	**Ventilators**	**Converters**	**Concentration**	**Draining**	**Foundry**	**Refining**	**Roasting**	**Calcining**	
Chuquicamata	19	19 054	62	27	45	46	-	43	1	4	-	-	
Potrerillos	17	10 350	60	47	3	4	20	144	3	1	14	2	
El Teniente	2	150	84	10	19	4	21	102	2	2	-	11	

The rest	15	1 700	20	9	8	8	7	24	4	-	-	12
Total	**53**	**31 254**	**226**	**93**	**75**	**66**	**48**	**313**	**10**	**7**	**14**	**25**

Companies	**Explosives**				
	Gunpowder (kilogram)	**Dynamite (kilogram)**	**Fuses (feet)**	**Explosives (number)**	**Electric detonators (number)**
Chuquicamata	-	2 307 000	1 614 189	207 677	2 524
Potrerillos	-	631 715	3 811 114	238 798	113 344
El Teniente	1 361	412 683	6 406 400	1 454 744	-
The rest	24 279	55 938	951 422	220 839	-
Total	**25 640**	**3 407 336**	**10 824 811**	**2 122 058**	**115 868**

Companies	**Transport**													
	Railway						**Engine vehicles and animal traction**				**Animals**			
	Steam, electric and petroleum locomotives		**Loading trucks**		**Carts**	**Railway cars**	**Passenger cars**	**Trucks**	**Tractors**	**Carts and wagons**	**Cattle**	**Donkeys**	**Horses**	**Mules**
	Outside mines	**Inside mines**	**Outside mines**	**Inside mines**										
Chuquicamata	45	-	866	-	-	-	16	32	2	-	-	11	77	12
Potrerillos	7	26	90	200	-	-	25	42	1	8	-	-	12	41
El Teniente	23	26	239	-	17	7	7	10	1	-	-	-	70	4
The rest	14	2	150	-	-	-	6	1	-	-	26	-	61	97
Total	**89**	**54**	**1 345**	**200**	**17**	**7**	**54**	**85**	**4**	**8**	**26**	**11**	**220**	**154**

*The Spanish term is "máquinas de trabajo".

Source: Dirrección General de Estadística (1940): *Minería e Industria 1939*. Chile.

Appendix 10. Mining engineering study programs in Norway, selected years

Mining instruction at the Royal Frederick University

Year	Courses/subjects*
Around 1860	Mineralogy (and "mineralogical exercises") Lithology Stratigraphy Geology (paleontology, petrology, rock formation etc.) "Mining construction" Physical geography Metallurgy (ore dressing, smelting) "Mining fabrication" Physics Chemistry "Electricity" Thermodynamics Optics Mechanics Mathematics (geometry, stereometry, trigonometry, algebra, equations, spherical trigonometry, "applied mathematics") Hydrostatics Hydrodynamics
Around 1890	Mineralogy Geology (paleontology, petrology, rock formation etc.) "Mining construction" Mathematics Hydrodynamics Physical geography Mechanics "Study of machines" Experimental physics (mechanics, acoustics, optics, thermodynamics, magnetism, electricity) Metallurgy (special and general metallurgy) Chemistry? Chemical technology Mathematics (calculus, geometry, space geometry) Thermodynamics Ore dressing

Around 1910	Metallurgy Geophysics Experimental physics (acoustics) Thermodynamics Electricity Physics Chemistry? "Mining" Geology Metallurgy Petrography (petrographic optics) Mineral and rock microscopy Mathematics Mechanics Stratigraphy Mineralogy Crystallography Physical geography Mineral processing Mining law Electrochemistry Electronic engineering

*Courses, subjects and lectures referred to in the University and school annals and annual reports. It is sometimes unclear whether references were general courses or subjects within a course.

Sources: *Universitets- og skoleannaler* [University and school annals] (1834-1910): Kristiania; *Det Kongelige Norske Frederiks Universitets Aasberetning* [The Royal Norwegian Frederik's University Annual Report] (1840-1911): Christiania: Brøgger & Christie's Bogtrykkeri.

Mining instruction the year 1920 at Norwegian Institute of Technology (NIT)

Courses	Weekly hours							
	1st semester		2nd semester		3rd semester		4th semester	
	Lectures	Exercises	Lectures	Exercises	Lectures	Exercises	Lectures	Exercises
Mathematics I	4	3	4	2				
Descriptive geometry	3	3						
Mechanics I	2	3	2	3				
Mechanics II					4	4		

Physics	4		4					
Exercises in the physical laboratory						3		
Experimental chemistry	2		2					
Inorganic chemistry	4		4					
Mineralogy and geology	3	1	3	4				
Mineralogy and crystallography	2*)	2			2*)	2	2	2
Basic features of machine building	2	3	2	3				
“Machine parts”					4	6	3	6
Mechanical technology A					4			2
Surveying $_{1}$)				1	3	3	3	3
Qualitative analysis	2	$_{2}$)						
Quantitative analysis			1	$_{2}$)				
Technical writing		$_{3}$)						

Courses	**5th semester**		**6th semester**		**7th semester**		**8th semester**	
	Lectures	**Exercises**	**Lectures**	**Exercises**	**Lectures**	**Exercises**	**Lectures**	**Exercises**
Electrical engineering	2		2					
“Descriptive machine teaching”	3	2	3	2	3	2	3	2
Mineral and rock microscopy	3	1			3	1		1
House building I	4			6				
Water building	2		2					
“Mining”	3	1	2	1	3	1	2	1
Mineral processing $_{4}$)	2	2			2	2		
Mining law $_{5}$)			2				2	
Mining measurement and magnetometer			1	1				
Metallurgy	4		3		4		3	
Chemical laboratories and metallurgical exercises		$_{6}$)		$_{6}$)		$_{6}$)		
Social economy and law	2		4		2			
Bookkeeping	1	3						
“Samaritan course”						$_{7}$)		

Notes: *) Joint courses

$_{1}$) Hereto 5 weeks practical exercises in the field during holidays.

$_{2}$) Laboratory exercises by appointment

^{3}) By appointment

[4]) Every other year 1919, 1921, etc.
[5]) Every other year 1919, 1921, etc.
[6]) By appointment
[7]) Around 10 hours per semester

Admission to the 3rd year requires at least one month stay at a mine, and for admission to the final exam a 4 month stay at a mine is required (herein the above month included). Of these 4 months 2 months must include participation in practical work and at least one month stay at a mine, at least 3 weeks at a crushing plant and at least 3 weeks at a smelting plant.

Source: Den Tekniske Høiskole i Trondhjem. *Program for Studieåret 1919-1920*. Trondhjem: A/S Centraltrykkeriet Ellewsen & Co., pp. 46-47

Mining instruction 1939 at Norwegian Institute of Technology (NIT)

Courses	Weekly hours							
	1st semester		2nd semester		3rd semester		4th semester	
	Lectures	Exercises	Lectures	Exercises	Lectures	Exercises	Lectures	Exercises
Mathematics I	4	3	4	3				
Descriptive geometry	3			3				
Mechanics	3	3	2	2				
Physics					4		4	
Physics						2		2
Physical laboratory						3		
Technical writing		1)						
House building	2			3				
Mineralogy							4	
Crystallography					4			
Surveying 2)			1	2				
Surveying 3)					3	3	2	3
a. Construction engineering			2					
b. Steel and timber constructions					2			2
Material testing					1	2		
Inorganic chemistry	3		3					
Analytic chemistry	1		1					
Mechanic technology	2		1	1				
Machine elements	1	1	4	4		3		
“Machine teaching”					2			

Mining machines					2 5)			
Power engines							2	
Bookkeeping	1	2						
"Samaritan course"		4)						
Courses	**5th semester**		**6th semester**		**7th semester**		**8th semester**	
	Lectures	**Exercises**	**Lectures**	**Exercises**	**Lectures**	**Exercises**	**Lectures**	**Exercises**
Social economy, law, financial science and statistics	4	1	4					
Mining 6)	2							
Mining 7)	4	1	2	1	4	1	2	1
Mining law 7) 9)	1							
Mining measuring 7) 8)					1	1		
Mineral processing	3		3		3			
Mineral processing laboratory		10)		10)		10)		10)
Geology 11)	4		4		4		4	
Ore geology 12)	4		4		4		4	
Petrography 11)							1	1
Rock microscopy			1 9)					
Metallurgy	4		4		4			
Metallurgical laboratory		10)		10)		10)		10)
Electrical engineering	2		2					
Electrical engineering laboratory				3				
Physical chemistry and electrochemistry 6)					1		1	
Mining machines	2 **13)**	6		3				

Notes:

1) By appointment

2) For the students who specialise in metallurgy as majors. Hereto ca. 5 days practical exercises

3) For the students who specialise in mining and mineral processing or geology and ore geology. Hereto ca. 5 weeks practical excersises in the field during holidays between 4th and 5th semester

4) Ca. 10 hours in semester

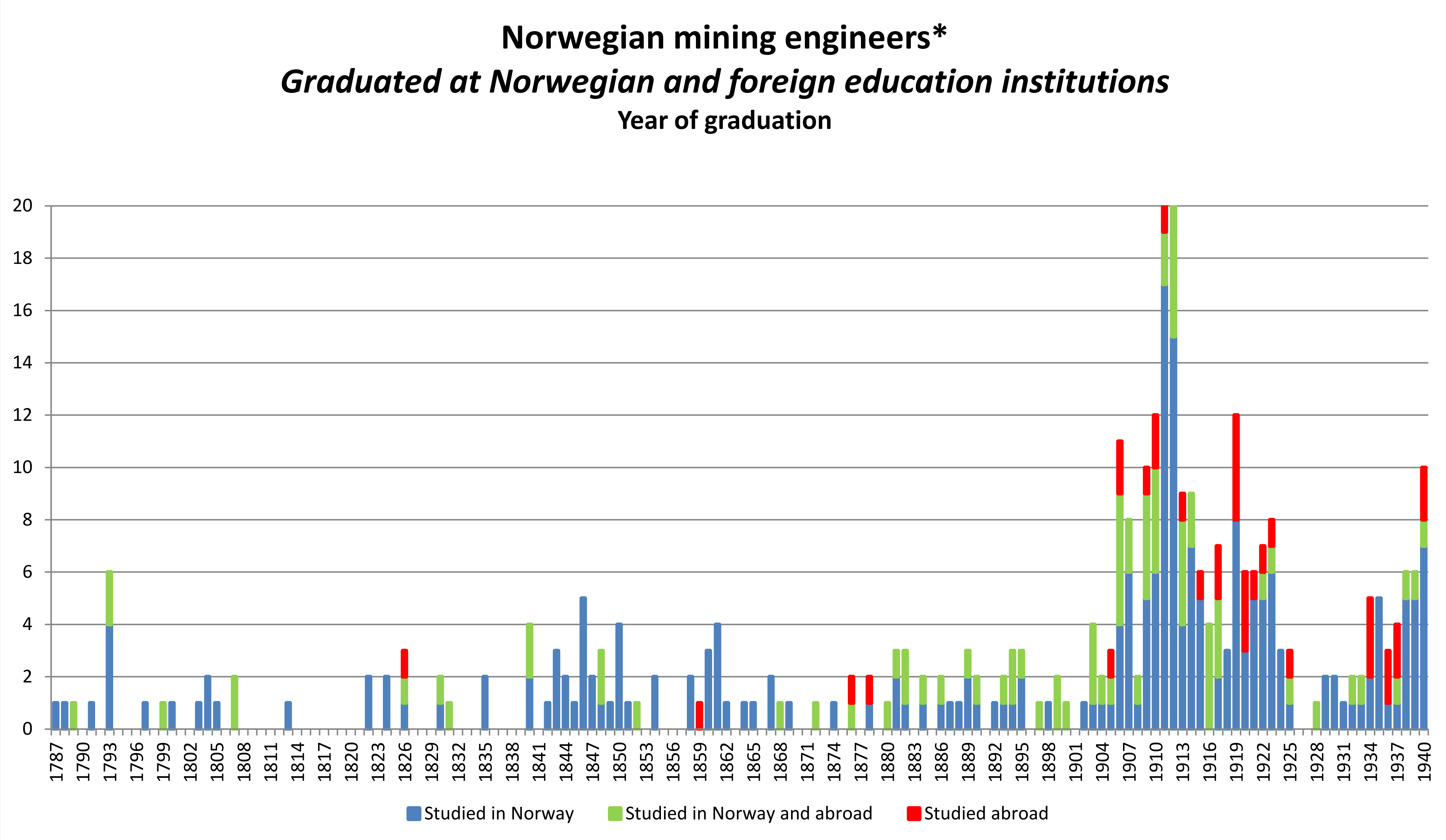
5) Joint lectures for 3rd and 5th semester

6) Every two years for the students who specialize in metallurgy

7) For the students who specialize in mining and mineral processing or geology and ore geology

8) Every two years, 1940-1942 etc. joint lectures for 3rd and 4th year
9) Every two years, 1939-1941 etc. joint lectures for 3rd and 4th year
10) By appointment for the students who specialize in mining and mineral processing or geology and ore geology; in general ore dressing laboratory, for the students who specialize in metallurgy; in general metallurgical laboratory
11) Every two years, 1939-1940, 1941-1942 etc. joint lectures for 3rd and 4th year
12) Every two years, 1940-1941, 1942-1943 etc. joint lectures for 3rd and 4th year
13) Joint lectures for 3rd and 5th semester
Source: Den Tekniske Høiskole i Trondhjem. *Program for Studieåret 1939-1940*. Trondhjem: A/S Centraltrykkeriet Ellewsen & Co, pp. 63-64

Appendix 11. Norwegian mining engineer graduates



*The Norwegian engineers who studied abroad is based on *Ingeniørmatrikkelen* by Bjarne Bassøe, who based his lists on a register from the Ministry of Education from 1952

and registers from foreign institutions. Some institutions might have accepted Norwegians without high school and some Norwegians completed high school abroad. According to Bassøe these are very few and probably all of the engineers are included. Foreigners who graduated at Norwegian institutions and later worked in the Norwegian mining industry are included, but they were also few.
Sources: Artiummatrikler studentene [student yearbooks] (1855-1940): Kristiania/Oslo; Eskedal, L. (1975): BTS-matrikkelen Ingeniører uteksaminert ved Bergen Tekniske Skole 1875-1975. Bergen: A.s John Grieg; Gløersen, J. (1932): Biografiske Oplysninger om Kandidater med eksamen fra Bergseminaret på Kongsberg. Oslo: Den norske ingeniørforening; Bassøe, B. (1961): Ingeniørmatrikkelen Norske Sivilingeniører 1901-55 med tillegg. Oslo: Teknisk Vekeblad; Brochmann, G (red.) (1934): Vi fra NTH de første 10 kull: 1910-1919. Stavanger: Dreyer; Amundsen, O. (1950): Vi fra NTH de neste 10 kull: 1920-1929. Oslo: Dreyer.

