DOCUMENTOS DE TRABAJO
ISSN 2174-4912

ENGINEERS AND THE *KNOWLEDGE GAP* BETWEEN ANDEAN AND NORDIC COUNTRIES, 1850-1939

José Peres-Cajías and Kristin Ranestad ∝

DT-AEHE Nº 2005
www.aehe.net

June 2020

DOCUMENTOS DE TRABAJO
ISSN 2174-4912

INGENIEROS Y *BRECHA DE CONOCIMIENTO* ENTRE LOS PAÍSES ANDINOS Y NÓRDICOS, 1850-1939

José Peres-Cajías ǂ and Kristin Ranestad§

DT- 2005, June 2020
JEL: N40, N50, N80, O33, O38

RESUMEN

En lugar de dotaciones exógenas, los recursos naturales pueden verse como recursos económicamente explotables gracias a mejoras en el *conocimiento*. Esto subraya la necesidad de comprender por qué algunos países abundantes en recursos naturales pueden desarrollar sus propias tecnologías, mientras que otros no. Abordamos este problema observando la evolución de las facultades de ingeniería y los ingenieros graduados desde 1850 hasta 1939 en países andinos y nórdicos, dos regiones donde los recursos naturales fueron críticos al comienzo del crecimiento económico moderno. Encontramos la consolidación de una *brecha de conocimiento* entre los países andinos y nórdicos durante la Primera Globalización que se materializó en: a) una diferencia drástica en el número total de ingenieros capacitados localmente; b) el papel que desempeñaron estos ingenieros en sus respectivos mercados laborales. Estas diferencias fueron el resultado de diferencias en el apoyo público a la educación primaria, y a las tradiciones migratorias. Ambas, a su vez, están vinculadas a contingencias históricas y geográficas.

Palabras clave: Capital humano, tecnología, innovación, Primera Globalización, patentes, minería.

ABSTRACT

Rather than exogenous endowments, natural resources can be seen as economically exploitable resources thanks to knowledge improvements. This underscores the need to understand why some natural resource abundant countries are able to develop their own technologies while others are not. We tackle this issue by looking at the evolution of engineering faculties and graduate engineers from 1850 to 1939 in Andean and Nordic countries, two regions where natural resources were critical at the onset of modern economic growth. We find the consolidation of a *knowledge gap* between Andean and Nordic countries during the First Globalization that was materialized in: a) a drastic difference in the total number of locally trained engineers; b) the role that these engineers played in their respective labor markets. These differences were the result of differences in public support to primary education and migration traditions. Both, in turn, are linked to historical and geographic contingencies.

Keywords: Human capital; Technology; Innovation; First Globalization; Patents; Mining.

ǂ Universitat de Barcelona, Spain. E-mail: joalperes@ub.edu
§ Lund University, Sweden. E-mail: kristin.ranestad@ekh.lu.se

ENGINEERS AND THE *KNOWLEDGE GAP* BETWEEN ANDEAN AND NORDIC COUNTRIES, 1850-1939[1]

1.- Introduction

The debate on the natural resources curse has generated a large body of literature (see, for instance, the surveys by Badeeb, Lean, & Clark, 2017 or Frankel, 2012). A stream of this literature stresses that the net effect of natural resource exploitation is mediated by the quality of institutions (Mehlum, Moene, & Torvik, 2006; Papyrakis & Gerlagh, 2004). The identification of this causal mechanism has improved the debate but there is still a black box concerning some of these issues (Ranestad, 2018).

In this context, the study of specific organizations is a valuable alternative. This is particularly true in the case of *knowledge* creation associated with natural resources exploitation. Indeed, according to David & Wright (1997) and Wright (2015) natural resources (and particularly mineral resources) must not been considered a gift of nature, but an outcome of human ingenuity. Specifically, by looking at the United States' experience during the late nineteenth century and early twentieth century, these authors propose that mineral exploitation generated technical challenges that enabled a constant improvement of techniques, methods and machines. Thus, beyond the mere availability of factors of production, "the successful extension of the mining frontier also required (…) the ability to recognize potentially valuable deposits, innovations in techniques of extraction, and metallurgical breakthroughs" (Wright, 2015: 124).[2]

If this idea can be generalized,[3] natural resources would be economically exploitable resources derived from knowledge and technology improvements rather

[1] This work is funded by Vetenskapsrådet (The Swedish Research council). Project *Sustainable Development, Fiscal Policy and Natural Resources Management. Bolivia, Chile and Peru in the Nordic countries' mirror*, Reference: 2016-05721. Peres-Cajías also acknowledges funding from Generalitat de Catalunya-AGAUR through the Beatriu de Pinós program (BP2016-00407). We thank two anonymous referees, Marc Badia-Miró, Edward Beatty, Andoni Collao, Manuel Contreras and Felipe Valencia for their comments to previous versions of this paper. Their suggestions were critical to improve our work.

[2] "Perhaps the best evidence that American mineral abundance was not a simple matter of endowment is that the size and importance of the sector emerged in historical time" (Wright, 2015: 121). The authors also stress that whereas practical knowledge was important, US mining "increasingly drew upon higher-order forms of knowledge and individuals with advanced scientific training" (Wright, 2015: 124). Therefore, the exploitation of natural resources allowed increasing both the stock of specialized human capital and available technologies, which in turn benefited other sectors of the economy (Wright, 2015: 133-134).

[3] For instance, Ville & Wicken (2013) propose that, even in the present day, natural resource exploitation is critical to understand the economic success of Australia and Norway. According to the authors, in both

than exogenous endowments. Therefore, the natural resource curse is not destiny but a process that is mediated by the countries' ability to invest in "indigenous, country-specific knowledge and human capital pertaining to exploitation, extraction, processing, and sometimes usage of domestic resources" (Wright, 2015: 135).

From this perspective, it becomes critical to understand why some natural resource abundant countries are able to develop their *own technologies* while others fail. Ville & Wicken (2015) identify three main explanations for the Australian and Norway successes: a) there is an old common share belief that knowledge is useful for society; b) there are critical organizations that enable *access to knowledge*, allows the *diffusion of knowledge* and consolidate *dynamic networks*; c) there has been a gradual improvement of *local knowledge* capabilities that has allowed solving local problems through local *technological innovations*.

Regarding the second determinant before mentioned, the role played by educational organizations stand out. These have been at the core of previous research that compared development paths of successful natural resource abundant countries (Australia, Canada, United States or Nordic countries) with that of Latin America (Blomström & Meller, 1991; De Ferranti, Perry, Lederman, & Maloney, 2002; Ranestad, 2018). Specifically, significant differences in investment in general and technical education have been identified.

This paper aims to expand this analysis and compare the evolution of a particular educational organization (engineering faculties) in Andean and Nordic countries between 1850 and 1939. Both regions are natural resource abundant and adopted an export-led growth strategy in this period. Moreover, both were small open economies (Ducoing et al., 2018) that, at least initially, depended on foreign technologies. These regions diverged economically in the twentieth century: the Nordic countries converged to the most developed cluster and the Andean cluster remained among the laggards. The analysis of these divergent fortunes can shed light on why some natural resources abundant countries have been able to achieve more sustainable growth paths while others have not.

The study focuses on the 1850-1939 period given our interest in the roots of economic divergence. In effect, we have shown that economic divergence between these two regions (measured by the GDPpc) became evident just after the Great Depression (Ducoing et al., 2018). Nevertheless, we have proved that there was a constant diversification of the export basket in the case of the Nordics between 1850 and 1939 (Badia-Miró, Carreras-Marín, Navarro, & Peres-Cajías, 2020). This diversification is not evident when natural resource exports' share of total exports is

---

countries there has been a constant renewal and extension of natural resource based industries thanks to the consolidation of enabling sectors; specifically, capital goods production, and research and development activities. The interaction between these enabling sectors and natural resources exploitation has both increased the complexity of the natural resource sector and generated spillovers to the rest of the economy.

analyzed but differences become clear through a detailed examination of the number of products exported, the technological complexity of these exports and the number of destinations. Differences between the two regions are also significant in terms of industrialization: it expanded significantly in the Nordic countries and remained weak in the Andean ones during the 1850-1939 period.

We propose that differences in both exports complexity and industrialization can be better understood by looking at *knowledge* differences.[4] We approach this issue through the analysis of engineering faculties. This is justified both by theoretical and historical reasons. In relation to the former, we depart from López, Molero, & Santos-Arteaga (2010) who recall that differences in the ability of laggard countries to adapt state of the art technologies can be determined by institutional frictions and differences in education processes and levels. In their model, they prove that, even without institutional frictions, differences in education processes and levels can generate poverty traps and divergent growth paths for identical available technologies. Thus, “the lower the knowledge of the labor force or the quality of the technological infrastructure of a country, the lower the factor productivity obtained from the new technology and the probability of generating new innovations" (López et al., 2010: 107). As for historical justifications, there is a large body of literature that proves the engineers’ centrality during the Second Technological Revolution (Ahlström, 1982; Bertilorenzi, Passaqui, & Garçon, 2016; Maloney & Caicedo, 2017).

