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Abstract

Chile and Norway are two 'natural resource intensive economies', which have had different development trajectories, yet are closely similar in industrial structure and geophysical conditions. The questions of how and why Chile and Norway have developed so differently are explored through an analysis of how knowledge accumulation occurred and how it was transformed by learning into technological innovation in mining, a sector which has long traditions in Norway and has by far been the largest export sector in Chile for centuries. Similar types of 'knowledge organisations' with the direct aim of developing knowledge for mining were developed in both countries. Formal mining education, scientifically trained professionals, organisations for technology transfer and geological mapping and ore surveys are compared in search of differences which may explain the underlying reasons for variations in economic growth.

JEL classification: N30, N50, L72

Keywords: natural intensive economies, Chile, Norway, mining, innovation, mining education, technical education, knowledge organisations

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1. Introduction

Countries rich in natural resources which exhibit poor economic performance, are often understood as being 'cursed' and recommended to shift to industries which are not based on raw materials. A key empirical problem with the 'resource curse' argument, however, is that some of the richest countries in the world, such as Norway, Sweden, Canada and Australia, have developed fast-growing economies based on natural resources. In this paper, I compare the mining sectors in two resource intensive economies, that have had markedly different development trajectories, yet are closely similar in structure and geophysical conditions, namely Chile and Norway. Chile and Norway are mountainous countries with long coastlines and extensive natural resource bases. Norway has developed strongly around natural resource industries such as metal and mineral extraction, timber industries, and fish, and has created a high-income diversified economy. Chile, in contrast, with closely similar resource industries, has failed to experience anything like the same success.

Differences in economic performance across natural resource intensive economies suggests that an abundance of natural resources does not necessarily lead to stagnation. Conversely, some countries have arguably developed *because* of their natural resources, not in spite of them. Evidence suggests that industries in rich natural resource economies have been highly knowledge intensive, dynamic and innovative, they have created linkages to other industries within the economy, and developed specialisations and new industries which have contributed to complex economic structures (see e.g. Andersen [2012]; De Ferranti et al. [2002]; Hirsch-Kreinsen et al. [2003]; Ville and Wicken [2012]). This is in accordance with the wider argument that knowledge is the foundation of economic growth. Comparative studies of Scandinavia and Latin America use this idea, and argue that certain key factors ensured positive development in the former, while they hindered development in the latter (see De Ferranti et al. 2002; Blomström and Meller 1991 for comparisons). They focus on the use of foreign technology, agricultural reforms, political regulations and education systems. This comparative approach is useful, however the discussion remains general. Few of the factors are discussed in detail and little empirical evidence is provided to support the arguments. We still have little knowledge of why some natural resource industries have been more innovative than others in these countries.

In this paper I seek to go beyond general comparisons, and to systematically compare how knowledge accumulation occurred at two locations. Based on the argument that learning depends on an innovation-friendly institutional and organisational context, I examine and compare the functions and outcomes of knowledge organisations which aimed to develop technological knowledge for mining in Chile and Norway. The analysis aims to shed light on the diverging paths of Chile and Norway by looking to a natural resource sector that both countries developed in a period in which mining faced new challenges in terms of finding, removing and processing ores and radical technological changes were adopted to continue rational operation.

2. Empirical comparative approach

To understand differences in development, and the foundation of economic growth, it is essential to determine how knowledge accumulation actually occurred and how it was transformed by learning into technological innovation. Instead of analysing incentives for innovation, such as property rights, and making economic growth models which generalise reality, some economic historians analyse organisations through which knowledge was created, transferred, modified and used (see for example Mokyr 2005; Bruland 1998; Bruland and Smith 2010; O'Brien 2011). Differences in institutional and organisational structures, using Douglass C. North's definition of institutions as 'rules of the game' and organisations as actors bound together by a common purpose (North 1991), are used to explain why some countries have experienced considerably more economic growth than others. Yet, there is a lack of empirical evidence when it comes to *how* knowledge has been accumulated and how organisational and institutional structures have influenced innovation (see Bruland [1989]; Craft [2010]; Edquist [2001] for critical reviews of innovation studies). I argue that the key to understanding how learning and innovation happened,