Appendix 12. Mining engineering study programs in Chile, selected years

Mining instruction 1859 at the University of Chile

Year 1859	
Courses	
1st year	Mathematics (superior algebra, spherical trigonometry, three dimensional geometry, descriptive geometry)
2nd year	Mineral chemistry Physics Mathematics
3rd year	Docimasy Mineralogy Geology Measuring of mines Topography
4th year	Mechanics Exploitation of mines Laboratory analysis

Source: *Anales de la Universidad de Chile* [Annals of the University of Chile] (1859): Santiago: Universidad de Chile, p. 977

Year 1889	
Courses (every course 6 hours)	
1st year	Analytic geometry (2 and 3 dimensions) Superior algebra Differential and integral calculus Descriptive geometry (and applications) Drawing and graphic work

2nd year	Rational mechanics and theoretic hydraulic Topography, theoretic part (1st semester) Topography, instruments and practice Topography (2nd semester) Sternotomy General physics General chemistry Drawing, graphical work and practice
3rd year	Machines (specially applied to mines) Mineralogy and use of blowtorch Industrial physics, technology and analytic chemistry Astronomy and geodesy Drawing, graphic work and practice
4th year	Construction materials and general construction General and applied geology Docimasy, industrial and analytic chemistry Exploitation of mines, 1st part (measuring and tillage) Drawing, graphic work and practice
5th year	General construction (2nd part) Accounting General metallurgy Exploitation of mines, 2nd part (mechanic preparation) Special metallurgy Political economy and administrative law: mining law Analytic chemistry Drawing, graphic work and practice

Source: *Anales de la Universidad de Chile* [Annals of the University of Chile] (1889): Santiago: Universidad de Chile, pp. 49-51

Year 1908				
Courses	**Weekly hours**			
	1st year		**2nd year**	
	Lectures	**Exercises**	**Lectures**	**Exercises**
Analytic geometry of two and three dimensions	4 ½	9		
Descriptive geometry and its applications	4 ½			

Superior algebra	3			
General physics	3			
General chemistry	3	3		
Freehand drawing		6		
Differential and integral calculus			3	
Rational mechanics and application of geometry (“grafostatica”)			3	
General physics (heat, electricity and magnetism)			3	
Physical chemistry and electrochemistry (1st part)			2	
Analytic chemistry (1st part)			1	
Mineralogy			3	
Topography			3	

Courses	Weekly hours					
	3rd year		4th year		5th year	
	Lectures	Exercises	Lectures	Exercises	Lectures	Exercises
General construction (1st part) and technology	3					
Industrial physics and electrical engineering	3	3				
Material resistance (1st part)	3					
Geology	3					
Physical chemistry and electrochemistry (2nd part)	3					
Nomography	1 ½					
Electrical engineering			3	3		
Material resistance (2nd part)			4			
Machines (1st part)			3			
Analytic chemistry (2nd part) and docimasy			1			
Industrial chemistry			2			
Metallurgy (1st part)			3			
Mining exploitation (1st part)			3			

Architecture					3	
Machines (2nd part)					3	
Project formation and budgets					1	
Administrative law, legislation and economy					3	
Mining laws					1	
Mining exploitation (2nd part)					3	
Special metallurgy and electro metallurgy					4 ½	

Source: *Anales de la Universidad de Chile* [Annals of the University of Chile] (1908): Santiago: Universidad de Chile, pp. 364-366

Year 1919						
Courses	**Weekly hours**					
	1st year		**2nd year**		**3rd year**	
	Lectures	**Exercises**	**Lectures**	**Exercises**	**Lectures**	**Exercises**
Plane geometry and superior algebra (1st part)	4					
Space and descriptive geometry	4	4				
Plane and spherical trigonometry and analytic geometry (1st part)	5					
Cosmography	2					
General physics (1st part)	3	4				
General chemistry (1st part)	3	4				
Drawing (1st part)		4				
Superior algebra (2nd part)			3	1		
Descriptive geometry (2nd part) and its applications			3	4		
Analytic geometry (2nd part)			4	1		
General physics (2nd part)			3	4		
General chemistry (2nd part)			3			
Qualitative analytic chemistry			1	4		
Mineralogy and geology			3	2		
Drawing (2nd part)				2		
Accounting			1			
Differential and integral calculus					3	1

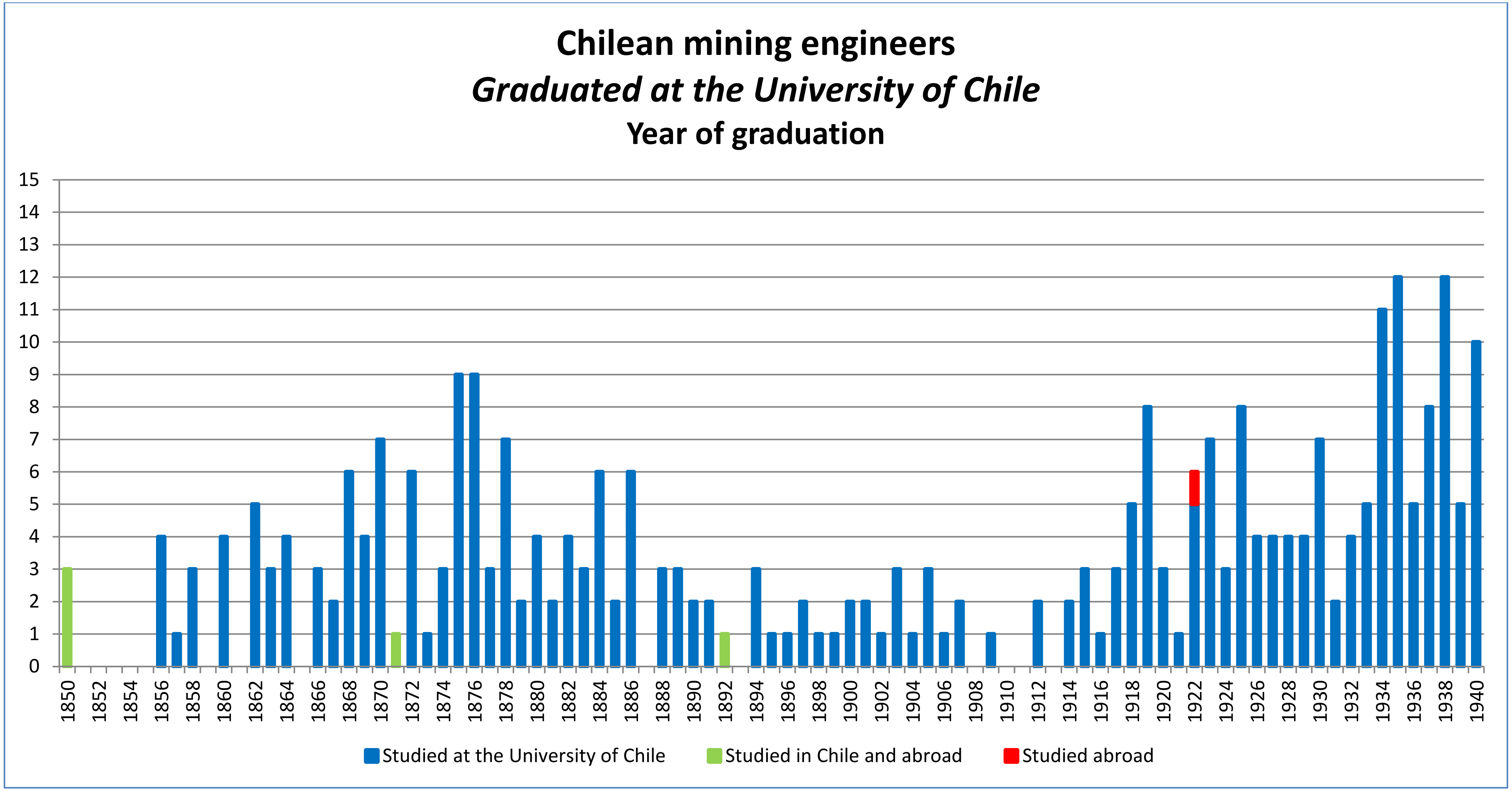
Rational mechanics					4	4
General physics (3rd part)					4	4
Physical chemistry and electrochemistry					2	1
Quantitative analytic chemistry					1	6
Topography (1st part)					2	1
General construction (1st part)					2	1
Workshop						3

Courses	**Weekly hours**					
	4th year		**5th year**		**6th year**	
	Lectures	**Exercises**	**Lectures**	**Exercises**	**Lectures**	**Exercises**
Material resistance (1 semester)	4	4				
Industrial physics	2	3				
Industrial chemistry (1st part)	2	1				
Docimasy (1st part)	1	6				
Topography (2nd part)	2	2				
Machines (1st part)	3	3				
Mining exploitation (1st part)	3					
Metallurgy (1st part)	3	6 evenings per year				
Mineralogy (1st part) and use of blowtorch	3	1				
Geology (1st part)	3	1				
Industrial architecture			3	2		
Docimasy (2nd part)			1	3		
Machines (2nd part)			3	4		
Mining exploitation (2nd part)			3	10 days per year		
Metallurgy (2nd part)			2	2		
Electro engineering			3	4		
Saltpetre technology			2	1		
Industrial chemistry (2nd part)			2	1		
Geology (2nd part), economy			2	1		
Mineralogy (2nd part), applications on microscopic petrography				2		
Machines (3rd part)					3	4
Metallurgy (3rd part)					1	6 evenings per year

Geology (3rd part), South America and paleontology					2	2
Mineralogy (3rd part), applications on petrographic microscopy						2
Steel industry					3	2
Transport: railways, roads and air cables					2	2
Political economy					2	
Legislation and administration					3	
Preparation of foundations, specifications and mining budgets						2

Source: *Anales de la Universidad de Chile* [Annals of the University of Chile] (1919): Santiago: Universidad de Chile, pp. 924-928

Appendix 13. Chilean mining engineer graduates



Sources: Album Histórico de la Escuela Univ. de Minas de Copiapó 1857-1950 (1950): Santiago; Boletin de la Sociedad Nacional de Minería [Bulletin of the National Mining Society] (1893): Santiago: Sociedad Nacional de Minería, p. 63; Egresados de Ingeniería Civil de Minas Universidad de Chile 1856-2003 (Santiago, 2003): Fundacion de Ingenieros de Minas de la Universidad de Chile; Domeyko, I. (1872): "Reseña de los trabajos de la Universidad desde 1855 hasta el presente", in Anales de la Universidad de Chile (October 1872), pp. 576-577; Compañía de Minas Beneficiadora de Taltal (1924): Memoria, segundo semestre 1923. Valparaíso.