For all these reasons, we suggest that the analysis of the stock of available engineers from 1850 to 1939 can improve our understanding of the divergent paths of Andean and Nordic countries. We define this stock as the <u>innovative capacity</u> of a country and we propose that it is a function of changes in <u>the innovative potential</u> and changes in <u>indigenous innovations</u>. We operationalize this simple analytical framework through different variables. Following Maloney & Caicedo (2017), we measure the innovative capacity through the *stock of locally trained engineers*.[5] In order to offer a qualitative assessment of this variable, we also describe the role played by these locally trained engineers in their respective labor markets. As for the study of the innovative potential, we look at the creation of *engineering faculties* and the *number of graduated students* in these institutions throughout time. Since we need to asses if this potential was in line with effective innovations, we use the *number of granted patents* to measure indigenous innovations. Whereas patents have different shortcomings when comparing

[4] To be sure, we are not claiming that differences in the stock of indigenous-country-specific knowledge is *the* variable that explain the roots of divergence between Nordic and Andean countries.

[5] The authors define engineers as “the stock of higher level scientifically oriented human capital available during the second wave of the Industrial Revolution” (Maloney & Caicedo, 2017: 3). Moreover, given that they are interested in local technical capacity, their variable is constructed taking into account only engineers with domestically emitted university degree. Using this variable, they found no correlation between the stock of engineers *c*. 1900 and national income in 1900, but a strong and significant relationship between the stock of engineers *c*. 1900 and national income *c*. 2000. Therefore, they argue that the support of technical knowledge at the turn of the 20th century put the seeds of future growth.

innovation between countries,[6] they provide information on the vitality of an entrepreneurial ecosystem. Furthermore, patents were progressively dominated by engineers during the Second Industrial Revolution (Inkster, 2003).

Our study confirms the idea of a growing *knowledge gap* between Andean and Nordic countries during the 1850-1939 period (Ranestad, 2018). This gap was materialized in: a) a drastic difference in the total number of locally trained engineers; b) the role that these engineers played in their respective labor markets. The immediate causes of these differences lies on the higher levels of literacy (and therefore higher potential to acquire specialized education) in Nordic countries, as well as in their early and massive migration tradition. These determinants, however, can be traced back to institutional differences in the public support to basic education since the seventeenth century and the geographic closeness of Nordic countries to other economies that were industrializing.

After this introduction, Section 2 analyses differences in basic education between the two groups of countries from 1850 to 1939. Sections 3 and 4 presents the evolution of the main engineering faculties and the number of graduated students. Section 5 compares the patent systems and the number of granted patents. Section 6 analyzes the availability of locally trained engineers relative to the size of the mining sector –an economic activity that was present across the Andean and Nordic countries. Section 7 deals with the role that these engineers had in their respective labor markets. Section 8 concludes.

2.- Literacy and basic education

Before looking at the evolution of engineering faculties and the number of graduated students in these institutions, we study different indicators of basic education in Andean and Nordic countries from 1850 to 1939. This is because minimum levels of literacy and basic education are necessary to receive, learn and transfer codified information, which is the vehicle of knowledge creation and diffusion.

The contrast in terms of literacy rates between Andean and Nordic countries is remarkable: problems were constant in the former and full literacy rates were achieved in the latter at the end of the nineteenth century (Table 1). Regarding the Nordic countries, Cipolla (1969: 113) stresses that more than 70% of the adult Nordic population, including Denmark, Faeroe Islands, Iceland, Finland, Sweden, Norway, along with Germany, Holland and Scotland, was literate by 1850.There are also estimates for Denmark and Norway that suggest that, already in 1873, around 87% were able to write and read and 99% were able to read (Hodne, 1981: 250). Other sources

[6] For instance, it is stressed that the study of patents does not allow differentiating between inventions, improvements or innovations (Inkster, 2003). Likewise, it could be the case that definitions or prices to get patents are greatly different.

show that by the 1890s the literacy rate was near a 100% in Denmark, Sweden and Norway, while Finland was lagging behind (O'Rourke & Williamson, 1995: 299).

Table 1. Literacy and basic education indicators in Andean and Nordic countries, 1850s-1930s

	Literacy						**Numeracy (ABCC indicator)**					
	Bolivia	**Chile**	**Peru**	**Finland**	**Norway**	**Sweden**	**Bolivia**	**Chile**	**Peru**	**Finland**	**Norway**	**Sweden**
1850s	10.0									100.0	98.4	100.0
1860s		18.0							45.0	100.0	99.0	99.7
1870s		25.7	18.0				44.0		66.9	98.9	98.8	99.8
1880s	13.0	32.0					55.3		73.0	100.0		100.0
1890s		52.9		89.0	98.0	98.0	59.7	87.4	76.4	99.8		99.9
1900s	16.0	50.4					70.3	86.3	81.9	100.0	100.0	99.9
1910s	20.2						78.9	91.3	85.1	98.8	100.0	100.0
1920s	22.5	63.3					84.5	93.3		99.5	99.0	98.4
1930s	24.9	75.3	42.0				89.3	94.5		100.0	100.0	100.0
	Enrollment rates in primary education						**Average years of education**					
	Bolivia	**Chile**	**Peru**	**Finland**	**Norway**	**Sweden**	**Bolivia**	**Chile**	**Peru**	**Finland**	**Norway**	**Sweden**
1870s		18.7			60.8	56.9		0.9	0.3	1.5	5.7	4.2
1880s	2.0	14.0		6.6	58.8	72.1	0.6	1.0	0.4	1.5	5.7	4.6
1890s	4.8	20.2	9.5	10.2	65.4	74.5	0.7	1.6	0.4	1.6	5.7	5.0
1900s	7.9	21.7	12.5	18.8	66.8	68.9	1.2	1.7	0.5	1.7	5.8	5.5
1910s	13.4	38.8	15.3	26.4	68.6	66.9	1.8	2.0	0.6	2.0	6.0	5.9
1920s	15.1	42.3	16.4	38.7	69.4	60.7	2.4	2.9	1.2	2.7	6.3	6.2
1930s		55.6	22.4	51.2	71.6	63.7	2.7	3.9	1.7	3.6	6.5	6.6

Sources: Literacy rates: for Bolivia, estimations by Velásquez-Castellanos (2017); for Chile, Díaz, Lüders & Wagner (2016); until 1880s for people older than 7 and since 1890s for people older than 15; for Peru, Arroyo Abad (2016); for the Nordic countries, O'Rourke & Williamson (1995). Enrollment rates in primary education from Benavot, & Riddle (1988). For numeracy, Baten (2015) in Clio-Infra. For average years of education, Bas van Leeuwen, Jieli van Leeuwen-Li, and Peter Foldvari (2015) in Clio-Infra.

The Andean and Nordic countries also differ when it comes to numeracy: while there is no evidence of age-heaping in either of the three Nordic countries since the mid-nineteenth century, this was a constant problem in Bolivia and Peru.[7] In fact, despite improvements, age heaping restrictions persisted in these two countries until the early twentieth century.

Differences are also striking when we compare enrollment rates in primary education. On the one hand, they were around 60% in Norway and Sweden already in the mid-nineteenth century. In the former, there were constant improvements throughout the entire period that can be linked to the early development of a basic school system:

[7] The ABCC indicator is a normalization of the Whipple Index which ranges from 0 (severe problems of age heaping) to 100 (no evidence of age-heaping).

since 1827 all children in the country between seven and fourteen years old should receive teaching in reading, writing and some calculation for at least three months a year. Later, in 1860, a law established regular school for all children during seven years (Hodne, 1981: 242-243).

In the case of Sweden, Westberg (2019) stresses the existence of continuous investments in basic education by Swede municipalities as a result of the School Act of 1842 and the strong preference at all levels of society for basic education. This preference is traced back to the Church law (1686) and the imposition of literacy requirements (also at the very local level) in the context of Protestantism consolidation across the country. Andersson & Berger (2019) recognize the importance of this long-term determinant, but also propose that the continuous investment in education at the local level during the nineteenth century (i.e. a period of restricted political participation) deserve alternative explanations. Among plausible reasons, they highlight the patronage role of local elites, responses to the proletarization of the rural population and changing preferences of the elites in a new context of state-building. In any case, both proposals are part of the long tradition of scholars that highlight that levels of human capital and schooling in Sweden were considerably higher than what would be expected given its economic development.

School enrollment in Finland is also noticeable since it jumped from very low levels in the mid-nineteenth century up to 50% in the 1930s. The direct reason for this lagging behind is unclear. Notice, however, that instruction in writing was optional until 1866, when a school law made it mandatory (i.e. more than twenty years after Sweden and almost forty years after Norway). It is pointed out that school attendance was low in the nineteenth century, and that the schools were mostly attended by children from higher classes. Although mass campaigns to improve literacy was introduced at the end of the seventeenth century, as in Sweden, spread of popular literacy in Finland is found to become significant only in the early twentieth century (Markussen, 1990: 40; Tveit, 1991: 244).

Regarding the Andean countries, the improvements that are identified in enrollment rates in Table 1 were not enough to overcome the lower ranks in international comparisons. For instance, in the case of Chile, which was the most successful case among the Andean countries, scholars indicate that the development and expansion of the basic school system was slow. In 1860, a reform clarified that the state (i.e. public institutions) should be the main provider of primary education, either through municipalities, state funded religious congregations or the central government; yet only 17% of the age appropriate population attended primary school that year (Díaz, Lüders & Wagner, 2016). It was not until 1920, a century after independence, that mandatory primary education was introduced, meaning compulsory primary schooling for both sexes for four years before the age of thirteen.[8]

In Peru, educational initiatives took place in the 1870s in the context of the guano boom. However, it was not until the centralization of education (1905) that primary education became free and compulsory (Arroyo, 2016). This change is not negligible given that, in contrast to the Swedish case, decentralization in Peru was associated with lower levels of educational spending. Indeed, Arroyo, (2016) stresses that improvements in educational outcomes in Peru between 1876 and 1940 were very unequal in regional terms. She specifically suggests that there was a negative relationship between education progress and the relative importance of indigenous population. According to her, this was the case because of the control that local elites had over education expenses and their low interest in the expansion of education since this could affect their political prominence (franchise was restricted by literacy and economic restrictions).