and the actors involved, is to go beyond analysing the aims of organisations. We should, in addition to their objectives, also examine how organisations, such as education, industrial societies and research centres, in fact developed technological knowledge, how people learned, and how knowledge was used directly to change technology. This requires in-depth analyses of the organisations and institutions. Furthermore, comparisons should be made, across countries, of organisations and institutions involved in innovation processes, with the objective of finding similarities and differences between them. The aim is to gain a fundamental understanding of the core of the foundation of economic growth and variations in economic growth across countries.

In this paper, the functions and outcomes of similar types of knowledge organisations in Chile and Norway, which were directly involved in creating, transferring, using and diffusing knowledge, are analysed and compared with the aim of finding out more about how they worked and their similarities and differences. The method is implemented by: (1) making a framework of how innovative and technologically advanced mining at the time was carried out and the knowledge organisations involved: terms, notably natural sciences, tacit and codified knowledge, managerial knowledge, know-what, know-how, know-who and know-why are used to detect different aspects of knowledge involved in innovation processes; (2) describing the gap in development between the two mining sectors and; (3) systematically comparing the functions and outcomes of similar types of knowledge organisations and how they influenced innovation, or the lack of it, in the two sectors. First, this involves analysing the study programs of the formal mining instruction in the two countries. Second, the number of professional workers and the extent to which they reached across the mining sector are examined. Third, organisations which aimed to transfer knowledge, notably from abroad, are explored. Finally, organised geological mapping and ore surveys are analysed in the two countries. I use primary sources from archives in Chile, Norway and the United States in the form of written documents, graduate lists, study programs, student yearbooks, engineering reports, technical magazines, company reports, and correspondence, newspapers and statistics.

3. Setting a framework for mining: use of complex technology

From the late nineteenth century, mining worldwide faced major challenges, in particular due to a gradual exhaustion of high-grade ores and start-up of new mineral and metal production. Maintaining profitability in new global settings involved adopting new techniques to find ores, for ore prospecting, removing ore, organisation of work and ore processing. More powerful machinery and power sources became common. Mechanical and electrical power largely replaced steam, animal, and manual power and enabled deeper mines and larger scale production. New converters, furnaces, ore dressing- and smelting techniques permitted the utilisation of lower grade ores. As these changes occurred, the knowledge that was used in technologically up-to-date mining became increasingly specialised (for general technological development in mining see Singer et al. [1958a; 1958b).

Constructions and structures beneath the earth was particularly difficult, since the mines could easily collapse. As mining developed, intricate mathematical calculations were essential to make deep, large and sustainable mines and knowledge of geometry, geology, physics, construction engineering and skills in precision were used to design and make tunnels, adits, shafts, install lifting devices and make ventilation systems. Thus, management and administration at modern technologically advanced mining companies required scientifically trained engineers and other professionals with knowledge of a broad spectre of natural science domains to lead operation efficiently and to use the complex technology. Operations at these companies became gradually more dependent on mining engineers and technicians (Børresen 2007; Musgrave 1967; Macchiavello Varas 2010). Professionals with other educational backgrounds, such as electro-engineers, mechanical engineers, chemists, economists etc. also became indispensable, as mines became gradually deeper and bigger, constructions increasingly multifaceted and new chemical and electro-metallurgical techniques developed (Musgrave 1967).

At the same time, much learning happened through doing and practice, which suggest a large degree of 'tacit knowledge' in all mining activities (Mokyr 2006). This was related to the 'local specificity' (Andersen et al. 2015, 48-49) and different conditions of each mine and processing plant when it came to geological settings, sizes of ore deposits and composition of minerals of metals.