Appendix 14. Mining engineers employed at mining companies in Norway, late eighteenth century to 1940

Arranged alphabetically by company

Number of mining engineers	Year employed	Company				
		Name	Number of workers*	Year of establishment	Nationality	Production
3	1904-1906	Alten Copper Mines	300 (max.)	1826-1878 and 1896-1909	English/Swedish	Iron/copper
1	1892	Astrup Copper Mines				Copper
5	1850s-60s-1918	Bamle Apatite Mines	75 (max.)		Norwegian/French	Apatite
5	1859-1919	Bamle Nickel Works	129 (max.)	1859-1884 and 1916-1919	Norwegian	Nickel
20	Continously	Big Norwegian Spitsbergen Coal Company	Around 590 (max.)	1916	Norwegian	Coal
4	After 1890-1914	Birtavarre Copper Works Ltd.	155 (max.)			Copper
16	Continously	Bjørkåsen Mines	448 (max.)	1917	German	Copper/pyrite
2	1898	Blika Mines	11	1882-1901	French	Copper/silver/pyrite
5	1820s-1898	Blue Colour Works	1300-1400 (max.)	1776 (to 1898)	Norwegian	Cobolt
1	Early nineteenth century	Bolvik (Volds) iron Works		1692 (to 1865)	Norwegian	Iron
2	1897 and 1930s	Bossmo Mines	250 (max.)	1894-1938		Pyrite
3	1927-1938	Bremanger Power Works Electric Iron Plant		1928		
1	1869	Bøilestad Copper Works (Arendal Mining and Smelting Co. Ltd)	147 (max.)	1866-1882	Foreign	Copper
2	1890s-1898	Christiania Mine Company	7 (max.)			
3	1920s	Christiania Nail Works**	Thousands	1853	Norwegian	Steel
3	1916-1918	Dalen Mines Ltd.				
3	1900s-1930	Dunderland Iron Mine	374 (max.)	1902	British	Iron
1	1897	Eidsvoll Gold Works	28	1758-1908		Gold
1	1912	Electro Steel Works in Jøssingfjord				Steel
6	1913-1918	Elektrokemisk Ltd.	Thousands	1904	Swedish/Norwegian	Steel
13	Continously	Evje Nickel Works(sold to Falconbridge Nickel Works in 1929)	350 (max.)	1872-1894 and 1908-1920	Norwegian/English	Nickel
16	From 1829	Folldals Works	371 (max.)	1748	Norwegian	Copper
4	1905-1934	Fosdalen Mines	123 (max.)			
2	Early nineteenth century	Fritsø Iron Works	67 (max.)	1640 (to 1868)	Norwegian	Iron
1	1898	Glomsrudkollen Zink Mines				Zink
3	1862-early twentieth century	Grimelien Copper Works	50	1862-1883	Norwegian	Copper
7	Early twentieth century	Grong Mines	Around 100	1912	Norwegian	Pyrite
4	1916-1920	Gursli Molybden Mines	147 (max.)	1915-1919	Norwegian	Molybden
5	1898-1910	Hadeland Mining Works	77 (max.)			Zink
1	Early nineteenth century	Hakadal Iron Works	70 (max.)	1550 (to 1869)	Norwegian	Iron
1	1912	Hardanger Electrical Iron and Steel Works		1909		
1	1868	Hardanger Iron			Norwegian	Iron
1	1927	Haugsvik Smelting Works		1926	British	Aluminium
1	1862	Holtaalens Copper Works				
5	1910s-1938	Hosanger Nickel Works	86 (max.)			Nickel
1	1938	Humblen Limestone Mine	23			Limestone
1	1910s	Hundholmen Feltspat Mine				
1	1910s	Hæstad Mines				
1	1920s	Høiåsen Mines	18 (max.)	Restart 1917		Nickel
2	1927-1933	Ila and Lilleby Smelting Works		1936 (1906 and 1927)		Carbide
1	1913	Ilen Smelting Works				Carbide

1	1910s	Iron Mine in Beitstaden				Iron
2	1872-1904	Jalsberg Works	170	Before 1870		Lead/zinc
5	1910s-1939	Killingdal Mines	240 (max.)	1674	Norwegian/English	Copper/pyrite
4	1913-1932	Kings Bay Coal Mines	160 (max.)	1916	Norwegian	
7	1903-1933	Kjøli Mine	105 (max.)	1766-1798,1857-68, 1896-1907, 1910-1940		Copper/pyrite
1	1920s	Kjørholt Limestone Mine	77 (max.)			
75	Continously	Kongsberg Silver Works	Around 370 (max.)	1623	Norwegian (public)	Silver
1	Around 1919	Kristian Gave Copper Works	4			Copper
16	Continously	Kristiansand Nickel Refinery (Falconbridge Nickel Works)	577 (max.)	1910	Norwegian/Canadian	Nickel
2	Early 1910s	Kvina Mines	27			
2	1910s-1925	Kvikne Mining Company				
1	1883	Kristiansund Mining Plant				
1	1930s	Laksådalen Molybden Mines	67 (max.)	1937		
1	1910s	Landfald Mine				
1	1910s	Langø Iron Mines	11	1609-1665 and 1882-1921		Iron
1	1867	Lindviken Pyrite Mines	23 (max.)	Before 1866		Pyrite
24	From late nineteenth century	Løkken Works (Orkla)	670 (max.)	1652	Norwegian; Swedish from 1904	Copper/pyrite
8	1906-1919	Meraker Mines	75 (max.)	1761-1920	Norwegian/German/ Belgian	Copper/pyrite
1	1928	Mines and Ore Ltd.				
2	1910s	Mining Company Dovre				Pyrite
1	1916	Molsaa Pyrite Mines				
1	1850	Neskilen Iorn Mines (Fossum Iron Works)	47 (max.)	End of seventeenth century (to end of nineteenth century)	Norwegian	Iron
1	1874	Norderhov Nickel Works	5			
1	1933	Nordic Aluminium Industry (Norwegian Aluminium Company)				Aluminium
2	1903 and 1920	Nordic Mining Company Ltd.	43 (max.)	1902	Swedish	
6	1928-1935	Northern Norway Mining Company (bergverkselskapet «Nord-Norge»)				
1	1899	Norway Mining Company Ltd. (Bergverksaktieselskapet Norge)	85 (max.)			
6	1910s-1938	Norwegian Aluminium Company (NACO)	Around 1000	1916	Norwegian/North American	Aluminium
1	1919	Norwegian Electrical Metal Industry				
1	1917	Norwegian Electrical Steel Works		1916-1917		
2	1920-1930s	Norwegian Metallurgical Company				
1	1909	Norwegian Mining Company Ltd. (A/S det norske bergselskap)				
1	1880	Norwegian Mining Company (Norske gruvekompanis feldstapt og apatitgruver)				Feldspar
1	1930s	Norwegian Feldspat Company Ltd.				Feldspar
1	1921	Norwegian Steel Ltd.		1823	Norwegian	Steel
2	1820s and 1937	Næs Iron Works	114 (max.)	1665	Norwegian	Iron
3	1907-1917	Ofoten Ore				
5	1924-1929	Porsa Copper Mines	72			Copper
1	1917	Porsgrund Electrometallurgical Ltd.		1913	Swiss	Steel

1	1910s	Ramsaas Nickel Works				Nickel
1	1908	Ranen Lead and Silver Works	6			
3	1909-1938	Rausand Mines	142 (max.)			
10	Continously	Ringerike Nickel Works	261 (max.)	1849-1920	German	Nickel
1	1872	Rom Nickel Works	100	1866-1876	Norwegian	Nickel
1	1911	Rødfjellet Pyrite Mines	46	1911-1920		Pyrite
1	1918	Røen Mine				Crome
1	1916	Røragen Chrome Iron Mines				
52	Continously	Røros Copper Works	700 (max.)	1644	Norwegian	Copper
6	1909-1920s	Røstvangen Mines	201 (max.)	1904-1921	Swedish	
1	1910	Salangen Mining Company	259 (max.)	1907	German	259 (max.)
1	1910s	Sargijok Gold Company				
2	1881-1885	Senjen Nickel Works	430 (max.)	1872-1886		Nickel
1	1875	Sigdal Nickel Works	39 (max.)	1874-1879	Norwegian	Nickel
3	1910s-1936	Skaland Graphite Works	45	1917	Norwegian	Graphite
1	Early twentieth century	Skandia Copper Works		1906		Copper
1	1890s	Skara Silver Mines (Kongsberg Silver Works)	60-70	1769-1782 and1789-1810, closed 1892		Silver
1	Early twentieth century	Skorovas Pyrite Mines			Norwegian	Pyrite
1	1910s	Smorten Iron Mines				
2	1919	Stavanger Electro Steel Works		1911		Steel
11	Continously	Stordø Pyrite Mines	367 (max.)	1907	Norwegian (public)	Pyrite
1	1907	Storolva Pyrite Mines				Pyrite
1	1908	Storvold Mines				
20	Continously	Sulithjelma Mines	1750 (max.)	1887	Swedish/Norwegian	Copper/pyrite
3	1911-1919	Svanøe Pyrite Mines	Around 100	1870s-1923	Norwegian	Pyrite
2	1879-1880	Svenningdal Mines	50-60	1876-1900	Norwegian	Silver
13	Continously	Sydvaranger Mine Ltd.	1570 (max.)	1906	German/Norwegian	Iron
2	1910s	Tinfoss Iron Works	34 (max.)	1910		Iron
4	1918-1939	Titania Ltd.	142 (max.)	1902	Norwegian	Iron
1	1910s	Trollerud Silver Works				
1	Late nineteenth century	Tronsli Mining Company	13	1884- around 1910		Copper
9	Continously	Vigsnes Copper Works	678 (max.)	1865	French	Copper
13	1910s-1930	Åmdal Copper Works	400 (max.)	1691	Foreign	Copper
9	1918-1940	Ørnehommen Molybden Mines Ltd. (Knaben Molybden Mines Ltd.)	391 (max.)	Before 1885	English	Molybden
8	After 1805-1926	Ulefos Iron Works	373 (max.)	1657	Norwegian	Iron
1	1917	Undal Works	22 (max.)	1865		
1	1917	Vadda Mines Ltd	69 (max).	1914	Swedish	Copper
1	Early twentieth century	Varaldsø Pyrite Mines	8			Pyrite
2	1910s	Vaterfjord Molybden Mines				
1	1874	Vegaardshei Apatit Mine				Apatite
1	1910s	Vingelen and Foss Mine in Østerdalen				
4	1871-1918	Vinoren Silver Works	75 (max.)	Before 1866	Norwegian	Silver
2	1877-1910s	Værdalen Nickel Works	100 (max.)			
1	1861	Ytterøen Works (the Norwegian Pyrite Company)	217 (max.)	1635-1912 (closed down several times)	Norwegian/English	Copper/pyrite
2	1910s	Åsåren Copper Mine		seventeenth century		Copper

*These are approximate numbers including functionaries
**Christiania Nail Works produced steel, but elaborated products (nails) which are strictly not part of mining.
Sources: Sources: *Artiummatrikler studentene* [student yearbooks] (1855-1940): Kristiania/Oslo; Norges offisielle statistikk (1866–1940): *Norges Bergværksdrift.* Kristiania/Oslo: Statistisk sentralbyrå; Eskedal, L. (1975): *BTS-matrikkelen Ingeniører uteksaminert ved Bergen Tekniske Skole 1875-1975.* Bergen: A.s John Grieg; Gløersen, J. (1932): *Biografiske Oplysninger om Kandidater med eksamen fra Bergseminaret på Kongsberg*. Oslo: Den norske ingeniørforening; Bassøe, B. (1961): *Ingeniørmatrikkelen Norske Sivilingeniører 1901-55 med tillegg*. Oslo: Teknisk Vekeblad; Brochmann, G (red.) (1934): *Vi fra NTH de første 10 kull: 1910-1919*. Stavanger: Dreyer; Amundsen, O. (1950): *Vi fra NTH de neste 10 kull: 1920-1929*. Oslo: Dreyer.

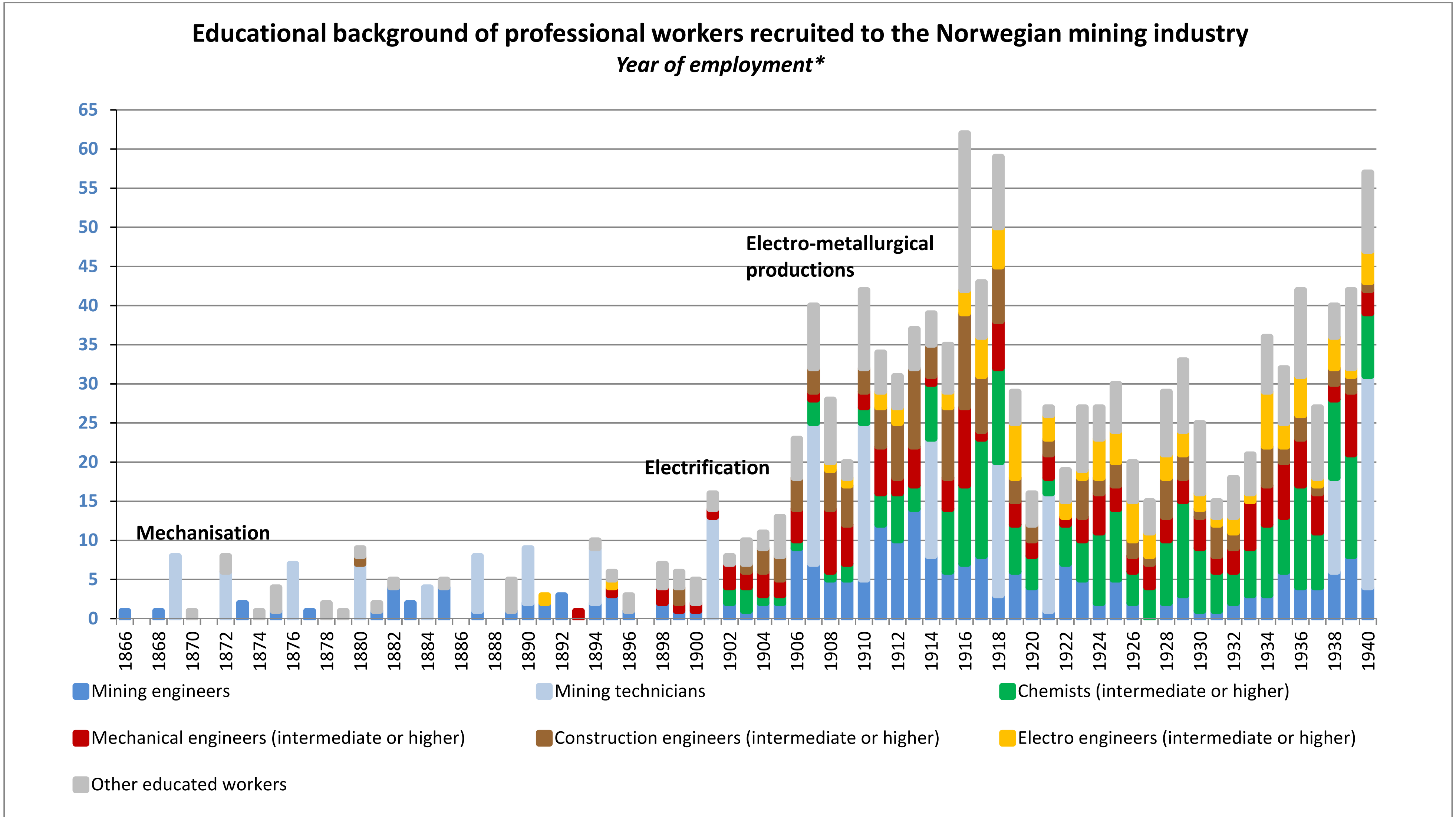
Appendix 15. Mining technicians employed at mining companies in Norway, late nineteenth century to 1940