The critical role of centralization was more evident in Bolivia, where improvements in both literacy and basic school enrollment were a consequence of the new educational policy imposed by the *liberales*. This policy implied a centralization and an increase of education expenses (1904) and the introduction of a new pedagogy system where the formation of teachers played a critical role (1907) (Peres-Cajías, 2017; Velásquez-Castellanos, 2017). These changes had positive impacts that are noticeable when looking at the previous evolution of the Bolivian educational system, but were still very poor by international standards: in the 1920s, for instance, basic school enrollment rates were around 15%.

Thus, even until the Second World War, no Andean country overcame a 60% enrollment rate in basic education, the rate that was achieved by both Norway and Sweden in the 1870s. Then, not surprisingly, differences in average years of education between the two groups of countries, that were already large in the mid-nineteenth century, persisted throughout the entire period under consideration. According to figures in Table 1, Norwegians and Swedes had on average more years of education (in a range between 2.6 and 5 years) than any Andean country.

Altogether, this evidence shows that there was a potential "bottleneck problem" in Andean countries with too few qualified students to enter higher and technical education programs. For instance, there is evidence that in Bolivia, of 905 students who were enrolled in the first year of basic education in 1925, only 139 were still enrolled in the sixth year in 1930 and, among them, only 5 entered to higher or technical educational programs, and only 1 effectively graduated (Velásquez-Castellanos, 2017: 535). Thus, differences in the quantity of students that could attend higher education

[8] See *Ley de Instrucción Primaria Obligatoria* and Documento IV/4 *Lei Sobre Educación Primaria Obligatoria* (1920). In any case, 100% primary school attendance was not obtained until the end of the 1950s (Díaz et al., 2016).

should be considered when looking at differences in the innovative potential of Andean and Nordic countries.

3.- The innovative potential: engineering faculties

Previous studies emphasize an early development of engineering faculties in Nordic countries (W. Maloney, 2002) and poor improvements in the case of Latin America (De Ferranti et al., 2002: 60). The year of foundation of the first mining or engineering school across the world illustrate these differences in timing (see the Appendix). On the one hand, it confirms the early beginning of mining engineering in Norway, where formal mining engineering started in 1757 with the Mining Seminar in Kongsberg. Thereafter, engineering programs 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 specializations.[9]. In 1910, the Norwegian Institute of Technology (NIT), much based on the German Technische Hochschulen, was founded and provided engineering programs on a tertiary level (Hanisch & Lange, 1985: 23).

Formal engineering education also started relatively early in Sweden and Finland. In the former, the Royal Institute of Technology was established in 1827 (as Institute of Technology). It had its roots in the School of Mechanics, which was founded in 1798, and the Mechanic Laboratory, established in 1697 (Lindgren, 2011). Moreover, lower technical two-year mining programs were provided at the Mining Schools in Falun and Filipstad, founded in 1822 and 1830, respectively (Nordisk Familjebok, 1878). In 1869, the Mining School in Falun was incorporated in the Institute of Technology. Since then, the Royal Institute provided three different mining engineering programs of three years: mining mechanics, metallurgy and mining engineering. In 1871, the Institute of Technology also took over the civil engineering course formerly arranged by the Higher Artillery College. In Finland, the Helsinki University of Technology was founded in 1849, which was thereafter renamed Polytechnical School (1872) and Polytechnical Institute (1878). Meanwhile, two other intermediate technical schools were founded in Vaasa and Turku, on the west and south-west coast (Aalto University).[10]

In Latin America, the Spanish crown established mining schools at the end of the eighteenth century, yet they stopped its regular operation already at the beginning of the nineteenth century because of the independence wars. This explains, for instance, the re-launch of the mining school in Mexico by Benito Juárez in 1867 (Maloney &

[9] Other technical schools and evening schools were founded in a number of towns and 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) (Bergh, 1983: 52). Technical evening schools were also founded in cities such as Stavanger and Kristiansand in the late 1870s (Hodne, 1981: 245).

[10] See https://www.aalto.fi/en [12 02 2020).

Caicedo, 2017). Similarly, several Latin American countries joined the efforts made by current developed economies and installed both mining and engineering schools at the mid-nineteenth century. However, as illustrated by Colombia, political instability could affect the regular operation of such schools, as the first mining school operated irregularly during the nineteenth century.

Undoubtedly, Chile was among the pioneering countries in Latin America in terms of organizing engineering and technical schools. For instance, engineering programs were provided from 1856 at the Faculty of Mathematics of the University of Chile (Domeyko, 1872: 20). Additionally, intermediate technical schools of different kinds were founded in the second half of the nineteenth century. The most famous was the School of Arts and Crafts (established in Santiago in 1849), but there were also other schools founded throughout the entire country. These efforts included the Mining Schools of Copiapó (1857), La Serena (1887), Santiago (1887) and, later on, Antofagasta (1918); the Chemical and Industrial Laboratory of Iquique (1898)[11]; and, the Industrial Schools of Chillan, Concepción and Temuco (all three created in the early twentieth century) (see Muñoz, 1909). These initiatives suggest that Chile was not necessarily different from Nordic countries in the creation of technical schools throughout the First Globalization. Furthermore, these schools –as in the Nordic countries- included practically-oriented programs directed towards a specific industry (such as mining, carpentry or architecture) as well as general programs with more general preparations (such as chemistry, mathematics or civil or electrical engineering).

In Peru, there was a failed first attempt to open a mining school in 1852 (López Soria, 2012). In 1875, the initial project of a mining school opened effectively as a general engineering school –the *Escuela Nacional de Ingenieros*- in 1876 with two degrees: civil engineering and mining engineering. Some years later, the school's offer included industrial engineering (1901) and electric engineering (1903). In contrast to the Bolivian case (see below), since its inauguration, there was a significant demand from potential students; moreover, some of them were sons of Peruvian bourgeoisie. Likewise, lack of resources for a proper functioning was not a restriction since a specific tax on mining producers was created which, at least at the beginning, was completely administered by the school.

As for the Bolivian case, the delay in the creation of a formal engineering school is noteworthy given the long mining tradition of the country since the mid-sixteenth century. Whereas the government tried to respond to this limitation both in colonial[12]

[11] This institution provided analysis, tests and services to the saltpeter and mining industry and courses of two years in chemistry, industrial chemistry and chemical analysis.

[12] The first attempt to create a mining school was made by governor Ventura de Santelices y Venero, who set the *Academia de Minas* in 1757. Three years later, however, this institution was closed. The second attempt was made by governor Jorge Escobedo y Alarcón in 1779; the institution closed four years later. The last initiative started in 1789 and ended in 1794. No further efforts were made during colonial times because of the economic crisis in Potosi from the early 1800s and Independence wars (1809-1825) (Ovando-Sanz, 1975).

and republican[13] times (Serrano Bravo, 2004: 95-99, 116), there was no engineering schools until the early twentieth century. Then, thanks to two decrees promulgated in 1904 and 1905, the Bolivian government stipulated the creation of two mining schools in Potosi and Oruro. The former, however, closed in 1910 (Ovando-Sanz, 1975; Salamanca Trujillo, 1993) and the latter -named *Escuela Práctica de Minería-* started in 1906 but remained closed in 1907 and 1908 because of high drop-out rates and the lack of demand from potential students (Salamanca Trujillo, 1993: 33).

The *Escuela* reopened in 1909 in a separate building and with a renewed budget. Two years later it was upgraded to *Escuela Nacional de Minería* (National School of Mining) and offered three different technical programs (mining, *agrimensores* and *ensayadores*). In 1917, it was transformed to the *Escuela Nacional de Ingeniería* (National School of Engineering) and offered a program in mining engineering. In practice, the engineering school absorbed the students enrolled in the former technical school and had its first graduates three years after its inauguration. In spite of these improvements, the lack of sufficient demand by potential students persisted. For instance, even if scholarships were available, the average number of enrolled students during the 1918-1926 period was 34, below the 40 that were enrolled in average during the 1910-1917 period (Contreras, 1990: 71). There were also problems with hiring professors given that salaries were not necessarily competitive in a market were engineers and skilled human capital were also demanded by mining and railway companies (Contreras, 1990: 72-73).[14]

Despite this relative late appearance, engineering faculties played a critical role in fostering access and disseminating technical knowledge in Andean countries. For instance, both in Bolivia and Peru, the national schools of engineering were for a long time the only institutions that provided technical education across the country.[15]

[13] The first attempt in republican times was the *Colegio Mineralógico* in Potosi. A school that was created in 1829 but was apparently closed in 1845. There is information of the central government's intentions to open mining schools in Potosi and Oruro in 1853. Two years later, however, the prominent miner Aniceto Arce was complaining about the inexistence of such institutions. The intention to open a mining school in Potosi reappeared in 1861. The evidence about the operation of this institution is somehow contradictory, but it is well known that another prominent miner, Isidoro Aramayo, was complaining again about the absence of such institutions in the late 1870s. In 1891, Aniceto Arce, now president of Bolivia, created a mining school in Potosi. One year later, the school closed because of the lack of students (Ovando-Sanz, 1975; Serrano Bravo, 2004).