To continuously be updated on new technology it was essential to know who to contact, acquire information about what was new, understand how technology functioned, to have a deep understanding of why it functioned the way it did and to know how to transfer and use the machinery, equipment and techniques rationally (for an explanation of know-how, know-why, know-who and know-what see Lundvall [2010], 330). In sum, technological changes were supported by complex knowledge specialisations:

Table 1.Simple overview of knowledge used in technologically advanced mining

Steps in the mining process	Knowledge areas	New knowledge areas from the late nineteenth century	Tacit knowledge	Relevant knowledge of new technology
1.Geological surveys/prospecting	Geology Mineralogy Chemistry Economics	Electro-engineering Economics Administration	High degree	Continuous acquisition of: know-how know-what know-who know-why
2.Removal of ores	Physics Mathematics Construction-engineering Mechanics			
3.Processing of ores	Geology Mechanics Chemistry Mineralogy Metallurgy (electro-engineering, electro-chemistry etc.)			

Source: Ranestad (2015, 151-197)

Technological knowledge was attained from many places, either from within the country or abroad, and in a variety of ways. The start-up and advance of innovative mining companies depended on a whole set of interacting organisations, which accumulated knowledge, developed technological capabilities and continuously adopted more efficient technology:

Table 2.Simplified model of steps in mining innovation processes and organisations involved

Innovation activity	Organisations
Be informed about new technology	Technical magazines (technical and scientific societies) Industrial exhibitions Formally trained professionals (universities and technical schools) Mining consultants (domestic or foreign)
Create, transfer and install more efficient equipment, furnaces, machinery and techniques	Geological mapping and ore surveys External companies (mechanical workshops) Research establishments (laboratories, research centres) External experts (professors, consultants, workers)

Use of new technology	Workers Engineers, technicians and other professionals with relevant scientific and practical knowledge

Source: Ranestad (2015, 151-197)

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, the different knowledge aspects outlined here, and the organisations which supported the development of these, formed a setting that was indispensable to innovate and carry out efficient and successful mining.

4. An overview of the two mining sectors: a gap in development

Mining has historically been the most important economic sector in Chile and represented up to eighty to ninety per cent of export in the late nineteenth century and twentieth century (Braun et al. 2000, 165-167). Thousands of small and big companies formed the sector, and after the turn of the century it increased to even more (OCEa 1909-1940). In Norway, the mining sector was smaller, but increased from 6, 5 per cent of exports in 1900 to 29, 2 per cent in 1939 (SSB 1952, 1953). From the 1970s, the extraction of oil and gas began, and developed to become the most important economic industry. Some years, oil and gas have accounted for more than fifty per cent of exports (WDI).

Both countries have long mining traditions, but they developed in very different ways in the late nineteenth and early twentieth centuries. There were 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 in three aspects, namely (1) to the relative extent to which mineral ores were utilised; (2) the technological level of the sector as a whole and (3) linkages to the domestic capital goods industry.

Perhaps the most remarkable negative trait in Chile was thousands of abandoned mines and the large unutilised mineral and metal ores. Chile had, and has, much natural resource potential, in terms of hydroelectric capacity and deposits of iron, silver, gold, sulphate, zinc, manganese and some of the world's largest deposits of copper (Gandarillas Matta 1915; SNM 1890-1940). This potential was not taken advantage of (Gandarillas Matta 1915; Macchiavello Varas 2010). In Norway, in contrast, in addition to traditional metals, such as copper, silver, iron and nickel, new large-scale mineral and metal productions were initiated in the late nineteenth century and an electro-metallurgical industry based on the utilisation of hydroelectric power was branched out (Carstens 2000).