Number of mining technicians	Year employed	Distributed on the following companies
8 {	1869	Kongsberg Silver Works
		Røros Copper Works
		Ulefos Iron Works
		Vinoren Silver Works
6 {	1872	Kongsberg Silver Works
		Røros Copper Works
		Ulefos Iron Works
7 {	1876	Kongsberg Silver Works
		Røros Copper Works
		Ulefos Iron Works
7 {	1880	Kongsberg Silver Works
		Røros Copper Works
		Ulefos Iron Works
4 {	1884	Kongsberg Silver Works
		Røros Copper Works
		Ulefos Iron Works
7 {	1887	Kongsberg Silver Works
		Røros Copper Works
		Sulithjelma Mines
		Ulefos Iron Works
7 {	1890	Kongsberg Silver Works
		Røros Copper Works
		Sulithjelma Mines
		Ulefos Iron Works
7 {	1894	Kongsberg Silver Works
		Røros Copper Works
		Sulithjelma Mines
		Ulefos Iron Works
		Bossmo Mines
13 {	1901	Kongsberg Silver Works
		Røros Copper Works
		Sulithjelma Mines
		Ulefos Iron Works
		Bossmo Mines
		Kjøli Mine
18 {	1907	Kongsberg Silver Works
		Røros Copper Works
		Sulithjelma Mines
		Ulefos Iron Works
		Bossmo Mines
20 {	1910	Kongsberg Silver Works
		Røros Copper Works
		Sulithjelma Mines
		Ulefos Iron Works
		Bossmo Mines
		Kjøli Mine
15 {	1914	Kongsberg Silver Works
		Røros Copper Works
		Sulithjelma Mines
		Ulefos Iron Works
		Bossmo Mines
		Kjøli Mine
17 {	1918	Kongsberg Silver Works
		Røros Copper Works
		Sulithjelma Mines
		Ulefos Iron Works
		Bossmo Mines
		Kjøli Mine
15 {	1921	Kongsberg Silver Works
		Røros Copper Works
		Sulithjelma Mines
		Ulefos Iron Works

		Bossmo Mines
		Kjøli Mine
12 {	1938	Kongsberg Silver Works
		Røros Copper Works
		Sulithjelma Mines
		Ulefos Iron Works
		Bossmo Mines
		Kjøli Mine
26 {	1940	Kongsberg Silver Works
		Røros Copper Works
		Sulithjelma Mines
		Ulefos Iron Works
		Kjøli Mine

Source: Statens bergskole (1966): *Bergskolen 100 år Jubileumsberetning 1866-1966*. Trondheim; Øisang, O. (1942): *Rørosboka: Røros bergstad, Røros landsogn, Brekken og Glåmos kommuner: 3-4: Røros Kobberverks historie,* 2. bind. Trondheim: Rørosbokkomiteen: kommisjon hos Globus-forlaget; Helleberg, O. A. (2000): *Kongsberg sølvverk 1623-1958: kongenes øyesten – rikenes pryd.* Kongsberg: Forlag Langs Lågen i samarbeid med Sølvverkets venner.

Appendix 16. Professional workers employed in the Norwegian mining industry



*In 79 of the cases the exact year of employment in the mining sector is uncertain.

Sources: Alstad, O. (red.) (1916): Trondhjemsteknikernes Matrikel Biologiske meddelelser om samtlige faste og hospiterende elever av Trondhjems Tekniske Læreanstalt 1870-1915. Trondhjem: F. Bruns Boghandel; Artiummatrikler studentene [student yearbooks] (1855-1940): Kristiania/Oslo; Christiansen, H. O. et al. (1937): 25-års jubileumsberetning 1912-1937 Bergen Tekniske Skole Oslo Tekniske Skole Trondheim Tekniske Skole. Norway: Norsk Teknisk Landsforbund; Festskrift i anledning af Kristiania Tekniske Skoles 25 aars jubilæum (1898): Kristiania: J. Chr. Gundersens Bogtrykkeri; Baggethun, R. (1980): Horten Ingeniørhøgskole Horten tekniske skole En beretning om landets eldste tekniske skole gjennom 125 år. Horten: Gjengangerens trykkeri; Heier, S. (red.) (1955): 100 års biografisk Jubileums-festskrift, Horten Tekniske Skole 1855-1955. Horten: A/S Gjengangerens trykkeri; KTS (1946): 50 årsberetning om ingeniørkullet fra Kristiania Tekniske Skole 1896. Oslo; Kristiania tekniske skole (1947): Ingeniørene fra KTS 1897-1947. Oslo; Ingeniører fra Kr.a Tekniske Skole 1897 (1922): Kristiania: A. W. Brøggers Boktrykkeri A/S; K.T.S. ingeniørene av 1909: matrikkel utarbeidet til 25-års jubileet 1934 (1934): Oslo; Oslo Tekniske Skole (1894): Skrift ved 50 års jubileet for ingeniørene fra K.T.S. 1894, Oslo; KTS til Ingeniørkullet av 1910: 20 årsjubileum år 1910-1930 (1930): Oslo; Trondhjems Tekniske Mellomskoles virksomhet i de 3 første læseaar 1912-1915 (1916): Trondhjem: Waldemar Janssens boktrykkeri; Skrift ved 50 års jubileet for ingeniørene fra K.T.S. 1894 (1944): Oslo: Universal-trykkeriet; Eskedal, L. (1975): BTS-matrikkelen Ingeniører uteksaminert ved Bergen Tekniske Skole 1875-1975. Bergen: A.s John Grieg; TTL (1922): 1897-1922. Kristiania: C. Dahls Bok & Kunsttrykkeri; Trondhjem tekniske læreanstalt (1895): Festskrift ved Afslutningen av Trondhjems Tekniske Læreanstalts 25de Læseaar .Trondhjem: Aktietrykkeriet i Trondhjem; Bassøe, B. (1961): Ingeniørmatrikkelen Norske Sivilingeniører 1901-55 med tillegg. Oslo: Teknisk Ukeblad.

Appendix 17. Lack of mining engineers and students in Chile

Articles, reports, comments etc. in the Mining Bulletin in which lack of mining engineering students and engineers is mentioned

Year	Name/title	Subject	Source
1890	Luiz Zegers/mining engineer and professor	Lack of students and engineers in the coal industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1890), p. 419-421
1891	Luis Zegers/mining engineer and professor	Lack of students and engineers in the coal industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1891), pp. 5-6
1891	Augusto Orrego Cortés/consultant	Lack of engineers in the gold industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1891), pp. 6-7
1891	Augusto Orrego Cortés/ consultant	Lack of students	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1891), pp. 18-19
1891	Augusto Orrego Cortés/ consultant	Lack of engineers in the gold industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1891), pp. 40-47
1891	Luis Zegers/mining engineer and professor	Lack of students and engineers in the mining industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1891), pp. 159-163
1891	Luis Zegers/mining engineer and professor	Lack of students and engineers in the mining industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1891), pp. 218-219
1892	Francisco J. San Roman	Lack of students at Mining Schools of Santiago and Copiapó	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1892), p. 16
1892	Carlos Délano	Lack of engineers in the coal industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1892), pp. 175-177
1892	Luis Zegers/mining engineer and professor	Lack of students and engineers in the mining industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1892), pp. 223-228
1892	Luis Zegers and José de Respaldiza	Lack of students and engineers in mining, specifically in the coal industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1892), pp. 264-265
Copies of the Mining Bulletin between 1893 and 1899 are unavailable			
1900	Manuel Antonio Prieto/president of the National Mining Society and O. Ghigliotto Salas/secretary	Lack of engineers in the mining industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1900), pp. 225-234
1900	Manuel A. Prieto/director of Mining Company Arturo Prat and President of the National Mining Society O. Ghigliotto Salas/secretary	Lack of engineers in the mining industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1900), p. 260

1901	Carlos Vattier	Lack of engineers in the mining industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1901), pp. 15-27
1901	The National Mining Society	Lack of engineers in the mining industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1901), pp. 186-191
1903	Eleazar Lezata A./civil engineer	Lack of students and engineers in the industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1903), pp. 418-422
Copies of the Mining Bulletin of 1905 and 1906 are unavailable			
1907	Carlos Besa/president of the National Mining Society O. Ghigliotto Salas/secretary	Lack of engineers in the industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1907), pp. 361-367
Copies of the Mining Bulletin of 1908 and 1909 are unavailable			
1910	John Hays Hammond	Lack of engineers in the industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1910) pp. 110-114
1910	A.Pizarro A./director of mining companies in Atacama and professor Belisario Días Ossa/professor	Lack of students at the University	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1910), pp. 115-122
1911	Ignacio Díaz Ossa/mining engineer and director of the Mining School of La Serena	Lack of engineers in the industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1911), pp. 1-5
1912	Ignacio Díaz Ossa/mining engineer and director of the Mining School of La Serena	Lack of students and engineers in the industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1912), pp. 555-559
Copies of the Mining Bulletin of 1913 - 1915 are unavailable			
1916	Carlos Besa/president of the National Mining Society Osvaldo Martínez/secretary	Lack of students at the Mining Schools and technicians and engineers in the industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1916), pp. 180-201
1918	The National Mining Society	Lack of students and lack of engineers in the mining industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1918), pp. 492-494
1918	The National Mining Society	Lack of engineers in the mining industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1918), pp. 451-487
1919	The National Mining Society	Lack of engineers in the mining industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1919), pp. 841-842
1919	Javier Gandarillas M.	Lack of engineers in the coal industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1919), pp. 843-844

1919	Javier Gandarillas M.	Lack of engineers in the mining industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1919), pp. 857-858
1919	Mining engineer at the University of Chile	Lack of engineers in the copper industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1919), pp. 391-412
1920	I.R. Finla	Lack of engineers in the mining industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1920), pp. 241-259
1920	Pope Yeatman/consultant and mining engineer at Braden Copper Company	Lack of engineers in the mining industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1920), pp. 250-
1921	The National Mining Society	Lack of engineers in the mining industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1921), pp. 626-631
1921	Berth Koerting/professor	Lack of engineers in the mining industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1921), pp. 632-641
1922	George Otis Smith	Lack of engineers in the coal industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1922), pp. 477-480
1922	Javier Gandarillas M./president of the National Mining Society Olvaldo Martínes C./secretary	Lack of students and engineers in the industry	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1922), pp. 455-464
1923	The National Mining Society	Lack of scientific knowledge	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1923), pp. 499-502
1925	The National Mining Society	Lack of engineers in mining	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1925)
1925	The National Mining Society	Lack of mining engineers and geographers	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1925), pp. 307-311
1925	The National Mining Society	Lack of mining engineers in the mining sector	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1925), pp. 663-665
1925	The National Mining Society	Lack of mining engineers in the mining sector	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1925), pp. 745-746
1926	Germán Nienhüser/secretary of the Corps of Mining Engineers	Lack of mining engineers	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1926), pp. 4-7

1930	The National Mining Society	Lack of mining engineers	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1930), pp. 581-582
1930	National Institute of Mining Engineers	Lack of mining engineers	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1930), pp. 637-638
1931	The National Mining Society	Lack of mining enigneers	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1931), pp. 8-14
1931	Mining and Petroleum Department	Lack of mining engineers and geologists	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1931), pp. 352-364
1931	The National Mining Society	Lack of mining engineers	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1931), pp. 659-662
1931	National Institute of Mining Engineers	Lack of mining engineers	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1931), pp. 673-675
1933	The National Mining Society	Lack of mining engineers	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1933), pp. 387-391
1933	The National Mining Society	Lack of mining engineers and geologists	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1933), pp. 392-394
1934	The National Mining Society	Lack of mining engineers and geologists	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1934), pp. 72-74
1934	The National Mining Society	Lack of mining engineers and geologists	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1934), pp. 119-122
1934	The National Mining Society	Lack of mining engineers	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1934), p. 672
1935	National Institute of Mining Engineers	Lack of mining engineering students	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1935), p. 246
1935	Jorge Muños Cristi/professor and mining engineer	Lack of mining engineers	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1935), pp. 403-404
1936	National Institute of Mining Engineers	Lack of mining engineers	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1936), p. 379
1936	The National Mining Society	Lack of mining engineers	*Boletín de la Sociedad Nacional de Minería*

			(Santiago, 1936), pp. 605-607
1937	National Institute of Mining Engineers	Lack of mining Engineers	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1937), pp. 1599-1600
1939	Credit Bank of Mining	Lack of mining engineers and scientists	*Boletín de la Sociedad Nacional de Minería* (Santiago, 1939), p. 310

Sources: *Boletin de la Sociedad Nacional de Minería* [Bulletin of the National Mining Society] (1890-1940): Santiago: Sociedad Nacional de Minería.