[14] Furthermore, external threats to the regular operation of the mining school continued. For instance, the national government sought to close it in 1928 because of the lack of public resources. Likewise, the school did not operate properly during the years of the Chaco War (1932-35) against Paraguay (Salamanca Trujillo, 1993).

[15] In Peru, the Escuela Nacional de Agricultura, which offered technical education in agriculture, opened in 1902. The Facultad de Artes Industriales was founded by German technicians in 1910 in the north of the country (Universidad Nacional de Trujillo) and offered skilled technicians for the sugar and oil industries. Then, it was not until 1933, when the Pontificia Universidad Católica del Perú started offering in Lima a grade on civil engineering. Other faculties on civil engineering were opened in the rest of the country (Arequipa and Cuzco) just in 1947. In Bolivia, the National Institute of Agronomy and Veterinary was inaugurated in La Paz in 1907, moved to Cochabamba in 1910 and closed in 1915 (Contreras, 1988). The Physics and Mathematics Faculty was set in La Paz in 1929 but closed between 1932 and 1935 because of the Chaco war and started offering civil engineering courses only from 1937 -industrial

Moreover, there was a continuous effort to spread this technical education beyond the school rooms through the creation and publication of magazines that could be read by a broader public. For instance, a lot of teachers of the Peruvian mining school published in the *Boletín* that was published by the school from 1885. Similarly, former teachers and students of these schools were among those that created or consolidated corporate bodies of engineers.

Furthermore, engineering programs in the Andean countries tried to replicate the best practices available in the developed economies. On the one hand, if we focus on mining engineering studies, study programs in Andean and Nordic countries were very similar (Table 2).[16] For instance, they were set to several years and were one of the longest studies provided at university level (4-6 years). Also, in both groups of countries mining engineering programs combined natural science courses (mathematics, geology, etc.) and specific mining courses (use and repair of mining machinery, mine structures, etc.). In all cases, teaching was based on different methods: a) lectures in classrooms; b) practical exercises, such as drawing and laboratory work; c) geological excursions and visits to companies and plants;[17] d) working practice or final thesis at mining companies.

Certainly, there were some differences between study programs. For instance, specializations and splitting up of the programs occurred in Chile and Norway after the turn of the century, with one program focusing on mining and the other on metallurgy. These changes might respond to the increased production, mineral and metal specializations and new techniques that were adopted around the world at the time. Such a program division did not happen in Bolivia (Contreras, 1994: 96, 102). In this country, by contrast, there were English courses that were not, at least initially, included in the study programs of the other Andean countries.

In any case, changes were made continuously in all the study programs. Very often, new courses were added after radical technological changes were spread throughout world mining. For instance, new courses in mining machinery were introduced in the programs *after* mining companies in different places in the world had started a mechanization process. Similarly, electro-engineering was introduced as a new course in the early twentieth century, which was after electric power had become common among large mining businesses. Thus, mining engineering programs seemed to

---

engineering was offered since 1943 (Facultad de Ingeniería, 2000). The *Instituto Superior Técnico de Minas* in Potosi was opened in 1939 (Contreras, 1988). The private foundation created by Simon Patiño, one of the most prominent Bolivian miners at that time, started granting students who wished to study engineering abroad. This initiative, however, started just in 1931.

[16] The analysis is based on the PhD thesis of Kristin Ranestad who examined several primary sources both in Chile and Norway, the three first volumes of the Historia de la UNI and Salamanca Trujillo (1993).

[17] It is true that financial issues restricted sometimes Bolivian students' visits to far away mines (Contreras, 1995; Salamanca Trujillo, 1993). However, the emphasis on practical training during the 1920s stands out; either through visits to the mines or working in the mining industry during holidays. For instance, "85% of students worked in the mines for an average of 98 days" in 1928 (Contreras, 1990: 75).

adapt to changes that happened in the world mining industry.

Table 2. General overview of mining engineering programs in Bolivia, Chile, Norway and Peru

Mining instruction in Norway		Mining instruction in Chile		Mining instruction in Peru		Mining instruction in Bolivia
Continuous courses	**New courses (first adopted)**	**Continuous courses**	**New courses (first adopted)**	**Continuous courses**	**New courses (first adopted)**	**Study Plan 1918**
Mathematics	Study of machines (1871)	Mathematics	Drawing (1889)	Mathematics	General construction (1880)	Mathematics
Mechanics	Electro engineering (1909)	Mechanics	Machines (1889)	Mechanics	Industrial economy (buss. adm., accounting) (1886)	Mechanics
Geology	House construction (1911)	Geology	Construction (1889)	Geology	Electricity (1896)	Geology
Mineralogy	Social economics and law (1911)	Mineralogy	Political economy and administrative law (1889)	Mineralogy	Applied mechanics (1898)	Mineralogy
Mining construction		Chemistry (metallurgy)	Electro engineering (1908)	Metallurgy	Petrology (1903)	Chemistry
Mine factory		Docimasia		Docimasia	English (1930)	Docimasia
Metallurgy (ore treatment and analysis)		Topography		Topography		Topography
Machine drawing		Mines exploitation		Mines exploitation		Mines exploitation
		Mines measuring		Drawing		Drawing
				Machines		Metallurgy
				Technology		Machines and engines
				Political economy		Electro engineering
				Mines legislation		English
						Mines Legislation, Hygiene and Accounting

Sources: Ranestad (2016: 6), López-Soria (2012: 14-15) and Salamanca (1993:69).

4.- The innovative potential: graduated engineers

The previous section highlighted that there were significant differences in the year of foundation of mining/engineering schools in Andean and Nordic countries with a clear "catching up" effort by Andean governments from the late nineteenth century. Moreover, the analysis of the educational programs suggests that they were comparable. Was this effort by Andean government sufficient to balance the availability of engineers? To answer this question, we turn to assess the total number of engineers (including technicians) graduated in Andean and Nordic countries throughout time.

As for the Nordic countries, Grönberg uses graduate lists from Nordic technical schools to sum up the total number of "technical school graduates"[18] from 1880 to 1919. He finds a total number of 5,530 graduates in Sweden, 3,152 in Denmark, 3,099 in Norway and 1,209 in Finland. Whereas the author recognizes that there might be graduates missing from these lists and that his estimations may represent four-fifths of all graduates, these numbers give an indication of the supply of engineers in Nordic countries (Grönberg, 2019).

We also have information about the number of locally trained engineers in Andean countries in different primary and secondary sources. For Bolivia, we can aggregate information from technical school graduates (1911-1917) and engineering graduates (1917-1939) in Oruro.[19] Here, we make an upper bound estimate given that, from 1917 to 1931, data makes reference to all students that finished their studies and not only those that finished their studies *and* presented a final thesis.[20] This gives us a total of 73 locally trained engineers from 1910 to 1939 (Table 3).

It could be argued that, given the late creation of an engineering school in this country, native engineers educated abroad should also be considered. For instance, the Bolivian government set up a scholarship program in 1906 to study abroad. Available data indicates that 20, 19 and 8 grants for engineering programs were provided in 1906, 1910 and 1914, respectively. However, the total number of granted students (taking into account engineering and other programs) was equivalent to 10% of university students and few among them completed their studies and returned to Bolivia (Contreras, 1990: 150-151). Moreover, the scholarship program ended in 1915 and was not relaunched thereafter. Indeed, in the 1930s, a second relevant scholarship program was private. Among the granted students by the Patiño Foundation, only four graduated from engineering programs during the 1930s (Contreras, 1988).

---

[18] This makes reference to graduates from the higher technical schools (at least three years of education) and includes mechanical, electrical and naval engineers, civil construction engineers, chemical engineers, mining and metallurgy engineers and architects.

[19] The data focuses on Oruro since there were no other graduates in other parts of the country until the 1940s (see Contreras, 1990: 143, 148).

[20] Because of lack of information, data for 1932 and 1937-1939 considers only those who finished their studies and presented a final thesis. There were no graduates between 1933 and 1936 because of the Chaco War.