From the end of the nineteenth century, the copper production in Chile started to decline. High-grade copper ores were exhausted and only lower grade copper deposits of under four percent copper remained. In the early twentieth century, North American companies began to exploit some of these low-grade copper ore deposits, using up-to-date technology in terms of mechanised equipment, large electric power plants and electrolysis. Small and medium sized domestic companies, in contrast, produced less pure minerals and metals and used old and inefficient technology based on human and animal power and 'pirquen' work[1]. Workers removed and extracted ores without the organised structure of modern mining companies. Thus, there was a clear technological gap within the mining sector. The saltpetre industry was also in decline (see e.g. Soto Cardenas [1998]; Villalobos [1990]; Macchiavello Varas [2010] for descriptions of the challenges in the mining sector). In Norway, on the other hand, there was no clear technological gap between companies. Actually, domestic companies, such as Kongsberg Silver Works and Røros Copper Works, were often ahead of foreign companies in the use of new technology (Carstens 2000; Børresen 2007).

[1] Miners collecting minerals and paying a fixed price or parts of the outcome to the owner

The two countries also differed when it came to linkages between the mining sector and the domestic capital goods industry. Mining companies in Norway, both domestic and foreign firms, gradually increased the use of domestic workshops for supply of complex machinery, equipment and other relevant inputs for the continuous improvement of operational techniques (BMK 1895-1906, 1906-1919; Berg 1998; Sæland 2005). Such linkages contributed to learning experiences and positive effects for the Norwegian economy as a whole. In Chile, on the other hand, such linkages, which had existed to some degree in the late nineteenth and early twentieth centuries, weakened from the 1920s, when the whole capital goods industry began to decline (Villalobos 1990). The large foreign companies from the early twentieth century purchased practically all inputs from abroad (Mamalakis 1976; Wilkins 1974; Wilkins 1970). The next sections present an empirical comparative analysis how and why the two sectors came to develop so differently.

5. Comparative empirical analyses of knowledge organisations for mining in Chile and Norway

An important reason for this comparison, is that similar types of public and private organisations with the aim of developing knowledge for mining, referred to in table 2, were developed, or accessed, in Chile and Norway in the nineteenth and early twentieth centuries:

(1) Intermediate and higher mining engineering programs
(2) Geological maps and ore analyses
(3) Innovative companies
(4) Mining societies and technical magazines
(5) Professional workers and consultants
(6) Scholarships for study travels
(7) Industrial exhibitions

The formation of these organisations suggests an ambition in both countries to advance the mining sectors. However, we need to analyse these organisations in further detail to actually understand how they functioned and their effect on innovation.

a. Mining instruction: similar in character

In 1757, the Mining Seminar in Kongsberg in Norway was established. Later, in 1814, the mining engineering program was transferred from Kongsberg to the Royal Frederick University in Christiania and in 1914 it was again transferred to the newly opened Norwegian Institute of Technology. In 1867, the Ministry of Finance opened an intermediate mining school, Kongsberg Silver Works Elementary Mining School. In Chile, the Faculty of Mathematics and Physical Science provided education in mining engineering from 1853. Additionally, public intermediate mining schools were established at some of the important mining districts around the country. The Mining School of Copiapó was founded in 1857; the two mining schools of La Serena and Santiago were founded in 1887, but the Mining School of Santiago was closed down in 1912. The Industrial School of Saltpetre and Mining in Antofagasta, was founded in 1918, and provided a practical education directed towards the saltpetre industry. 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 and more focused on practical exercises and work.

The content of the study programs were remarkably similar in the two countries. The mining engineering programs included general natural science courses as well as 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, in addition to mining subjects, such as the use and repair of mining machinery, courses about mine structures and constructions, metallurgy, ore survey etc. The knowledge areas, on which mining activities were built, outlined in table 1, roughly matched the mining engineering programs in both countries (see table below):

Table 3. Simple overview of knowledge domains and mining engineering study programs

Knowledge areas	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

Source: Ranestad (2015, 256-314)

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 in both countries, but the teaching was based on a shorter introduction of the subjects. The somewhat shorter mining technician programs excluded in-depth teaching of scientific theories, but focused instead more on hands-on practice and exercises (SB 1966; EMC 1957)

Changes were made continuously in the study programs in both countries. Changes and adoption of new courses 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 the mechanisation process and electro-engineering, which was introduced as new courses both places in the early twentieth century, occurred after the shift to electric power around the turn of the century. Specialisations were gradually made in the mining engineering programs from the turn of the century, with one program focusing on mining and the other on metallurgy (NIT 1932; UC 1890). These changes responded to the increasing number of productions, specialisations and new techniques that were adopted at the time. Old laboratories and workshops were gradually upgraded in both countries and new and improved teaching facilities were constructed. The Government in Chile used contacts in Europe to employ professors for the courses which lacked teachers (Domeyko 1872).