Appendix 18. Mining engineers employed at mining companies in Chile, late nineteenth century to 1940

Arranged alphabetically by company

Number of mining engineers	Year employed	Company				
		Name	Number of workers*	Year of establishment	Nationality	Production
2	1880s	Arturo Prat Mining Company	Pirquen	Before 1883	Chilean	Silver
1	1920s	Betlehem Chile Iron Company		1913	North American	Iron
1	1920s	Chilean German Dutch Algarrobo Iron Company		1914	Chilean/German/Dutch	Iron
1	1870s	Coal Company of Magallanes	120 (max.)	Before 1872	Chilean	Coal
1	1920s	Coal Company Parga			Chilean	Iron
2	Mid-nineteenth century	Company of José Tomás Urmeneta	7 150 (max.)	Mid-nineteenth century	Chilean	Copper
1	1923	Company of Lora				
3	1870s	Descubridoras Minas of Caracoles	Pirquen	Before 1872	Chilean	Various minerals
1	Before 1942	Gold Company Rosario de Andacollo			Chilean	Gold
1	Early twentieth century	Iron Company of Coquimbo		Before 1913	Chilean	Iron
1	Early twentieth century	Iron Company Totoral		Before 1905	Chilean	Iron
2	Late nineteenth century	Llahuín Company		Before 1887	Chilean	Gold
4	Late nineteenth century-1923	The Coal Company of Lota	10 000 (7 000 at the mines) (max.)	1852	Chilean	Coal
1	Early twentieth century	Mining Company Andacollo		Before 1907	Chilean	Gold
1	1920s	Mining Company Chañaral		Before 1920		
2	1930s	Mining Company Chañaral and Taltal		Before 1930	Chilean	Gold
2	Early twentieth century	Mining Company Collahuasi		Before 1907	English	
1	1880s	Mining Company Desengano		Before 1886	Chilean	A number of metal
1	Early twentieth century	Mining Company Domeyko		Before 1918	Chilean	A number of metal
3	Before 1888-1920s	Mining Company Emma Luisa of Guanaco		Before 1888	Chilean	Various minerals
1	Early twentieth century	Mining Company Juan Godoy			Chilean	Silver
1	1920s	Mining Company Las Condes		Before 1924	Chilean	Copper
3	1920s-1930s	Mining Company Las Vacas		Before 1889	Chilean	Gold
1	1870s	Mining Company Los Bronces	Pirquen	Before 1887	Chilean	Various minerals
1	1870s	Mining Company San Agustin		Before 1905		
2	1910s-1920s	Mining Company Taltal	Pirquen	Before 1902	Chilean	Silver
1	Late 1930s	National Company of Petroleum				
1	Late nineteenth century	Playa Blanca in Antofagasta				
1	1922	Rio Blanco Copper Corporation		1924	North American	Copper

*These are approximate numbers

Sources: *1ª memoria de la Compañía Minera Las Condes* (1924): Santiago: Librería "El Mercurio"; *Anales de la Universidad de Chile* [Annals of the University of Chile] (1843-1940): Santiago: Universidad de Chile; Astorquiza, O. (1942): *Compania Carbonifera e industrial de Lota 1852-1942*. Valparaíso: Imprenta y Litografía "Universo" S.A.; *Boletin de la Sociedad Nacional de Minería* [Bulletin of the National Mining Society] (1890-1940): Santiago:

Sociedad Nacional de Minería; Compañía Aurífera Rosario de Andacollo (Agosto 1942): *5ª memoria*. Santiago: Imp. Lathrop; Compañía minera de Chañaral y Taltal (1937-1942): *Décima septima memoria y balance*. Santiago: Imp. "Wilson"; Compañía de Minas Beneficiadora de Taltal (1903-1940): *Memorias*. Valparaíso; Compañía Esplotadora de Los Bronces (1887): *Memoria correspondiente al primer periodo de la negociación, terminado el 30 de junio de 1887*. Santiago: Imprenta Cervantes; Compañía Minera de Andacollo (1907): *Memoria sobre la visita a las Minas*. Santiago: Imprenta "Rápida" S. Torres & Co; Compañía Minera de Chañaral (1925): *Memoria y balance*. Santiago: Imprenta y Litografía "La Ilustración"; Compañía Minera de Gatico (1905): *Memoria*. Santiago: Imprenta y Encuadernación "La Union"; Compañía Minera de Llahuín (1887): *Memoria*. Santiago: Imprenta de "El Progreso"; Compañía Minera "Poderosa" de Collahuasi (1905): *I Memoria del Directorio Balance al 30 de junio de 1905*. Valparaíso: Sociedad "Imprenta y Litografía Universo; Compañía Minera Domeyko (1920): *Cuarta memoria*. Santiago: Imprenta, Litografía y Encuadernación "La Ilustración"; Domeyko, I. (1872): "Reseña de los trabajos de la Universidad desde 1855 hasta el presente", in *Anales de la Universidad de Chile* (October 1872); Sociedad Minera "Desengano" (1883): *Reseña de la marcha de la negociación durante el primer semestre de abril a septiembre de 1886*. Santiago: Imprenta de "el independiente"; Descubridoras de Caracoles (1872): *Memoria*. Santiago: Imprenta de "El Ferrocarril"; Empresa Minera "Monte Blanco" (1907 and 1913): *Memorias*. Santiago: Imprenta, Litografía y Encuadernación Barcelona; Escuela de Minas de Copiapó (1957): *Boletin Centenario Escuela de Minas de Copiapó 1857-1957*. Santiago: Impr. Artes y Letras; Gran Compañía Arturo Prat (1883-1921): *Memorias*: Santiago; *Informe presentado por el que suscribe al consejo directivo de la Sociedad Carbonífera de Magallanes sobre el reconocimiento i estudio de los Depósitos carboníferos existentes en el territorio de Magallanes* (1872): Santiago: Imprenta de "El Ferrocarril"; La Compañía Minera "Las Vacas" (1914-1935): *Informes*. Valparaíso; Millán, A. U. (2004): *La minería metalica en Chile en el siglo XIX*. Chile: Editorial Universitaria; Michell Villalón, R. (1931): *Compañía Minera "Juan Godoy"*. Santiago; Minas Descubridoras de Caracoles (1874): *Memoria*. Valparaíso; Muñoz Maluschka, E. (1987): *Andina Historia del nacimiento de una mina*. Santiago: Salesianos; Nazer Ahumada, R. (1993): *José Tomás Urmeneta. Un empresario del siglo XIX*. Chile: Centro de Investigaciones Diego Barros Arana; Peña i Lillo, O. (1928): *Monografia sobre el mineral de fierro de "El Tofo" que explota la Bethlehem Chile Iron Mines Company en la provincia de Coquimbo*. Santiago: Soc. Imprenta y Lit. Universo; Sociedad Minera Emma Luisa del Guanaco (1888-1903): *Séptima memoria*. Santiago: imprenta "Santiago"; Villalobos, S. et al. (1990): *Historia de la ingenieria en Chile*. Santiago: Editorial Universitaria.

Appendix 19. Chilean mining engineers as consultants

Name	Institution	Activity	Year	Source
Paulino Barrio	Ministry	Made reports about the geological formation, technology and extraction, mine and transport systems in the coal industry in Coronel and Lota.	1857	Barrio, Paulio del (1857): *Noticia sobre el terreno carbonífero de Coronel I Lota, I sobre los trabajos de esplotación en él emprendidos*. Santiago: Impr. Nacional.
José Zegers Recasens	Ministry of Finance	Made reports about the guano industry in Tarapacá,	1884	Zegers Recasens, J. (1884): *Memoria presentada al señor ministro de hacienda por el inspector de guaneras de Tarapacá*. Pabellón de Pica, Tarapacá.
Samuel Valdés	Ministry of Interior	Made reports about mining and agriculture	1887	Valdés, S. (1887): *El estudio minero i Agricola*. Santiago: Imprenta nacional.
Rojas Delgado, Matías	Government	Saltpetre industry, Aguas Blancas; made a report to the government about the found deposits.	Around 1870	Villalobos, S. et al. (1990): *Historia de la ingenieria en Chile*. Santiago: Editorial Universitaria, p. 185
Pedro Lucio de la Cuadra		Worked with making topographic and geological maps of Chile. Published books and articles about mining.	1868	Lucio Cuadra, P. (1868): *Apuntes sobre la Geografía Física y Política de Chile*. Santiago: Imprenta nacional.
Augusto Orrego	National Mining Society and the Ministry of Industry and Public Works	Made a report about the gold industry, including a short description of deposits, procedures, techniques and companies. Made another report about the coal industry.	1890	Orrego, A. (1890): *La Industria del oro en Chile, memoria excrita por encargo de la Sociedad Nacional de Minería*, Santiago: Imprenta Nacional.
Luis Zegers	Ministry of Finance and the Departmental Committee of Victoria	Made report about the guano industry, including the analytic operations needed to analyse the mineral. He also made a note about the Andes Mountains.	1875 1883	Zeguers, L. L. And Yañez B., A. (1883): *Guanos, su composición i manera de ensayarlos*. Santiago: Imprenta Nacional. Zegers, L. L. (1875): *Noticia acerca de la Cordillera de Los Andes*. Santiago: Imprenta Nacional. Santiago: Imprenta Nacional.
Augusto Villanueva	Ministry of Finance	Worked with Amadeo Pissis and made reports about Chilean geology. Made reports to the government about saltpeter deposits in northern Chile.	1877-78	Villanueva, A. (1878): *Salitres i guanos del desierto de Atacama*. Santiago: Imprenta Nacional. Villalobos, S. et al. (1990): *Historia de la ingenieria en Chile*. Santiago: Editorial Universitaria, p. 185
Carlos Avalos	National Mining Society	Wrote reports about Chuquicamata mine and other reports about mining.	After 1900	Various articles in the Mining Bulletin
F. A. Sundt	National Mining Society	Wrote a general report on mining and metallurgy in Chile, including transport, mines, foundries, companies, regions, technology etc.	1910	Sundt, F. A. (1910): *Monografías Mineras i Metalúrgicas*. Santiago: Soc. Imprenta y Litografía "Universo".
Oscar Peña y Lillo	Institute of Mining Engineers	Made report on gold processing	1934	Peña y Lillo, O. (1934): *El Beneficio de los Minerales Auríferos por Cianuración*. Santiago: Soc. Imp. Y Litografía Universo.
Mariano Riveros Cruz	Department of Mining and Petroleum	Made analyses of the saltpetre and mining industry	Around 1930	*Boletin minero* (1930), p. 755
Fernando Sepúlveda Veloso	Ministry of Development	Made reports on gold and gold washing, including ore deposits, methods, conditions for extraction etc.	1936	Sepúlveda Veloso, F. (1936): *Lavaderos de oro*. Santiago: Editorial Nascimiento.
Eduardo Ovalle Rodríguez	National Mining Society and Institute of Mining Engineers	Wrote reports about gold operations	1927	*Boletin minero* (1927), p. 23 Ovalle Rodríguez, E. (1934): *Explotación de Minerales de Oro*. Santiago: Soc. Imp. Y Lito. Universo.

Roberto Müller Hess	Credit Bank of Mining	Wrote a report on the possibility for petroleum operation, incluing yealds, information about required machinery, personnel etc.	1939	Müller H., R. (1939): *Proyecto de Refineria de Petroleo del Estado*. Caja de Credito Minero.
Hector Flores W.	National Mining Society	Wrote a report on geology of lead	1944	Flores W., H. (1944): *Antecedentes geologicos sobre los Yacimientos de Plomo*. Santiago: Talleres Graficos "La Nacion" S.A.
Hector Rojas Albornoz	Mining Asociation of Antofagasta	Made a report on mining in Antofagasta	1963	Rojas Albornoz (1963): *Visión Panoramica de la Minería chilena y Antofagastina*. Asociación Minera de Antofagasta.