Table 3. Total number of technical engineers and engineers graduated in Andean and Nordic countries, 1870-1939

<table>
<tr><th rowspan="2"></th><th rowspan="2">Bolivia</th><th colspan="2">Chile</th><th rowspan="2">Peru</th><th rowspan="2">Finland</th><th rowspan="2">Norway</th><th rowspan="2">Sweden</th></tr>
<tr><th>A</th><th>B</th></tr>
<tr><td>1880-1884</td><td></td><td></td><td></td><td>5</td><td rowspan="8">1,209</td><td rowspan="8">3,099</td><td rowspan="8">5,530</td></tr>
<tr><td>1885-1889</td><td></td><td></td><td></td><td>25</td></tr>
<tr><td>1890-1894</td><td></td><td></td><td></td><td>30</td></tr>
<tr><td>1895-1899</td><td></td><td rowspan="5">327</td><td></td><td>37</td></tr>
<tr><td>1900-1904</td><td></td><td></td><td>59</td></tr>
<tr><td>1905-1909</td><td></td><td rowspan="4">469</td><td>61</td></tr>
<tr><td>1910-1914</td><td>6</td><td>71</td></tr>
<tr><td>1915-1919</td><td>10</td><td>81</td></tr>
<tr><td>1920-1924</td><td>15</td><td></td><td>47</td><td colspan="3" rowspan="5"></td></tr>
<tr><td>1925-1929</td><td>17</td><td></td><td></td><td>60</td></tr>
<tr><td>1930-1935</td><td>19</td><td></td><td></td><td>182</td></tr>
<tr><td>1936-1940</td><td>6</td><td></td><td></td><td>170</td></tr>
<tr><td>Total</td><td>73</td><td></td><td></td><td>828</td></tr>
</table>

Sources: For Nordic countries, Grönberg (2019); for Bolivia, (Salamanca Trujillo, 1993: 102, 116, 184-182); for Chile, (Mellafe, Rebolledo, & Cárdenas, 1992: 122) and Oficina Central de Estadística. Anuario Estadístico de la República de Chile, Educación (Santiago, 1905-1925); for Peru, final appendixes in *Historia de la UNI*, vols. 1-3.

Certainly, there were also Bolivians who studied abroad by their own means. Their relevance in the Bolivian labor market can be approached through the analysis of the number of foreign diplomas that were revalidated by Bolivian authorities. This gives a total number of 46 engineers for the period 1901-1940 (Contreras, 1990). We could assume, as Contreras does, that only half of native students that returned to Bolivia revalidated their diplomas. In this case, we would have a total number of 92 native engineers educated abroad. Even if we assume this upper bound estimate and we add the mining engineers graduated in Oruro (73), the engineering students granted by the Bolivian government (a maximum of 48) and those graduated thanks to Patiño's grants (4), we obtain 217 Bolivian engineers graduated from 1901 to 1940. This figure is well below those recorded in Nordic countries and the other two Andean countries (see Table 3).[21]

In the case of Chile, the total number of graduated engineers and technicians can only be estimated using numbers from different secondary sources. Between 1898 and

[21] There was a great expansion in the total number of graduated engineers during the 1940s. In any case, Contreras (1990: 164) offers an estimate of 470 Bolivian civil and mining graduated (in Bolivia and abroad) engineers from 1900 to 1950. This figure is still far below those obtained in the rest of the countries under study.

1918, it is found that 304 studied to be civil engineers and 23 were specialized in mining (Mellafe, Rebolledo, & Cárdenas, 1992: 122). It should be noted, however, that there were a great variety of technical courses offered in Chile and we have information that, between 1905 and 1925, a total of 469 individuals graduated from the mining schools in Santiago, La Serena, Copiapó, Antofagasta and Iquique (see column B in Table 3).[22]

As for Peru, given the centrality of the *Escuela de Ingenieros* in technical and engineering education, we can use records of graduates from this institution to infer the availability of engineers. From 1876 to 1929, information refers to effective graduate students and from 1930 to 1939 it includes those who finished their studies but did not defend a final thesis. This last inclusion is explained by the lack of detailed data of graduates by program and the growing gap, after the early 1920s, between students who finished their studies and those who presented a final thesis.

With all this information we can do a comparison on the number of graduated engineers, which shows striking differences between the two regions (Table 3). For instance, while Bolivia had around 16 locally trained engineers between1880 and 1919,[23] Sweden had 5,530. In Peru, the total number of graduates is less than 1,000 from 1880 to 1940, i.e. sixty years. This figure was surpassed in the three Nordic countries (and by far in the case of Norway and Sweden) in a shorter period (1880-1919). In Chile, if we assume that graduation rates were uniform throughout time, we can calculate the average rate of graduation per year of engineers (327/20=16.35) and technicians (469/20=23.45) and apply this rate for a forty-year period (1880-1919). In this scenario, we obtain a maximum number of 915 technicians and 638 engineers. This gives a total number of 1,553 graduated engineers, which is higher than in the rest of the Andean countries and Finland, but 2 and 3.5 times lower than Norway and Sweden, respectively. Differences are also notorious in per capita terms: if we divide available engineers in 1919 to total population in 1919, there were 0.007 engineers per thousand people in Bolivia, 0.42 in Chile (assuming the availability of 1,553 engineers) and 0.08 in Peru. In Finland, Norway and Sweden, there were 0.38, 1.19 and 0.95 engineers per thousand people, respectively.

5.- Effective innovation: patents systems and granted patents

The previous section shows significant differences in the number of graduated engineers in Andean and Nordic countries. The goal of this section is to explore if this higher innovative *potential* in Nordic countries was in correspondence with higher

[22] Information of 1916 and 1920 on mining technicians is unavailable. Also consider that graduates from the surveyor/geographical engineering and the industrial schools of Arts and Crafts are not considered in Table 3.

[23] A maximum of 100 Bolivian engineers could be obtained if we add those students granted by the Bolivian government and those that studied abroad. This would imply 0.04 engineers per 1,000 inhabitants.

levels of *effective* innovation. As previously stated, we tackle this issue by looking at the evolution of patents systems and the number of granted patents.

As for Nordic countries, a patent system developed early on in Sweden. The Swedish patent laws were issued in 1819, 1834 1856 and 1884. According to Andersson & La Mela (2020), this last one was the "modern one" since it was the third patent law in the world, after the United States (1836) and Germany (1877), to include a "rigorous novelty examination" performed by professional patent examiners. In Norway, patent legislation was promulgated in 1839, 1873, 1885 (clearly inspired in German legislation) and 1910 (Basberg, 2006). In Finland, the first patent law was decreed in 1876, after Sweden and Norway. According to Andersson & La Mela (2020), it was almost a word for word copy of the Swedish law of 1856, even though Finland was part of the Russian Empire. Then, inspired by Swedish, Norwegian, and German legislation, the patent law was changed in 1898.

Interestedly, Chile also developed a systematic body of Intellectual Property early on (Escobar, 2014). This consisted in the recognition of property rights for authors and inventors in the Constitution of 1833, the promulgation of a Copyright Law in 1834 and the Patent Law of 1840, which persisted with few remarkable changes until 1920. Following the Spanish tradition, the Patent Law recognized legal protection for both inventions and introductions of new products into the country. From 1872, the legislation repealed this last right and protection was only granted to inventions, which, since 1851, required a mandatory examination by specialists (not necessarily public officials). In Peru, whereas the Constitution of 1828 recognized property rights for both inventors and those who introduced new products to the country, a specific law on patents was not issued until 1869 (Villarán de la Puente, 2015). The law recognized legal protection both for inventions and introductions of new products, being this last right repealed in 1933. As for Bolivia, to the best of our knowledge, there is not a systematic work on the evolution of the patent system during this period. We found disperse information (*Decreto Supremo* 11.09.1877 and *Decreto Supremo* 08.05.1885) that shows that some legal protection was provided to introductions.

Assuming that patents are a good indicator of countries' effective innovation, the Andean countries clearly lagged behind the Nordic ones during the First Globalization. Indeed, there is evidence of 2,540 patents granted in Chile (both for inventions and introductions) from 1840 to 1910 (Inkster, 2003). We do not know the distribution of these patents between nationals and foreigners. However, we have data on patent applications from 1877 to 1910 (3,650 in total) and we know that 56% of these were made by Chileans, 40% by non-residents and 4% by immigrants (Escobar & Arellano, 2019). For Peru, systematic data is still being processed by an ongoing research project (Monsalve & Carrasco, 2019).[24] In any case, there is information of 108 invention patents granted from 1911 to 1918, but only 3% of them were granted to Peruvian

[24] The historical study of patents in Latin America is still in an early stage and still deserves more attention (Beatty, Pineda, & Sáiz, 2017).

citizens (Villarán de la Puente, 2015). By contrast, Andersson & La Mela (2020) find 35,513 and 3,841 granted patents in Sweden and Finland, respectively, between 1866 and 1910. In the former case, around 50% were granted to nationals; in the latter, the average rate was around 30%. In Norway, Basberg, (2006) finds 27,453 granted patents between 1860 and 1914, being 20-30% of them to Norwegian citizens.

Thus, available data suggests that granted patents were considerably lower in Andean countries. Moreover, even if only patents granted to nationals are considered, we would obtain around 17,000 and 7,000 patents in Sweden and Norway, respectively, and around 1,300 in Chile. Granted patents in Chile and Peru were so low in comparison that the total number of patents provided in these countries might be provided in a single year in the Nordic ones. Indeed, the number of patents in Sweden passed from 500 annually in the late 1880s, to more than 1,000 annually in the late 1890s, and peaked to almost 2,500 annually around 1905. In Norway, the number of patents increased and reached 500 annually in the late 1880s, almost 1,500 annually in the late 1890s and almost 2,000 annually before WWI. In Finland, the number of granted patents grew from the late 1890s, but the annual number was always below 500 before 1913 (Andersson & La Mela, 2020; Basberg, 2006).

We look at patents since we want to assess the countries' ability to create its indigenous country specific knowledge and technology related to natural resource exploitation. In this context, besides the aggregate figures previously presented, we need to identify the number of patents related with these activities. As for Norway, patens directed specifically towards the mining industry increased from 1 in 1861-65 to 22 in 1911-15 (a total of 65 patents between 1861 and 1915). A large share of the patents classified as "chemicals" (a total of 639 patents), "machinery" (a total of 556 patents) and "power supply" (a total of 106 patents) were probably also used in mining, as the removal and processing of ore was based on various types of mechanical and electric equipment, tools and chemical techniques, which would be classified under these categories. If we add all these categories, we find that a maximum of 5% of total granted patents in Norway were directly related to mining activities.