In sum, the study programs in both countries adapted to and supported the increasingly technologically complex mining industries. It is clear that the educational establishments in both countries provided highly relevant knowledge for the countries' mining sectors and, therefore, there is reason to believe that other knowledge factors instead explain how and why the two sectors developed so differently.

b. Mining engineers, technicians and other professionals: discrepancy

Mining engineers and technicians, but also chemists, construction engineers, mechanics, electricians and administrative workers were crucial for efficient mining operations. A clear distinction between the two countries is the number of mining engineer and technician graduates available in the country compared to the size of the two sectors. From 1850 to 1940 the total number of graduated mining engineers in Norway was 287 (AMS 1855-1940), while it totalled 302 in Chile (UC 2003). Both countries had a steady provision of mining engineers, but given that the mining sector in Chile was tenfold larger than the sector in Norway in terms of number of workers, productions and exports, Chile's 15 additional mining engineers were clearly far too few. Estimates suggest that Norway had access to many more mining engineers than Chile. If

mining engineers had an average career of forty years in both countries, the number of workers per mining engineer remained relatively stable between 45 and 92 in Norway, while the relative number of mining engineers declined in Chile; 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):

Table 4. Workers per mining engineer (selected years)

Estimated career of 40 years

Year	Norway				Chile			
	Workers	Number of mining engineer graduates*	*Estimated number of mining engineers available*	***Number of workers per mining engineer***	Workers	Number of mining engineer graduates*	*Estimated number of mining engineers available*	***Number of workers per mining engineer***
1860	--	3	--	--	21 367	4	*15*	***1 424***
1865	3408 (year 1866)	1	*48*	***71***	24 396	0	*27*	***903***
1870	3239	1	*50*	***65***	27 033	7	*49*	***552***
1875	2978	0	*49*	***61***	30 207	9	*69*	***438***
1880	2240	3	*50*	***45***	37 935	4	*94*	***404***
1885	2383	0	*51*	***47***	43 789	2	*111*	***394***
1890	2899	2	*45*	***64***	51 345	2	*122*	***421***
1895	2015	3	*51*	***40***	59 713	1	*129*	***463***
1900	3319	1	*49*	***68***	55 398	2	*124*	***447***
1905	4768	3	*52*	***92***	66 626	3	*122*	***546***
1910	6652	12	*91*	***73***	83 677	0	*104*	***805***
1915	8917	6	*152*	***59***	95 421	3	*91*	***1 049***
1920	6267	6	*179*	***35***	98 442	3	*86*	***1 145***
1925	8427	3	*198*	***43***	131 168	8	*94*	***1 395***
1930	9727	2	*191*	***51***	127 882	7	*103*	***1 242***
1935	9597	5	*197*	***49***	99 344	12	*130*	***764***
1940	10074	1	*221*	***46***	123 065	10	*163*	***755***

Calculated on the basis of number of mining engineer graduates and workers.
Source: Ranestad (2015, 314-54).
*Number of graduates the current year.

Chile would have required hundreds, and some years thousands of more mining engineer graduates to match Norway. In 1880, instead of 94, Chile would have needed 800 available mining engineers to reach 45 workers per mining engineer, as in Norway. In 1920, Chile would have required 2800 available mining engineers to obtain 35 workers per mining engineer, instead of 86. It was undoubtedly highly challenging for this small amount of mining engineers to reach across all thousands of positions at the mining schools, research establishments and the thousands of companies in the country.