Appendix 20. Mining technicians employed at mining companies in Chile, late nineteenth century to 1940

Arranged alphabetically by company

Number of mining technicians	Year employed	Company				
		Name	Number of workers*	Year of establishment	Nationality	Production
10	1916-1937	Andes Copper Company (Anaconda Copper Company)	9840 (max.)	1916	North American	Copper
12	1913-1938	Braden Copper Company (Kennecott Copper Company)	More than 9000	1904	North American	Copper
14	1916-1936	Chile Exploration Company (Anaconda Copper Company)	5-6000 (max.)	1912	North American	Copper
1	After 1928	Elisa de Bordos Plant				
4	1904-1940	The Coal Company of Lota	10 000 (max.)	1852	Chilean	Coal
1	After 1916	Mining Company Coquimbo-Atacama				
1	Before 1888	Mining Company Emma Luisa of Guanaco		Before 1888	Chilean	Various minerals
11	After 1912-1940	Saltpetre Company María Elena (Anglo-Chilean Mining Company)		1926	North American	Saltpetre
4	1927-1937	Saltpetre Company Pedro de Valdivia (Lautaro Nitrate Company)		1929	North American	Saltpetre
5	1920-1940	Saltpetre Company Tarapacá and Antofagasta		Late nineteenth century	British	Saltpetre
1	Before 1935	Santa Luisa Works				
2	Before 1935	Smelting Company				

*These are approximate numbers

Source: Prospecto de admision de alumnos para la Escuela de Minas de Copiapó (1935): Santiago: Soc. Imp. y Lit. Universo; Album Histórico de la Escuela Univ. de Minas de Copiapó 1857-1950 (1950): Santiago; Sociedad Minera Emma Luisa del Guanaco (1888): segunda memoria. Santiago: imprenta "Santiago".

Appendix 21. Lack of mining technicians and students in Chile

Articles, reports, comments etc. in the Mining Bulletin in which lack of mining technician students and technicians are mentioned

Year	Name/title	Subject	Source
1890	Ernesto Frick/director of the Mining School of Santiago	Lack of students at the Mining Schools	*Boletin Minero* (1890), pp. 79-82
1890	Buenaventura Osorio/secretary-director of the Mining School of La Serena	Lack of students	*Boletin Minero* (1890), p. 431
Copies of the Mining Bulletin between 1893 and 1899 are unavailable			
1901	The National Mining Society	Lack of mining shools and students	*Boletin Minero* (1901), pp. 283-285
1903	The National Mining Society	Lack of students at the Mining Schools and technicians in the industry	*Boletin Minero* (1903), pp. 219-227
1903	Guillermo Yunge/mining engineer at Mining Company Andacollo	Lack of students at the Mining Schools and technicians in the industry	*Boletin Minero* (1903), pp. 246-258
1903	Eleazar Lezata A./civil engineer	Lack of students and technicians in the industry	*Boletin Minero* (1903), pp. 418-422
1904	Romualdo Silva Prado	Lack of students at the Mining Schools	*Boletin Minero* (1904), pp. 389-390
Copies of the Mining Bulletin of 1905, 1906, 1908 and 1909 are unavailable			
1910	Carlos Schulze/mining engineer	Lack of students and technicians in the industry	*Boletin Minero* (1910), pp. 330-339
1912	Superior Counsil of Mining Education	Lack of students at the Mining Schools	*Boletin Minero* (1912), opp. 371-377
1912	Ignacio Díaz Ossa/mining engineer and director of the Mining School of La Serena	Lack of students and technicians in the industry	*Boletin Minero* (1912), pp. 555-559
1926	I.B. Hobsbawm	Lack of mining technicians	*Boletin Minero* (1926), pp. 644
1931	Institute of Mining Engineers	Lack of mining technicians at mining companies	*Boletin Minero* (1931), pp. 163-164
1933	The National Mining Society	Lack of mining technicians	*Boletin Minero* (1933), pp. 387-391
1934	The National Mining Society	Lack of mining technicians	Boletin Minero (1934), pp. 119-122
1934	The National Mining Society	Lack of mining students and technicians	*Boletin Minero* (1934), pp. 196-197
1934	The National Mining Society	Lack of mining technicians	*Boletin Minero* (1934), p. 306
1937	The National Mining Society	Lack of mining technicians	*Boletin Minero* (1937), pp. 1423-1424
1937	The National Mining Society	Lack of mining technicians	*Boletin Minero* (1937), pp. 1737-1741
1939	Credit Bank of Mining	Lack of mining technicians	*Boletin Minero* (1939), p. 310

1940	The National Mining Society	Lack of mining students and technicians	*Boletin Minero* (1940), p. 142
1940	R. Horacio Julio	Lack of specialised mining technicians	*Boletin Minero* (1940), p. 486

Appendix 22. Norwegian mining engineers and foreign travels

Travelling Norwegian mining engineers*

To foreign educational institutions, companies and industrial exhibitions

Year	Name	Funding	Countries visited	Activity**
Around 1790	Johan Michael Kruse	Unknown scholarship	Germany Feroe Islands Scotland	Study trip to German mining works. Studied mechanics and mining construction one year at Freiberg Mining Academy.
1791-92 Around 1813	Jens Esmark		Germany Hungary Poland England	Long study trip to foreign countries; Mining Academy in Freiberg, Chemitz, mining works at Hungary, Benatet, Poland and Schleisen. Later study trip to England.
1793	Christian Ancher Collett	Public scholarship	Sweden Germany	2 ½ years study trip to Swedish and German mining works.
1794	Peter Petersen	Public scholarship	Sweden	Studying mining in Sweden, Falun and Stockholm, during 3 years.
1797	August Christian Baumann		Sweden Germany	Studied in Falun. Study trip to big German mines.
Around 1800	Cajus Brandt	Fund “ad usus publicos”	Norway	Obtained 200 riksdaler annually to study coins and smelting plants at Kongsberg.
Around 1800-30	Poul Steenstrup	Public scholarship	Sweden Germany Austria	Study trip to Germany and Austria. Travelled to Sweden on behalf of King Carl Johan to examine iron works.
1804-05	Peter Joachim Holten		Sweden	Study trip to Stockholm.
1804-07	Christian Münster		Germany Poland Italy	Studied at a German educational institution and travelled abroad.
Between 1807 and 1812	Henrich Christian Strøm		Sweden France Germany England	Studied at Freiberg Mining Academy. Scientific study trips.
1808	Erich Otto Knoph	On behalf of Røros Copper Works	Sweden	Travelled to Falun Copper Works with two workers from the smelting plant to study copper smelting methods.
1820s 1830s	Baltazar Mathias Keilhau	Fund “scientific travels within Norway”	Norway Germany	Studied in Berlin and Freiberg. Study trip abroad for many years and many trips within Norway.
1822 and 1839	Knud Olsen	On behalf of Røros Copper Works	Sweden Germany	Long trips to several German and Swedish mines.
Around 1826 1846	Karl Friedrich Bøbert		Germany Belgium France Switzerland Sweden	Studied at the Mining Academy in Clausthal, University in Halle and Mining Academy in Freiberg. Visited German mines and travelled on the Continent to study turbines.
1829-32	Amund Lammers	Public scholarship	Sweden Germany	Studied at Falu Mining School 1830-31. Study trip to Freiberg, Austria, Italy, Switzerland and France.

		Scholarship from Kongsberg Silver Works	France Austria Italy Switzerland	
Around 1830	Knud Olsen	Scholarship from Røros Copper Works	Sweden Germany	Studied at different German and Swedish mining works and the Mining School in Falun.
1837	Peter Ascanius Schult	On behalf of Røros Copper Works	Sweden	Travelled to Falun in 1837 to study wires.
1837-38	Casper Hermann Langberg		Sweden	Study trips to the Production of Coin in Stockholm.
1843	Emil Bertrand Münster	Public scholarship	Germany Austria	Study trip to Germany and Austria. Studied smelting and amalgamation processes at Freiberg Mining Academy. Went also to Mansfeldt, Clausthal and other cities to study mines and plants, chemical factories, laboratories and collections.
1843-44	Sjur Amundsen Sexe	State scholarship	Sweden Germany	Visited mining works in Sweden and Germany and a short stay at the University in Berlin.
1845	Johan Andreas Sell	On behalf of Kongsberg Silver Works	Germany	Went to Germany to study machine techniques with machine expert Professor Julius Weisbach at the Mining Academy in Freiberg. Studied turbines in Sachsen.
1846	Karl Friedrich Bøbert	On behalf of Kongsberg Silver Works	Belgium France Switzerland Germany	Travelled around on the Continent to study turbines at mining works.
1849 1851-52 1862	Theodor Kjerulf	University scholarship	Norway Iceland France Germany Austria Czechoslovakia	Geological study trip at Hardangervidda, Norway. Later field trips to Iceland, France, Harz and Erzgebirde, Germany and Tirol in Austria. Stayed with researchers Karl Georg Bischof in Bonn and Robert Wilhelm Bunsen in Heidelberg. In 1851 at the University in Bonn and other places. Study trip to Berlin, Breslau and Vienna to inquire with specialists with regard to mapping.
1846-47 Before 1850	Tellef Dahll		Sweden Germany England	Study trip to German and Swedish mines. Went to England to learn about palaeontology and stratigraphy.
1855 1877-78	Carl Anton Bjerknes	Foreign scholarship Public scholarship	Germany France	Study trip to different places in Germany, such as the University in Göttingen. Participated at the International Exposition of Electricity in Paris in 1881. “Scientific study trip” to Germany and France.
1857	Knud Hauan		Sweden Germany	Went to Falun in Sweden and Freiberg to study.
1858	Hartvig Casper Christie	Public scholarship	Germany France	Studied physics at Universities in Göttingen and Paris.
1858	Harald Hansteen	On behalf of Røros Copper Works	Sweden	Went to Falun.
1858 1877	Carl Anthon Paaske		Germany	Study trip to Germany to study “Fahr-kunst”.
1859 1876 1886 1880s	Jacob Pavel Friis	On behalf of Kongsberg Silver Works and Røros Copper Works	England Germany Sweden France Italy	Went abroad to study steel drills. Went to Sweden to study the use of coke in smelting. Went with Anton Sophus Bachke to France and Italy to study electrolytic processes.

			Spain	
1865	Poul Hansen Birch Holmsen	On behalf of Kongsberg Silver Works	Germany	Went to Germany to study water column machines for ore lifting, turbines for drainage and lifting.
1867	Hans Elias Peter Andreas Holmsen	On behalf of Røros Copper Works	Sweden	Went to Swedish mines.
Around 1870	Knud Hauan		Germany	Studied at Freiberg Mining Academy
1871	Martin Philip Rasch		Germany	Studied the use of dynamite at German mining works in Harz and Freiberg.
1871-1913	Amund Theodor Helland	Public scholarship	Germany Italy England Holland Denmark	Studied mining in Switzerland and Germany 1876-77. Study trips within Norway and abroad. Studied microscopic petrography in Leipzig, went to the lakes in northern Italy and studied Norwegian glacial erratic in England, Holland, northern Germany and Denmark. Implemented later geological surveys in the Orkney Islands, Shetland Islands and Faeroe Islands before going to in Iceland.
1873-76	Gustav Bruun		Germany	Studied chemistry and mining at polytechnical schools in Munchen and Clausthal in Hanover
1876-77	Abraham Godtfred Puntervold		Germany	Studied at Dresdener Polytechnikum
Around 1878	Oscar Stave		France	Studied in France.
1879 1885-89	Olaf Aabel Corneliussen	Kongsberg Silver Works Scholarship Vigsnes Works scholarship	Wales England Belgium Germany France Luxembourg	"Scientific foreign trip" in 1879 to Wales, Cornwall, Belgium and Harzen to study mineral processing and "Fahr-kunster" at mines. In 1885 he went to the International Exposition in Antwerp in 1885 and the Universal Exposition in Paris in 1889. Studied mineral processing plants in Germany and cable lift plants in Luxembourg.
1880s	Jacob Roll		Germany	Studied in Germany
1880s	Anton Sophus Bachke	On behalf of Røros Copper Works	Sweden Denmark Germany Belgium England France Italy Spain	Studied pyrite and methods for cheaper processing of copper; Pierre Manhès process in France and electrolytic processes in France and Italy.
1880-1900 1927-28	Johan Herman Lie Vogt	University scholarship Unknown scholarships Foreign scholarship 2 summer travel scholarships Rathke scholarship	Norway Germany Sweden England France Spain Switzerland Italy The United States	Studied at Dresdener Polytechnikum and Freiberg Mining Academy. Travelled around Europe to study mining. Went at least 14 times to Sweden. Studied iron metallurgy and quantitative-chemical analysis at the Mining School in Stockholm. Visited many Swedish mining works and institutions. Several trips to Germany and many excursions around Erzebirge and Haz. Study trip to England and Scotland to visit iron ores and coal mines. Participated at the Liverpool International Exhibition in 1886, the Universal Exposition in Paris in 1889, the Exhibition of Mining and Metallurgy in London in 1890 and the Universal Exposition in Paris in 1900
Around 1881	Diderik Cappelen		France	Study trip to France and travelled with students from Ecole des mines in Paris.
1881	Truls Wiel Krefting		Germany	Finished studies at Freiberg Mining Academy.
1882	Hans Knutsen		Germany Greenland	Studied at Freiberg Mining Academy. Study trip to Greenland on behalf of the King.