However, the relevance of patents for natural resource exploitation can be also proved indirectly. Indeed, in an analysis of technological specialization based on patents data in the United States, Vertova (1999) finds that Sweden has specialized in technology related to machinery, metallurgical expertise and explosive. Furthermore, in contrast to other national cases, the Swedish case shows a remarkable stability of 75 years in its technological specialization. This leads the author to conclude that "niches of long-run specialization", "related to the natural environment and the abundance of natural resources" exist in Sweden (Vertova, 1999: 349). This, therefore, would suggest that the higher number of granted patents in Sweden shows effectively striking differences between Andean and Nordic countries in their ability to create their own technologies for natural resource exploitation.

6.- The innovative capacity: the stock of mining engineers

The goal of this section is to assess if the previously identified differences in the availability of graduated engineers and the number of indigenous innovations could explain differences in the way natural resources were exploited in Andean and Nordic countries. To begin with, we measure the relative availability of indigenous skilled workers in mining, a natural resource activity that was present both in Andean and Nordic countries. Specifically, we measure the ratio of *natives mining engineers* to total workers in mining activities (Table 4). Whereas the mining engineers' exact share of total workers at any given time is unknown, it is possible to make estimates using the information about graduation year and assuming a 40 years' career length –based on more detailed information on Norwegian engineers.

Our estimations show that the number of available Norwegian mining engineers increased from 48 in 1866 to 221 in 1940.[25] The number of workers per mining engineer varied but was on average around 57, varying from a minimum of 35 to a maximum of 92. There were in fact some indications of too many mining engineer graduates in Norway. For instance, in the 1930s, many students applied for the mining engineer program at the NIT, and according to Professor Harald Pedersen, the Department was not able to accept all of them (Den norske ingeniørforeigning og Den polytekniske forening., 1935: 99).

In addition to mining engineers, companies in Norway, both domestic and foreign, continuously recruited mining technicians graduated from Kongsberg (Statens bergskole, 1966: 21). Between 1869 and 1940, 191 mining technicians graduated from the Kongsberg Silver Works Elementary Mining School. 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, the school was temporary closed. Yet, using the same career length (40 years), the number of available mining technicians indicates an increase in supply: from less than 50 until the 1890s, up 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 80 in 1880.[26]

[25] For Norway, we have total number of mining engineer graduates from the establishment of the Kongsberg Mining Seminar in 1757 to 1940 (a total of 341 Norwegian mining engineers).

[26] The estimated number of workers per mining technician declined dramatically from 405 in 1870 to 213 in 1875 and 80 in 1880 due to a radical increase in the number of mining technicians in the 1860s and 70s (Ranestad 2018).

Table 4. Workers per mining engineer (estimated career of 40 years) in Andean and Nordic countries, 1865-1940

	Bolivia			**Chile**			**Peru**			**Norway**			**Sweden**		
	Est. Mining Eng. (A)	**Work. (B)**	**B/A**	**Est. Mining Eng. (A)**	**Work. (B)**	**B/A**	**Est. Mining Eng. (A)**	**Work. (B)**	**B/A**	**Est. Mining Eng. (A)**	**Work. (B)**	**B/A**	**Est. Mining Eng. (A)**	**Work. (B)**	**B/A**
1865				27	24,396	**904**				48	3,408	**71**			
1870				49	27,033	**552**				50	3,239	**65**			
1875				69	30,207	**438**				49	2,978	**61**			
1880				94	37,935	**404**	2			50	2,240	**45**	1	27,364	**27,364**
1885				111	43,789	**394**	3			51	2,383	**47**	21	28,846	**1,374**
1890				122	51,345	**421**	32			45	2,899	**64**	43	35,227	**819**
1895				129	59,713	**463**	59			51	2,015	**40**	75	26,284	**350**
1900				124	55,398	**447**	86			49	3,319	**68**	105	30,738	**293**
1905				122	66,626	**546**	123	14,451	**117**	52	4,768	**92**	165	31,222	**189**
1910	2	13,147	**6,574**	104	83,677	**805**	162	21,885	**135**	91	6,652	**73**	232	29,990	**129**
1915	10			91	95,421	**1,049**	188	25,260	**134**	152	8,917	**59**	280	46,863	**167**
1920	22	21,813	**992**	86	98,442	**1,145**	228			179	6,267	**35**	303	44,401	**147**
1925	42			94	131,168	**1,395**	254	26,052	**103**	198	8,427	**43**			
1930	64			103	127,882	**1,242**	263	28,137	**107**	191	9,727	**51**			
1935	87	26,253	**302**	130	99,344	**764**	248	19,389	**78**	197	9,597	**49**			
1940	97	50,000	**515**	163	123,065	**755**	254	36,121	**142**	221	10,074	**46**			

Sources: For Chile and Norway, number of mining engineers and workers from Ranestad (2018). Mining engineers for the rest of countries, see Table 3. Workers: for Bolivia, Mitre (1993: 221); for Peru, statistical appendixes in *Compendio Historia Económica del Perú*, vols 4 and 5.

Note: For Bolivia, Chile and Norway, figures represent mining engineers graduated at foreign institutions and local institutions. For Sweden, the numbers only include graduates from the Royal Institute of Technology 1880-1919. Figures for Peru in 1940 refer to 1939; numbers of workers for Peru in 1910 refers to 1912; the estimated mining engineers available for Sweden in 1920 refers to 1919.

It could be argued that the relatively high availability of mining engineers in Norway was a consequence of the small size of the mining labor force (less than 10,000 workers). Therefore, it is useful to look also at Sweden, an economy where mining activities were significantly larger (on average 7% of GDP between 1850 and 1839) and the mining labor force was around 30,000 people. Interestedly, and even if the numbers presented in Table 4 may be downward biased,[27] available Swedish mining engineers is estimated to increase from one in 1880 to 303 in 1919. As a consequence, a drastic decline in the number of workers per mining engineer is estimated to decline from 27,364 in 1880 to 147 in 1919.

Ranestad (2020) shows that 35% of the Norwegian mining engineers between 1787 and 1940 studied in other countries and Grönberg (2003, 2019) shows that Swedish engineers and technicians were part of an “outward looking” Nordic trend of studying and working abroad. Considering these trends, there were probably Swedish mining engineering students at foreign education institutions that are not accounted for in Table 4. If we assume that there were on average two mining engineer graduates per year from 1822 -the year formal mining education was introduced at the Mining School in Falun– to 1880[28] and, on average, five graduates after 1919[29], the number of workers per mining engineer would be constantly below 350: there would be 286 workers per mining engineer in 1865, 330 in 1880, 209 in 1900, 160 in 1915, 165 in 1925, and 197 in 1940.

In sum, both in terms of mining engineers and mining technicians, we find that there were around 40-350 workers per engineer in the Nordic countries between 1860 and 1940. Interestedly, the availability of workers per mining engineer in Peru falls in this same range during the first third of the twentieth century. This suggests that, despite the previous finding that the availability of *total* engineers was relatively low in Peru, the supply of *mining engineers relative to the sector* was not necessarily small. This, in turn, illustrates the success that the *Escuela Nacional de Ingenieros* had in its goal to provide mining engineers to the local labor market.

This positive trend, however, did not seem to develop in the other two Andean countries. For instance, in Bolivia, where mining exports represented at least 80% of total exports, it is true that the availability of local engineers increased during the first third of the 20th century but there were still 515 workers per mining engineer in 1940. Notice, moreover, that this estimation includes Bolivian graduates both at local and foreign institutions, being the latter estimated through the duplication of the number of mining engineers that validated their foreign diplomas.

[27] Figures in Table 4 underestimate the number of available Swedish mining engineers for three important reasons: a) it only considers the number of mining engineering graduates from Royal Institute of Technology; b) only those graduated in this institution from 1880 to 1920; c) data does not include Swedish mining engineer graduated in foreign institutions.

[28] This would probably be an underestimation, as the average number of graduates in the 1880s was 4,6.

[29] This would probably be an underestimation, as the average number of graduates in the 1910s was 8.9.

More strikingly, in Chile, where engineering education started earlier, the number of mining engineers was much lower than in Peru, Sweden and Norway: 296 mining engineers graduated from the University of Chile between 1856 and 1940. Using the same forty-year career estimate, the number of mining engineers increased from 15 in 1860 to 124 in 1900 and 163 in 1940. As a consequence, the number of workers per mining engineer varied, but remained normally over 400, and between 1,000 and 1,400 between 1915 and 1930.

Once more, this estimation includes Chileans that obtained their degrees abroad. However, in contrast to Nordic countries, it was not common to study abroad. For example, until 1940 there are traces of only six students from Chile going to other countries to study mining engineering at universities or mining schools. The three distinguished students Manuel A. Osorio, Teodosio Cuadros and Antonio Alfonso went to Europe in the mid-19th century. They were sent to study at the Mining Academy in Freiberg and the Mining School in Saint Etienne (Domeyko, 1872: 576-577; Sociedad Nacional de Minería, 1891: 63). Around twenty years later, in 1870, three more engineering students, one of them a mining engineer, were sent to France and Belgium, where they took university courses and visited industrial plants in England and Germany. The purpose was to train specialised professors to teach at the University of Chile (Galdames, 1934: 79). In 1893, mining engineer Casimiro Domeyko graduated at the Mining School in Freiberg (Jerez Bravo, 1950: 79). Decades later, in 1920, two mining engineers were sent to the United States to study “industrial chemistry and electricity” for at least two years (Universidad de Chile, 1920: 319-320).