Due to lack of the numbers of mining technicians at any given time, it is not possible to make the same estimate and comparison as for mining engineers, but we can still make some indications. In Norway, 191 mining technicians graduated from the Kongsberg Silver Works Elementary Mining School between 1869 and 1940 (SB 1966). 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, but with similar estimates as for the mining engineers, workers per mining technician always remained under ninety. In Chile, the total number of graduates from all mining schools is known from 1905 to 1925, which in this period totalled 415 graduates. The available numbers indicate that the provision of mining technicians was in general considerably higher than mining engineers. 1906 represents the year with the most mining technician graduates, with forty-five graduates. In 1925 the number had decreased to thirteen. (OCEb 1905-1925). Nevertheless, in spite of a higher number of mining technicians, 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 few mining technicians.

In Norway, a revision of student yearbooks from 1855 to 1943[2] shows that mining engineers and technicians, as well as other professionals, such as chemists, construction engineers, mechanical engineers, electricians, and also workers with administrative background, such as economists, accountants and secretaries, continuously entered the mining sector (AMS 1855-1940; Bassøe 1961). This flow of professionals to the sector enabled a spread of experience and know-how between companies. In Chile, the small- and medium sized companies normally did not employ professional workers. Directors and managers at these companies were without training and lower positions were filled by 'simple practitioners' without technical instruction and in many cases without primary school (SNM 1910, 330). Engineers, company managers, professors and other members of the National Mining Society explicitly requested more professional workers, especially mining engineers (see all years SNM 1890-1940). Civil engineers, mining technicians and others functioned as relatively good substitutes for the mining engineers, but also they were scarce (SNM 1925, 663-4). The foreign technologically advanced companies had an alternative, namely to hire foreigners. They recruited hundreds of engineers, as well as technicians, mechanics, chemists, electricians and other professional workers from abroad (Solano Vega 1918; ACMCR 1925-1928 staff). Foreign engineers almost exclusively held the leading and managing positions at these companies and thus worked without interaction with domestic professionals. This situation strengthened the technological gap within the sector and prevented valuable knowledge transfer from happening.

c. Organisations for knowledge transfer: discrepancy

Small catching-up economies often based their innovation processes on foreign technology (Bruland 1998). Efforts were made in both Chile and Norway to facilitate knowledge transfer to the mining sectors from other countries. Technical magazines with information about up-to-date technology was published in both countries (DNIF and DPF 1913-1940; SNM 1890-1940). Additionally, engineers and workers participated at industrial exhibitions to observe new machinery, drilling- lifting- and transport equipment, converters, furnaces, turbines etc. (AMS 1855-1940; SNM 1890, 96; Yunge 1905). 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 initiatives, which supported practical experience with foreign technology. To actually transfer and use machines and equipment it was not enough to read about them in magazines or observe them at exhibitions. Tacit knowledge was particularly present in mining and hands-on experience was crucial to select, transfer and adopt technology. Visits to foreign mining plants, research centres and universities where relevant technology was used in operation, was therefore key to enable technology transfer. During trips abroad engineers and technicians acquired contacts, information of new techniques, and most importantly they acquired practical knowledge and experience with foreign technology. Professors and engineers in both countries expressed the importance of such trips for capacity building (Domeyko 1872, 22; TU 1883, 133-4).

Continuous public and private programs for travel scholarships were established in Norway. Ninety-nine scholarships, grants and funds were provided to mining engineers between 1850 and 1940 with the aim of learning about mining technology. Over seventy per cent of the mining engineers went abroad to visit plants and industrial exhibitions, do practice, work for a longer period at a foreign company or to do field trips (AMS 1855-1940; Bassøe 1961). In Chile, in contrast, there are traces of only six public and private scholarships. There are no traces of mining engineers systematically abroad, as the Norwegians did from an early stage (Jerez Bravo 1950; UC 1843-1940; SNM 1890-1940). The small number of scholarships for knowledge transfer purposes put the Chilean mining engineers in a disadvantage and hindered a free flow of practical knowledge and experience with up-to-date technology to the mining sector. Although a number of factors should be in place for innovations to occur, companies could hardly transfer