1884-1900	Hjalmar Wilhelm Adolph Roscher	Rathke scholarship On behalf of Kongsberg Silver Works	Norway Germany France	400 kr. 2-3 months travel to Norwegian smelting plants with Rathke scholarship in 1884. Went later to study mining, Brandtske drilling machines on behalf of Kongsberg Silver Works. Went later to German and Austrian mines to study mineral processing. Participated at the Universal Exposition in Paris in 1900.
1885	Christian Thaulow Nissen		Germany	Studied mining and smelting at Freiberg Mining Academy.
1885-95	Emil Knudsen	State scholarship Scholarship from Vigsnes Copper Works	The United States Sweden Germany	Studied at the Technical School in München and Freiberg Mining Academy. Assisted at the International Exposition in Antwerp in 1885 and the World Exhibition in Chicago 1893. Visited Lake Angeline Mine (iron) where he studied electric locomotive transport in the mines. Studied at the Mining Academy in Houghton and travelled to mines and ore dressing plants in Houghton; Solway Works, Syracuse, where he studied Marwin's electrical drilling machine. He went to Sweden to visit an electric power station in Bergslagen and magnetic separation for iron ore in Stockholm.
1888	Ole Sandstad	Rathke scholarship	Norway	Metallurgical studies of Norwegian nickel, copper and coal mining works.
1888 1894	Emilius Knutsen Looft		Germany	Studied in Wiesbaden and later in Leipzig.
1893 1895	Emil Knudsen	On behalf of Røros Copper Works	Sweden	Went to Sweden to visit an electric power station in Bergslagen and magnetic separation for iron ore in Stockholm on behalf of Røros Copper Works. Went to Germany and Schuckert's factories around 1895 in relation to the installation of the electric power station at Røros Copper Works.
1894	Carl Casper Riiber	On behalf of Kongsberg Silver Works	Sweden Germany Hungary Austria	Went to study electrical drilling machines and lifts.
1889	Christian Thams (construction engineer)		Norway	Participated in the Norwegian pavilion at the Universal Exposition in Paris.
Around the 1890s	Henrik Kristian Borchgrevink	Rathke scholarship	Norway Canada Mexico Europe	Rathke scholarship, 200 kr. in 1891 to study removal and transport of ore at Norwegian mining works (construction methods and ore dressing). Travelled later to Canada and Mexico and around in Europe.
After 1890	Holm Egeberg Holmsen	2 scholarships for technicians	Sweden Germany Austria England Scotland	Studied at Freiberg Mining Academy. Study trip to Swedish, German and Austrian mines. Travelled later to England and Scotland. Participated at the General Art and Industrial Exposition of Stockholm in 1897.
1891 Around 1900	Carl Elieson Stabell		Germany	Study trip to Freiberg smelting plants and studied smelting processes of the time. Studied later at the Technical School in Dresden.
1891 1896-97	Carl Olaf Bernhard Damm	Rathke scholarship Public scholarship Unknown scholarships	Norway Sweden Germany Austria	Rathke scholarship, 200 kr. in 1891 to study removal and transport of ore at Norwegian mining works (construction). Did surveys and studied geology, analysis of rocks and petrography at the University in Uppsala and Heidelberg. Went also to Austria.
1893	Fritz Julius Mårthén		Germany Austria	Study trips.
1893 Around 1900	Andreas Holmsen	Unknown scholarships	Germany Switzerland Austria	Obtained 200 kr. to study northern mining works. Several study trips to study geology and techniques. Studied at technical schools in Zurich and Munich and Universities in Vienna and Paris.

			France	
1893-95	John George Dahll		Germany England	Studied at Freiberg Mining Academy and Royal College of Science in London. Many study trips abroad.
Before 1894	Gudbrand Thesen		Germany	Studied at Freiberg Mining Academy.
1896	Richard Frederik Stalsberg	Scholarship from Røros Copper Works	Sweden	Studied at Sala in Sweden
1897	Ole Nedrum Hagen	Scholarship from Kongsberg Silver Works	Sweden	Went to the General Art and Industrial Exhibition of Stockholm and a number of Swedish mines.
1897-99	Ole Andreas Bachke		Germany	Studied at Freiberg Mining Academy.
1897 1900	Theodor Wilhelm Holmsen (machine technician)	2 state scholarships	Norway Sweden France	Studied copper extraction at Løkken mine and went to the world exhibition in Paris in 1900 to study modern mining, especially pumps and lifting equipment. Studied ore dressing and metallurgical processes at 5 Swedish companies.
1898	Gudbrand Henriksen		Canada	Did research on cupronickel.
1899	Worm Hirsch Lund		Germany	Studied at Freiberg Mining Academy
Around 1899	Christian Horrebow Homan		England France Germany	Studied at Royal School of mines. Study trips to English, French and German mines and smelting plants.
Around 1900	Johan Carl Andresen		Europe	Several study trips.
1901	Thomas Georg Münster		Sweden Denmark Germany Austria	Study trip abroad to study coin systems.
1901-1906	Nils Erik Lenander		Sweden	Studied at the University of Uppsala and the Mining School in Stockholm.
1901-03 Around 1913	Lauritz Dorenfeldt Jenssen		Sweden Germany Spain The United States	Studied at Freiberg Mining Academy. Study trips.
1902 1903-04	Anton Winckler		The United States	Studied at Michigan College of Mines.
1903-05	Erling Lossius Jørgensen		Germany	Studied at Freiberg Mining Academy.
1902-03	Anton Martin Grønningsæter		Germany	Studied at Freiberg Mining Academy.
1904-05	Thoralf Brodtkorp		Germany	Studied at Freiberg Mining Academy.
Around 1905	Sven Dahlquist		Sweden	Studied at the Mining School in Falun.
Around 1905	Wilhelm Georg Tidemand		The United States	Study trips.
Around 1905	Hans Henrik Horneman	University scholarship	Norway	Geological surveys in Lister and Mandal.
1905 Around 1907	John Nikolai Johns		Germany Sweden	Study trip to a number of large mining companies and metallurgical plants. Studied machines in Sweden.
1905-06	Otto Fredrik Borchgrevink		Germany	Studied at Freiberg Mining Academy.
1905-06	Erik Christian Dahl Borthen		Germany	Studied at Freiberg Mining Academy.
Around 1906	Carl Bugge		Scandinavia Germany	Study trip abroad to study subjects related to coins. Studied mineralogy and crystallography in München.
Around 1906	Hans Helgesen		Belgium Germany Switzerland	Studied at National School of Mines in St. Etienne. Study trips.

Around 1906 1911-13 1928	Thorolf Vogt	Hjelmestjerne Rosencrone scholarship	Sweden Denmark Germany Scotland Austria	Travelled around Europe. Studied mineralogy and petrography at the University in Vienna and Göttingen. Geological expeditions to Svalbard.
Around 1906 1934-36	Harald Dahl		Europe Spain	Studied at Freiberg Mining Academy and later at the University in Clausthal. Travelled within Europe and visited Spanish pyrite mines.
1906-07	Arne Grønning		Germany	Studied at Freiberg Mining Academy.
1906-07	Alfred Birdy Ralson		Sweden	Studied at Falun Mining School.
Around 1907-1914	Alexander Christiansen		Italy Germany Austria	Studied mining at Freiberg Mining Academy. Study trips. Secretary and organiser for the mining section at the Jubilee Exhibition in Christiania in 1914.
1907-08	Nils Christensen		Germany	Studied at Freiberg Mining Academy.
1907-08	Carl Johan Gullichsen Steenstrup	Rathke scholarship	Norway Sweden	Study trips to Norwegian, Swedish and German mining works. Obtained 330 kr. in 1907 to study ore dressing, especially magnetic method for processing iron ore at Norwegian mining works.
1907-09	Dankert Einar Alme Torkildsen		Germany	Studied at Freiberg Mining Academy.
1907-09	Oscar Fredrik Graff		Germany	Studied at Freiberg Mining Academy.
Around 1908	Eyvind Stoltz	Public scholarship Rathke scholarship	Norway ?	Many travels abroad with scholarship. 300 kr. to study the metallurgy of copper, especially modern methods for complete extraction of Norwegian copper-containing ore. In the Committee for distribution of prices at the Jubilee Exhibition in Christiania.
Around 1908 1910s-20s	Steinar Foslie	Public scholarship	Germany Sweden Europe The United States Canada	Study trip to Central Germany and private trips around Europe. Participated at Geology conferences in Toronto in 1913 and Madrid in 1926.
1908-10	Erik Anton Dalset	2 public scholarships	?	Studied mining abroad.
Around 1908-20	Ragnvald Støren		Norway Denmark Germany Switzerland Italy	Travelled within Norway and abroad to study chemistry, “Elmer process” (flotation and processing), ore separation, processing of pyrite, zinc and coin system.
1908	Bertel Kristoffer Skjærdal	Rathke scholarship	Sweden	300 kr. to study magnetic processing of ore.
1908	Simon Smith	Rathke scholarship	Norway	Study travel to a variety of Norwegian mining works to study mining measurement and mapping of mines.
1908	Simon Karenus Høegh-Omdal		Germany	Study trip.
After 1908	Kristian Haslum		Norway Germany Belgium Sweden	Study travels to different mining plants in Norway, and Germany, Belgium and Sweden. Went to Belgium and Sweden to study copper extraction.
Around 1909	Harald Skappel		Germany	Studied at Freiberg Mining Academy.
Around 1909 1919	Einar Hæhre		Germany The United States	Excursions with J. H. L. Vogt to German mining works and smelting plants. Study trip to the United States in 1919.
1909	Hans Juell Borchgrevink		Germany	Studied at Freiberg Mining Academy
1909	Oscar Fredrik Graff		Germany	Studied at Freiberg Mining Academy.

1909-10	Marius Bredesen		Germany	Studied at Freiberg Mining Academy.
1909-10	Ole Andreas Rønning		Germany	Studied at Freiberg Mining Academy.
1909-11	Alf Severin Vaksdal		Germany	Studied at Freiberg Mining Academy
After 1909	Finn Holmsen Münster		Europe	Travelled to European countries to study pyrite production.
Around 1910	Bjarne Hofseth		England Puerto Rico	Studied at Camborne School of Mines, England. Study trip to Puerto Rico.
Around 1910-1912	Haakon Styri	The American-Scandinavian Society Scholarship	Sweden Germany Belgium France	Studied at Aachen Polytechnic University. Study trips abroad, went to Sorbonne.
1910	Eyvind Flood		The United States	Studied at Denver Technical School.
1910	Johan Johansson		Sweden	Studied at Falun Mining School.
1910	Otto Andresen	Rathke scholarship	Norway	100 kr. to study magnetic separation of iron ore at mining works in northern Norway.
1910-11	Arne Fredrik Blom		Sweden Germany	Studied at Falun Mining School and Freiberg Mining Academy.
1910 1914	Fredrik Sebastian Nannestad	Mining Fund	Norway Sweden Germany Canada	Studied modern techniques and ore processing in Europe and nickel ores in Canada.
1910 1924-25	Abraham Elias Kvalheim	State scholarship C. Sundt's scholarship	Germany Austria Belgium	Participated at the Universal and International Exposition in Brussels. Went to Germany and Austria to study mining. Did experiments with new methods and patents to utilize types of caliber.
1911-15	Emil Knudsen		Germany	Studied at Freiberg Mining Academy.
Around 1911	Julius Helverschou	State technical scholarship	Scotland Germany Norway	Study trips to Scottish, German and Norwegian mining districts. Studied deep drilling methods and water supply during drilling.
Around 1911	Lorentz Lorch Hagen	Rathke scholarship	Norway Sweden England	Study trips abroad. 150 kr. to study metallurgy, especially electro-metallurgy at Norwegian smelting plants.
Around 1911 1923	Carl Wilhelm Carstens	Public scholarship	Germany France	Studied at the University of Zurich. Travelled also to Paris.
Around 1911	Rolf Havig Støre		Germany	Studied at Freiberg Mining Academy.
1911	Albert Andreas Holter	Kongsberg Silver Works' travel scholarship	Sweden	Study trip to Sweden.
1911 1923	Hans Ingvald Kristoffer Merckoll	Mining Fund	Sweden England Belgium Germany	Studied iron ore and processing plants in Sweden. Studied coal mines 6 months in England, Belgium and Germany, especially prevention of coal dust explosions.
1911-12	Kristian Refsaas		Germany	Studied electro-chemistry and metallurgy at the Technical School in Darmstadt
After 1911	Gustav Newton Kirsebom	?	Western Europe	Business travels.
Around 1912	Harald Pedersen		Germany	Studied at Aachen Polytechnic University
Around 1912	Bjarne Reidar Saarheim		Sweden Belgium France England	Study trips.

Around 1912	Sverre Blekum		Germany Sweden	Studied the molybdenum industry.
1912	Sigurd Rudie		Germany	Studied at Freiberg Mining Academy.
1912	Johan Falchenberg Stadheim	Rathke scholarship	Norway ?	Study trips within Norway and abroad. 100 kr. To study mining at mining works in northern Norway.
1912	Peder Ytterbøe	Rathke scholarship	?	100 kr. To study electric iron smelting.
1912-13	Einar Dahl		Sweden	Studied mining and metallurgy at Filipstad Mining School.
1912-16 1919	Nils Hofman Aall		Sweden France Germany	Studied at the Technical University in Zurich and the Technical University in Stockholm. Study trips to France and Germany.
Around 1913	Georg Hauschildt Steen		Scandinavia Europe Germany Austria England	Many trips around Norway and European countries.
Around 1913	Otto Falkenberg	Unknown scholarship	Scandinavia Germany Spain The United States Canada	Studied at Clausthal Mining Academy and Berlin. Study trips.
Around 1913	Per Adam Petterson	State technical scholarship	Germany England Italy The United States North-Africa	Study trip.
1913-16	Georg Tysland	The American-Scandinavian Foundation's scholarship	France The United States Sweden England Germany	Studied electro-engineering and metallurgy at the University of Liège. Study trips abroad. Studied electric iron smelting in Pittsburgh, the United States.
1913 1920	Johan Asmus Lenschow	Scholarship	Sweden Germany	Study trip to Swedish and German mines to study mining engineering and processing plants.
After 1913	Albert Carinus Sunde		Germany England America China	Study trips.
Around 1914	Wolmer Marlow		Belgium Holland Germany Sweden	Study trips.
1914	Anders Kristian Olsen		Siberia Mongolia	Participated in Ørjan Olsen's expedition to Siberia and Mongolia.
1914	Adam Frans Wilhelm Faye		Germany	Studied at the Aachen Polytechnic University.
1914	Fredrik Hurum		Germany	Studied at the Aachen Polytechnic University and MIT Boston.