Not surprisingly, during the 1910s and 1920s contemporaneous sources claimed that, despite Chile having a huge mining sector, the number of civil engineer students was around ten higher than the mining engineer students. It was explicitly stated that “the number of mining engineers graduated in Chile was not enough to cope with the demand” (Sociedad Nacional de Minería, 1925: 663-664). Mining company managers, university professors, consultants and engineers wrote regularly, almost every year, about the lack of available mining engineers. In the 1913 annual report of the University, Counsellors of the Faculty of Mathematics referred to mining companies constantly requesting more mining engineers (Universidad de Chile, 1913: 66-67). In 1936, the National Institute of Mining Engineers still found that the lack of mining engineers was felt “each day” (Sociedad Nacional de Minería, 1936: 379). Indeed, 57 articles were published in the Mining Bulletin between 1890 and 1940 about the scarce number of mining engineer students at the University, and available mining engineers in the country.[30]

Civil engineers, of whom there were many more in Chile, were to some degree used by mining companies as substitutes for mining engineers. In 1925, the National Mining Society affirmed that “a large number of” the civil engineers from the

[30] There might have been more articles and what is indicated here as copies of the Bulletin are unavailable for the years 1893-1899, 1905-1906, 1908-1909 and 1913-1915.

University worked in mining even though they did not have knowledge or experience. The argument was that companies hired civil engineers because there were no mining engineers to be found (Sociedad Nacional de Minería, 1925: 663-664). Mining technicians also substituted mining engineers. Some of the mining technicians acquired positions that were meant for engineers, notably in management (Escuela de Minas de Copiapó, 1957: 12; Escuela de Minas de Copiapó, 1918: 13). It was perhaps only natural that mining technicians, with a similar education, only less theoretic, took the mining engineers' place in cases when mining engineers were hard to find.

Due to lack of the numbers of mining technicians in Chile 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 Chilean mining industry, sometimes over 100,000, mining technician graduates were probably also too few. In fact, engineers, professors and members of the National Mining Society were constantly complaining about a scarce number of students at the Mining Schools. For instance, 21 articles were published in the Mining Bulletin about the lack of mining technician students and graduates between 1890 and 1940.[31] 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 32 students at the time (Sociedad Nacional de Minería, 1891: 18). In the early twentieth century, the engineer Carlos Schulze explained that "(t)he three schools of mining that currently exist[ed] in Santiago, Copiapó and La Serena, [were] not in a position to satisfy the needs…" (Sociedad Nacional de Minería, 1910: 330). In 1934, the industry still requested more mining technicians. An article, published this year, suggested that "…there is not enough technical personnel to carry out [scientific exploitation] and guide the miner" (Sociedad Nacional de Minería, 1934: 306). 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" (Sociedad Nacional de Minería, 1940: 142). By contrast, there are few, if any, examples in the Mining Bulletin, or in other journals or magazines, of people arguing that there were enough mining technicians.

7.- The innovative capacity: the role of indigenous engineers in their economies

The previous section shows that the stock of formally trained engineers relative to the size of the mining sector was lower in the Andean countries than in the Nordic countries. This section aims at proving that this difference is a good indicator of knowledge differences and differences in the countries' ability to create its own technological innovations. For this, we analyze the role of native engineers in their respective labor markets given that: a) a higher relevance of native engineers in their labor market would allow reducing the dependence on foreign skilled workers; b) a higher density and labor mobility of engineers could spread innovation through job

[31] There might have been more articles and what is indicated here as copies of the Bulletin are unavailable for the years 1893-1899, 1905-1906, 1908-1909 and 1913-1915.

switching if they started working in high profile technological companies and changed to other companies in other sectors of the economy.

To begin with, we analyze the role of native mining engineers graduated at the *Escuela de Ingenieros* in Peru. According to Contreras (2020), the school was critical for the development of the Peruvian mining sector during the late nineteenth century. In relation to this idea, it has been proved that workers per mining engineer in Peru moved around the same ranges than in the Nordic countries. Furthermore, whereas we do not have information on the professional career of all engineering graduates, Table 5 shows information on some of the most prominent (López Soria, 2012). This compilation stresses that Peruvian engineers filled high-rank positions in local mining companies. Moreover, several of them stand out by their international mobility. Their role in the direction of multinational mining companies in Bolivia and in the creation of the Bolivian mining school is particularly noticeable. There are also several examples of former students becoming teachers and combining this activity with consultancy duties for private mining companies. This is not a minor issue since it has been suggested that the combination of teaching in engineering schools and consultancy for private companies was an effective way to prompt innovation in the mining sectors of Australia, Norway and the United States (Ville & Wicken, 2013; Wright, 2015).

Table 5. Job switching of selected Peruvian mining engineers

Mining Engineers	Social Networks	Graduation	Job 1	Job 2	Job 3	Job 4	Job 5	Job 6	Other
Remy, Pedro Felix (1856-1897)	Son of French immigrant	1880	State Engineer	Teacher ENI (Docimasia & Metallurgy)	Introduction of a new metallurgy process	Teacher ENI			Previous studies in Medicine; frequent publications in mining reviews: 46 articles in the *Boletín*
Balta, José (1866-?)	Son of Peruvian President	1888	Silver mines in Ticapalca	Introduction of new mixing method in Huanchaca (Bolivia)	Teacher ENI, combined with consultancy activities	Ministry of Development	National Deputy	Mining Director in Costa Rica	Frequent publications in mining reviews: 42 articles in the *Boletín*
Basadre y Forero, Carlos (1859-1909)		1888	Manager of Tacna Gas Company	Temporary teacher	National Senator	Ministry of Development			
Basadre y Forero, Jorge		1890	Specialization in Electricity in USA	Introduction of electricity in Peruvian mines and La Paz (Bolivia)	Introduction of new machines in Bolivian and Peruvian Mines				
Fort, Michel (1869-?)	Son of French immigrant	1890	Mineral smelting in high altitudes	General Superintendent of the "Compañía Minera de Casapalca"	Empresa Minera de Yauli	Consultancy for national and foreign mining companies	Teacher	Director (1910-1930)	

Noriega, Alberto		1891	Technic and directive duties in national and foreign mining companies	Creator of Banco Minero					Defender of inward-looking economic strategy
Fuchs y Carrera, Carlos Fernando (1871-?)	Son of German and Spanish immigrants	1892	Working in different national and foreign mining companies	Founder of different mining companies	Teacher	National Deputy			Frequent publications in mining reviews
Málaga Santolalla, Fermín (1868-1964)		1894	Discovery of a highly productive mine	Founder of its own mining company	Landowner and agrarian activities	National Deputy	Manager of different Peruvian mining companies		
Vantosse, Luis (?-1913)		1896	Junior engineer in Parinacocha	Subdirector of the Laboratoy of Docimasia	Working in different mining companies in Chile	Manager in national mining company	Consultancy for different mining companies in Bolivia	Teacher at the Mining School of Bolivia	
Umlauff, Augusto		1899	Working in different national and foreign mining companies in Peru	Founder of the Mining School of Bolivia	Manager of the Huanuni Tin Co.	Consultancy for B. Minchin			

Sources: The table was constructed using the information provided by López Soria (2012)**.**

We did not compile information on the professional career of Peruvian engineers graduated after 1900. However, the partial information we can deduct from the different volumes of the history of the Peruvian engineering school, suggests that locally trained Peruvian engineers had a decreasing relevance in the mining sector as the sector was progressively dominated by foreign companies.

By contrast, the analysis of the Chilean case shows a higher relevance of foreign engineers and a poor ability to reduce this dependence throughout time. For instance, North American copper companies, which made huge investments in some of the large copper mines in Chile in the early twentieth century, were continuously regretting the lack of native mining technicians and engineers. The magazine published monthly by the Braden Copper Company wrote in 1917 that the Mining Schools provided a "…limited supply of suitably trained men" (Braden Copper Co., 1917: 23). For this reason, it was stated that "…it has been thought necessary to import men – to contract them from the United States" (Braden Copper Co., 1917: 23). North American copper companies recruited hundreds of engineers, technicians, mechanics, electricians and others from other countries. Correspondence between engineers at Andes Copper Company provides an example. In relation to the building of a Sulphide Plant, 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."[32]

In fact, we have information that around 700 North Americans and Europeans were working at the Chuquicamata plant in 1920 (Sociedad Nacional de Minería, 1920: 277).

Indeed, practically all the leaders of company departments, management and directories at Braden Copper Company and Andes Copper Company were foreigners (Baros Mansilla, 2006; Hiliart, 1964; Solano Vega, 1918). In the same vein, 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" (Sociedad Nacional de Minería, 1910: 330).