[2] See Ranestad's doctoral thesis for an explanation of the student yearbooks and the use of these.

technology without hands-on practical knowledge and experience with the relevant techniques, equipment and machinery.

d. Geological mapping and ore surveys: discrepancy

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. Geological maps, prospecting and detailed scientific ore analyses were vital to begin and continue efficient and profitable mining. Without a deep understanding of the geology and about the existing mineral deposits and their potential profits, new mining projects could hardly take place and the mining sector could barely advance (David and Wright 1997). The utilisation of gradually lower grade mineral and metal ores from the late nineteenth century, increased even more the importance of detailed information about possible economic returns.

The most remarkable difference between the two sectors was in fact related to initiatives of detailed geological mapping, prospecting, detailed analyses of ore and economic planning. The Geological Survey of Norway was established in 1858. 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 (Børresen 2008). In Chile, one of the main problems was the lack of such geological surveys and ore analyses of the country's existing mineral deposits. A permanent organisation with the aim of systematically map the country's resources, did not exist in Chile. Sporadic geological work was carried out (Villalobos 1990), but it was not nearly enough to acquire complete and in-depth knowledge of existing ore deposits, 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 (De Ferranti et al 2002, 58-59). In short, 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. This, in turn, was linked to the small number of mining engineers and geologists in the country, who were indispensable for this type of work.

6. Concluding remarks

This paper has analysed and compared the functions and outcomes of a number of knowledge organisations for mining in Chile and Norway. On the surface, all of the knowledge organisations appear equal, and some of them also were. However, the formation of these organisations did not guarantee development, since, as seen, the sector in Chile did not develop optimally. A deeper analysis shows that the set of organisations in Chile blocked transfer, use and diffusion of knowledge, while in Norway the organisations facilitated knowledge development (see table below):

Table 5.Simple overview of knowledge organisations and the knowledge gap

Organisation	Measurement	Comparison
Mining education	Character of mining instruction	Equivalent
Mining engineers and technicians	The extent to which mining engineers and technicians reached across the sector	Discrepancy in amount
Engineers and other relevant professionals educated locally	The extent to which other relevant professional workers reached across the sector	Discrepancy in amount
Industrial exhibitions and technical journals	The extent to which companies acquired information about new technology	Equivalent
Study travels and work abroad	The extent to which mining engineers travelled and worked abroad	Discrepancy in amount
Geological mapping and ore surveys	The extent to which geological surveys and research institutions reached across the sector	Discrepancy in amount
Foreign consultants and expertise	Use of foreign professionals and consultants	Discrepancy*

* Foreign engineers and industrialists were crucial for the development of Chilean mining and were normally the ones who initiated changes in technology at the foreign companies. However, their dominance was negative in the sense that the lack of collaboration with domestic engineers and leaders prevented knowledge transfer within the sector.

The mining sector in Chile was huge, but developed slowly, while the mining sector in Norway continuously changed and adapted to global trends. Discrepancies in the functions and outcomes of the two countries' organisations explain to a large degree the development gap between the two sectors.

In Chile, the unsystematic operation at the technologically backward small and medium-sized companies did perhaps not require professional workers, but if they were to rationalise operation in terms of adopting new energy sources, machinery and processing techniques, mining engineers and workers with relevant scientific and practical experience were key. The issue was that, even if these companies wanted to innovate, there were far too few mining engineers, mining technicians and other professionals graduating from domestic educational establishments who could manage and operate these companies. Formally trained and experienced mining engineers were also essential in geological surveys and ore analyses, but lacked for such purposes too. Thus, the lack of geological maps and ore surveys in Chile were linked to the few mining engineers and geologists in the country. This was particularly serious because it prevented start-up of mining companies and advancement of industries. This was in marked contrast to the large-scale technologically advanced foreign companies, which used professionals from other countries instead. In Norway, there was a continuous supply of mining engineers, technicians and other professionals to the mining companies and National Geological Survey, which indicates that this country did not have this problem.