1920			The United States	
1915 1928	Gunnar Aasgaard		Sweden Germany Poland Holland	Study trip to study general development in machinery and constructions as well as specific machines. Went to coal, ore mines, workshops as well as new and old power stations in Ober-Schleisen and the Ruhr district and other places.
1916-17	Rolf Mastrander	Norsk Aluminium Co.	The United States	Went to Montana to study oil deposits and Latin America and Holland to search for ore deposits.
1916 1925	David Vaage	The Int. Labour Office	Czechoslovakia Germany France Belgium England	Study trip in 1916 to Mährisch Ostrau to study electrical mining plants. During the summer 1925 went to the mining districts in Harz to study mineral processing. Stayed for a while at the coal districts in France, Belgium, Germany and England to study safety techniques in coal mines for the Int. Labour Office.
Around 1916	Thorodd Wangensteen Messel		Germany Europe	Studied at Freiberg Mining Academy. Travelled around Europe.
Around 1916	Harald Severin Diderik Cappelen		Germany	Studied at Freiberg Mining Academy.
1916	Gunvald Birger Thorkildsen	State scholarship	Germany The United States Canada	Studied at Freiberg Mining Academy. Study trip to the United States and Canada to study modern mining.
1916 1920	Leif Lyche		Germany	Studied at the Technical School Breslau
Around 1917	Arne Drogseth		Sweden Germany Switzerland Russia	Studied “technical subjects”.
Around 1917	Carl Gottfred Larsen		England	Studied at Royal School of Mines in London
1916-17	Sverre Winnem		Germany	Studied at Freiberg Mining Academy
1917	Truls Wiel Graff		Germany	Studied at the Aachen Polytechnic University.
1917-22	Erling Robsahm		Germany	Studied at the Technical School in Darmstadt, the Aachen Polytechnic University and Breslau.
1917 1924	Trygve Brodtkorb		Sweden England The United States	Study trip to mining works.
1918 1922	Appollonius Lijedahl Rosenlund	On behalf of Kristiansand Nickel Refinery	Canada Sweden	Visited nickel mines in Ontario in Canada and site investigations used Swedish state railways.
Around 1918	Einar Trøften		Central Europe Sweden England	Study trips.
1919	Ferdinand Peder Egeberg		Germany The United States	Studied at Freiberg Mining Academy. Study trip to the United States to study modern techniques, especially flotation.
1919	Erland M. Lewin		England	Studied at Durham University.
1919	Finn Andersen		England	Studied at the Camborne School of Mines in Cornwall
1919	Otto Hansen		Britain	Studied in Glasgow
1919	Erik Einar Haag		Sweden	Studied at Falun Mining School
1920	Sigurd Westberg		The United States	Studied at the University of Pittsburgh
1920	Halvard Dale	Orkla Fund	Germany	Metallurgical studies.

			Austria	
1920-21	Brynjulf Dietrichson	Orkla Fund	France Belgium Spain	Study trip to France and Belgium. Stayed at mining works in France and Spain.
1921	Werner Carl Ferdinand Poensgen		Germany	Studied at the Aachen Polytechnic University.
1921	Karl Johan Hansen	Scholarship	Sweden Denmark	Studied technical schools in Sweden.
Around 1921	Gunnar Schjelderup		Germany The United States	Studied electrochemistry and metallurgy at the Technical School in Dresden. Studied practical operations at steel works.
1921-22	Enok Willmann		Germany	Studied at Freiberg Mining Academy.
1921-22	Leif Hartmann Støren		Germany	Studied at Freiberg Mining Academy.
1922	Torkell Berntin Gjerstad	State technical scholarship	Germany	½ year stay at Krupp industries in Germany.
1922	Johan Askeland (unknown)	Orkla Fund	Germany	Study trip to Germany to study modern mining and ore dressing.
Around 1923	Arvid Thunæs		Latin America Europe Canada	Travelled around.
1923	Alf Ihlen		The United States	Studied at MIT in Boston
1923	Johan Engelhart Braastad		Germany	Studied at the Aachen Polytechnic University.
1923	Rolf Falck-Muus		England France Germany Denmark	Study trips.
1923	Birger Egeberg	State scholarship	England France Germany	Studied at the Aachen Polytechnic University. Study trip to English iron and steel plants and visited France, Germany and England to study silver industry.
After 1923 1937-40	Magne Mortensen	Orkla Fund Norwegian Technical Institute scholarship	Norway	Several study trips. Visited Norwegian mines to study ore geology and electrical conditions and ore dressing. Studied also flotation processes.
Around 1924	Henning Mastrander	Orkla Fund Norway-America Fund	England Holland Belgium Germany The United States	Studied mining and entrepreneurship. Studied at the University of Columbia. Participated at congresses and visited modern American iron and coal mines and studied the application of new mining machines, loading facilities and electric machinery.
1924	Arne Okkenhaug	Orkla Fund	Sweden Germany	Studied mining.
1924	Bjarne Askeland	Orkla Fund	Sweden	Study trip.
1924	H. Chr. Jessen	Orkla Fund	The United States	Studied American ore dressing and mining techniques.
1924 and 1927-28	Gunnar Horn	Norwegian Military Goods Insurance Fund	Germany Poland	Study trips and stay at Technissche Hochschule og Preussische Geologissche Landesanstalt, Berlin.
1924 and 1931	Steinulf Smith-Meyer	State technical scholarship Orkla Fund	Germany Canada The United States	Study trip to German coal mining district. Study trip to mining works in Canada and the United States to study flotation techniques.
1925-27	Bjørn Fougner		Germany	Studied at the Technical School in Breslau

1925-26, 1932-33 and 1935	Einar Sverdrup		Germany England France	Several study trips.
1926	Einar Slaatto	Orkla Fund	England The United States Germany Holland	Study trips in Europe and studied mining and coal processing in the United States.
1926-48	Aage Christensen		Germany The United States	Studied at Freiberg Mining Academy. Study trip to a variety of mines.
1927-30	Joakim Lindholm	Orkla Fund	Germany Belgium The United States	Study trip abroad to study coal mining, ore dressing and administration.
1928-29	Johan Kraft Johanssen	Orkla Fund	The United States	Study trip abroad to study mining and ore dressing.
Around 1930	Henrik Steffens Hagerup Jenssen		Sweden England Germany The United States	Several study trips.
1931	Haakon Brækken	Mining Fund	The United States	Studied the development of geophysical methods of surveying.
1931	Robert Major Brun	Orkla Fund	Sweden Finland The United States	Studied mining and ore dressing.
1931-32	William Straube		Germany	Studied at Freiberg Mining Academy.
1932 1934	Per Munthe-Kaas Sandvik		England Sweden Germany	Study trips.
1933	Johan Fredrik Gørrissen		Germany	Studied at Aachen Polytechnic University.
1933-34	Per Sandved	Orkla Fund	Germany Sweden Czechoslovakia	Visited mines, smelting plants and laboratories.
1933-34	Arne Carlsson	Orkla Fund	Sweden Germany Austria Czechoslovakia Italy	Studied for a while in Sweden and Germany.
1933-34 1937	Harald Nordrum Ross	Orkla Fund	England Holland Germany	Studied modern coal mining in Germany and England.
1934	Hans Helge Schou		The United States	Studied at Michigan College of Mining and Technology
1934	Jarle Kuvås		Sweden	Studied at Goteborg Technical School
1934-35	L. Breder (not mining engineer)	Norwegian Technical Institute scholarship	Norway	Travelled around Norway to study mining plants.
1934-38	Christian Hiorth Aall		France	Studied in Grenoble and travelled around in France.
1934 1936-39	Hilmar Kragh When	C. Sundt's Scholarship	Germany Austria Hungary	Studied at Freiberg Mining Academy. Study trips abroad.

			Czechoslovakia Poland Holland Belgium France	
1935	Herbert Olav Bronder	Hs fund	Sweden Denmark Germany England	Study trips.
1935	Jan Herman Reimers		Germany	Studied at the Technical University in Karlsruhe
1935-36	Arne Hofseth	Orkla Fund	The United States	Studied geophysics at the Colorado School of Mines. Studied geophysical ore survey abroad.
Around 1936	Arne Boye Holt		France The United States	Studied physical metallurgy at School of Mines in Mons, organic chemistry at University of Columbia and organic and physical organic chemistry at Polytechnic Institute of Brooklyn.
1936	Ragnar Christoffersen	Orkla Fund	Sweden Germany	Studied mining.
1936	Thorstein Kavli		Germany	Studied at Aachen Polytechnic University.
1937	Einar Falkum (chemical engineer)	Norwegian Technical Institute scholarship	Svalbard	Studied utilisation of coal in Svalbard.
1937	Einar Olav Evensen	?	Germany	Studied at Aachen Polytechnic University.
1937	Erling Rytterager	?	Germany	Studied at Aachen Polytechnic University.
1938	Bjarne Holmsen	?	The United States Canada	3 months study trip to mines.
1938-39	Worm Lund	Orkla Fund	?	Studied iron processing.
1938-39	Thor Matheson Amdal	Orkla Fund	Sweden	Studied mechanical loading in modern mining.
1940	Olav Bergersen	?	Germany	Studied at Aachen Polytechnic University
1940	Christian Fredrik Sontum	?	The United States	Studied at the University of California

*These trips do not include geological excursions in Norway, which were continuously implemented by professors and students at the University and the NIT.

**In some cases (around 5) information about the engineer and the funding is known, but it is unknown whether the engineer actually carried out the trip or not.

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Appendix 23. Chilean mining engineers and foreign travels

Travelling Chilean mining engineers*

To foreign educational institutions, companies and industrial exhibitions

Year	Name	Funding	Countries visited	Activity
Mid-nineteenth century	Antonio Alfonso	Public scholarship	Germany	Studied at Freiberg Mining School and to visited mines all over Europe. Went also to Bolivia and Peru to do studies and came back in 1861.
Mid-nineteenth century	Manuel A. Osorio	Public scholarship	France	Studied at Mining School in France and visited mines.
Mid-nineteenth century	Teodisio Cuadros	Public Scholarship	Europe	Studied in Europe.
Around 1870s	José Antonio Carvajal		Germany	Went to Germany to collect minerals, machines, devices and equipment for the use in teaching at the Copiapó Mining School.
Around 1870	?		France Belgium England Germany	Studied at a University in France or Belgium and visited important industrial plants in England and Germany.
1877	Fidel Cabrera (engineer)	On behalf of Carboniferous Company of Lota and Coronel	England Germany Belgium	Sent by the company to study the most modern coal mining in practice at major coal centres.
1889	Washington Lastarria		Europe	Studied in Europe. Went to the Universal Exposition in Paris and was part of the mining and metallurgical commission.
1889	Luis Zegers		Europe	Studied in Europe. Went to the Universal Exposition in Paris.
1889	Alejandro Chadmick Amenábar		Europe	Went to Europe to investigate mining education and to the Universal Exposition in Paris.
1891	Francisco Garabantes San Román		The United States Switzerland	Participated at the International geological congress in Washington in 1891 and the Universal Exposition of Geography in Bern.
1893	Casimiro Domeyko		Germany	Studied at Freiberg Mining School.
After 1893	Casimiro Domeyko Alamos		Germany	Studied at Freiberg Mining School.
1901 1910	Guillermo Yunge Gabler	Public funds	The United States Europe	Was sent by the Government to the Pan-American Exposition in New York and travelled around the United States. Went later to Europe, especially Germany, to study the last updates in metallurgy and mining education.
After 1909 1912	Juan Blanquier Teilecht		Norway Europe The United States	Went to Norway to study synthetic saltpetre and the use of electric furnaces and to other European countries to study the use of electricity in mining, electrolysis of minerals and ore dressing machines. Went to the United States and Europe in 1912 to study for three years.

1911 1917	Félix Federico Corona (civil engineer)	Unknown scholarship	France England Sweden The United States	Went to France, England and Sweden to study mining. In Sweden studied advances in electrometallurgy and steel ovens. Went to the University of Berkeley in California to study electrical engineering with scholarship from University of California, Berkley, in 1917.
Before 1915	Roberto Harvey R.		The United States	Studied accounting and English in the Industrial Schools of Scranton and La Salle in the United States.
Before 1917	Hermógenes Pizarro Acuña		The United States	Studied in the United States.
Before 1923	Guillermo Alamos		The United States	Studied in the United States.

*These trips do not include geological excursions in Chile, which were continuously implemented by professors and students at the University.

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