The lack of professionals in Chile was perhaps linked to the poor status that characterised engineering and technician professions. However, the main challenge of recruiting students to the programs was due to the fact that a large share of the primary school cohorts did not attend school and even fewer passed the final high school exam (Braun 2000, 238; Blitz 1965, 305-6). This created a bottleneck in the education system. 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 (Engerman and Sokoloff 2005). In 1950 19, 8 per cent of the population was still illiterate (Blomström and Meller 1991, 7). Norway did not have the same challenge, as campaigns to improve the reading and writing skills of the population have roots back in the seventeenth century, a regular school system was established in 1860 and by the 1890s the literacy rate was near a hundred per cent (O'Rourke and Williamson 1995, 299).

It should be stressed that the size of the mining sector in Chile made its negative characteristics particularly severe. Without taking advantage of the country's mineral and metal deposits and catching up and adopting new technology that characterised advanced mining at the time, it was difficult for the sector to generate a boost and becoming a real driving force for the economy. The lack of linkages to other industries prevented dynamic learning and innovation processes from happening, which in turn had implications for the wider economy. At the same time, the knowledge gap between the two mining sectors might also have reflected other industries. For instance, the capital goods industry in Chile, which supplied the mining sector with indispensable machinery, equipment and furnaces, declined from the 1920s, while this industry in Norway had by this time developed into a 'leading branch'(Lange 1989, 17). Comparisons of these two industries, and others, might also be connected to whether or not they had access to relevant knowledge to build the industry.

This leads to the question as to *why* organisations functioned so differently in the two countries. In Norway, the state was much more active in supporting knowledge development as it funded the National Geological Survey, formal schooling and universities, and managed many of the scholarships for study travels. In Chile, members of the National Mining Society, professors and engineers expressed the need for more geological surveys, more professionals and more initiatives to send engineers abroad to learn, and some public and private initiatives were also

made, 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, considering that it was a country with a lot of natural resource potential, huge mineral and metal deposits and even some of the largest copper deposits in the world. The underlying reasons for the unfavourable development of these knowledge organisations in Chile was imbedded in 'rules of the game' of the society, but at the same time it seems like it was linked more specifically to the role of the state. Mapping the country's natural resources, education and knowledge transfer were simply given lower priority by the broader set of political decision-makers. The downgrading of the mining sector is illustrated by the budget from 1921, which shows that mining was not prioritised nearly as much as agriculture and manufacturing industries, even though it was clearly the largest export sector:

> 'Education and fostering of agriculture 2 358 180
> Education and fostering of manufacturing industries 1 477 588
> Education and fostering of mining (including mines and geology) 803 617' (SNM 1921, 457)

The reason why agriculture was given priority in Chile, was probably because the agricultural and oligarchic elite dominated the political agenda. The Colonial system was feudal and characterised by an exclusive elite with political and economic control. Chile has been considered one of the most stable democracies in Latin America (from 1831 to 1973), but the political and hierarchical social system meant a restricted access to capital, property rights, resources and education for others than a small limited group (e.g. Mamalakis 1976, 353; Muñoz Gomá 1986; De Ferranti et al. 2002, 65). 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. In Norway, in contrast, there were practically no land nobility or military caste and nobility privileges were abolished when the country became independent from Denmark in 1814. The feudal tendencies were week and small private farmers owned the majority of the soil. Self-owned farming represented eighty-one per cent in 1855 and ninety-five per cent in 1875 (Bergh et al. 1983, 36). This fairly equal income distribution, and small social differences, may have given rise to a more general positive attitude towards industrial development and fostering opportunities for all. However, a deeper comparative analysis of the institutional mechanisms which regulates such these knowledge organisations, and their historical background and development, should be carried out to further our knowledge of why industrial development and natural resource exploitation have been facilitated to a larger degree in some 'natural resource intensive economies' than others, and in this case more in Norway than in Chile.

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