As for the Bolivian case, given the late creation of the mining school and the relatively few Bolivians that studied abroad, the skills and specialized knowledge of foreign engineers was critical during the second half of the nineteenth century (Contreras, 1990: 230-237). During the first decades of the twentieth century, despite the fact that the mining sector tended to be progressively dominated by Bolivian

[32] 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

capitalists, high and intermediate positions were still filled by foreign engineers. This was particularly evident in the case of Patiño Mines, the most important mining company in the country. These positions were initially occupied by German engineers and afterwards by US engineers (Contreras, 1990: 239-242).

Once the first graduates from the mining school entered the labor market there was a gradual replacement of foreign engineers by Bolivian engineers. However, this replacement was not uniform across the industry and varied over time. During the 1920s, Bolivian engineers were mostly employed by Bolivian owned medium-sized mining companies, where they achieved top managerial positions during the 1930s (Contreras, 1990: 253). There were also ample opportunities for Bolivian students during their practice activities in Patiño Mines. Once they graduated, they could also be hired by the company but they remained in lower positions. Indeed, it was not until the late 1930s that a middle-high and a top managerial positions were filled by Bolivian engineers (in both cases by Bolivians that obtained their degrees abroad) (Contreras, 1990: 253-280).

The Bolivian case suggests that, irrespective of the nationality of the mine owner, the role of native Andean engineers in multinational companies was restricted. This is not a minor point in our discussion since, given the relative economic backwardness of both Andean and Nordic economies, we could argue that state of the art technologies were first (or just) introduced by multinational companies. In this context, the higher the presence of local engineers in these companies, the higher the potential diffusion of state of the art technologies to the rest of the economy.

In this context, it seems that Nordic engineers had a higher ability to work at multinational companies. In fact, an analysis of employment at multinational mining companies in Chile and Norway between 1860 and 1940 indicate this (Ranestad, 2020). In the former case, multinationals employed thousands of local workers to lower positions, but used almost exclusively foreigners for managing and middle-management positions. Moreover, there is no trace of any Chilean mining engineer working at these companies. By contrast, Norwegian workers were heavily involved in the start-up, operation and management of multinationals in their country. Thus, rather than enclaves that prevented knowledge transfer, multinationals developed in Norway more as clusters, and networks developed between multinationals and the local mining industry through job switching.

Ranestad’s analysis shows that multinationals in both Chile and Norway were willing, and perhaps motivated, to hire local workers. Thus, once more, the reasons for the different employment patterns of multinationals in Andean and Nordic countries are not simple. In any case, among the plausible explanations, Ranestad (2020) underline the following: a) a more active role of the Norway government since 1906 to control foreign ownership and the composition of directories; b) a higher availability relative to the size of the sector of specialized labor force (mining engineers) in Norway; c) stronger networking practices abroad among Norwegians.

In relation to this last idea, Ranestad (2020) shows that 75% of the mining engineers who graduated between 1787 and 1940 went abroad to do (partly or completely) their studies, do geological surveys, acquire information about specific techniques or do practice or work. Similarly, based on Grönberg (2003) figures, Westberg (2019) shows that 39% of the Swedish engineers who graduated between 1880 and 1919 emigrated to the United States or Western economies, but 71% of them migrated back. Thus, the initial "brain drain" of engineers changed into a "brain gain" given that Nordic engineers returned home with practical experience on up to date technologies and network connections with multinationals. Both elements may have generated a higher multinationals' trust towards Nordic engineers and, therefore, a higher predisposition (or lower animosity) to contract them in top rank positions.

Why did Nordic engineers migrate or move abroad to such an extent? It has been stated that Nordic countries had a particularly "outward looking" attitude towards foreign technology and knowledge (see, for instance, Lampe & Sharp, 2019). Similarly, Ranestad (2018, 2020) shows that the Norwegian government was much more active than for example the Chilean one in developing travel funds for engineers to go abroad and seek knowledge about up-to-date mining technology. However, it should be also noticed that Nordic countries were closer (both in geographical and economic terms) to the most developed economies and were among the most important suppliers of migrants to the North Atlantic economy during the second half of the mid-nineteenth century. Therefore, the mobility of Nordic engineers and their connections with multinationals companies in the most developed economies might be also facilitated by geographic and historical contingencies.

8.- Conclusions

The Andean and Nordic countries were closely similar in industrial structures and geophysical conditions (notably holding huge mineral and metal deposits) during the mid-nineteenth century, yet have had different development trajectories thereafter. We explore the role of differences in knowledge and the ability to create indigenous innovations to account for this divergence. To be sure, the measurement of differences in knowledge, scientific creation or innovation is not an easy task and the different indicators that are used nowadays (i.e. R&D expenses, number of patents) have both potentialities and shortcomings.[33] Moreover, the availability of data is not only restricted for historical periods but the present day. In this context, this paper has sought to measure knowledge differences through the analysis of engineering faculties and graduates from 1850 to 1939.

[33] Given this restriction, De Ferranti et al. (2002: 18), for instance, use four different indicators to measure knowledge in the twentieth first century: research and development as share of gross national income (GNI); scientists in R&D per million people; patent applications by residents and non-residents; patent applications in the United States by country.

Despite the existence of timing differences, we find that numerous initiatives were taken in both regions to develop technical and engineering programs, both programs directed towards specific industries and more general ones. Moreover, the content of the mining engineering programs in Norway, Bolivia, Chile and Peru were strikingly similar. However, the analysis shows that there were significant differences in the total number of locally trained engineers and in the role that these engineers played in their respective labor markets. This *knowledge gap* can be linked to geography (the Nordic countries being closer to European industrial powers), but, perhaps first and foremost to radical differences in literacy and primary school coverage.

References

Ahlström, G. (1982). Engineers and industrial growth. Higher technical education and the engineering profession during the nineteenth and early twentieth centuries: France, Germany, Sweden, and England. London: Croom Helm.

Andersson, D. E., & La Mela, M. (2020). Nordic networks: patent agents and the business of technology intermediation in Sweden and Finland, 1860–1910. *Scandinavian Economic History Review*, 68(1), 45–65. https://doi.org/10.1080/03585522.2019.1667425

Andersson, J., & Berger, T. (2019). Elites and the expansion of education in nineteenth-century Sweden. *Economic History Review*, 72(3), 897–924. https://doi.org/10.1111/ehr.12738

Arroyo, L. (2016). The Limits of the Estado Docente: education and political participation in Peru, 1876-1940. *Revista de Historia Economica - Journal of Iberian and Latin American Economic History*, 34(1), 81–109. https://doi.org/10.1017/S0212610915000233

Badeeb, R. A., Lean, H. H., & Clark, J. (2017). The evolution of the natural resource curse thesis: A critical literature survey. *Resources Policy*, 51, 123–134. https://doi.org/10.1016/J.RESOURPOL.2016.10.015

Badia-Miró, M., Carreras-Marín, A., Navarro, C., & Peres-Cajías, J. (2020). Andean countries in the Mirror of Nordic countries: the trade puzzle. Unpublished Manuscript.

Baros Mansilla, M. C. (2006). *Potrerillos y El Salvador. Una historia de pioneros*. Santiago de Chile: Corporación Nacional del Cobre de Chile.

Basberg, B. L. (2006). Patenting and early industrialization in Norway, 1860-1914. Was there a linkage? *Scandinavian Economic History Review*, 54(1), 4–21. https://doi.org/10.1080/03585520600578540

Beatty, E., Pineda, Y., & Sáiz, P. (2017). Technology in Latin America's past and present: New evidence from the patent records. *Latin American Research Review,* 52(1), 138–149. https://doi.org/10.25222/larr.46

Benavot, A., & Riddle, P. (1988). The Expansion of Primary Education, 1870-1940: Trends and Issues. *Sociology of Education*, 61(3), 191–210.

Bergh, T. (1983). *Norge fra u-land til i-land : vekst og utviklinslinjer 1830-1980*. Oslo: Gyldendal.

Bertilorenzi, M., Passaqui, J.-P., & Garçon, A.-F. (2016). *Entre technique et gestion: une histoire des "ingénieurs civils des mines" (XIXe-XXe siècles*). Paris: Presses des Mines.

Blomström, M., & Meller, P. (1991). *Diverging paths : comparing a century of Scandinavian and Latin American economic developm*ent. Washington: Inter-American Development Bank.

Braden Copper Co. (1917). *Topicos del Teniente Periodico quincenal dedicado a los intereses del personal de la Braden Copper Co.*, 6.

Cipolla, C. (1969). *Literacy and Development in the West.* Baltimore: Penguin.

Contreras, C. (2020). Logros y fracasos de la "Rebelión Moderna" en una economía de exportación: el caso de la minería peruana en el siglo XX. Unpublished Manuscript.

Contreras, M. (1988). Apuntes para una historia del desarrollo de la ingeniería en Bolivia. *Contacto*, 28, 28–36.

Contreras, M. (1990). The formation of a technical elite in Latin America: mining engineering and the engineering profession in Bolivia, 1900-1950. New York: PhD Thesis, Columbia University.

Contreras, M. (1995). Ingeniería y Estado en Bolivia, durante la primera mitad del siglo XX. In M. Cueto (Ed.), *Saberes andinos: ciencia y tecnología en Bolivia, Ecuador y Perú*. Lima: Instituto de Estudios Peruanos.

Contreras, M. E. (1994). *Tecnología moderna en los Andes: minería en Bolivia en el siglo XX*. La Paz: Asociación Nacional de Mineros Medianos.

David, P. A., & Wright, G. (1997). Increasing Returns and the Genesis of American Resource Abundance. *Industrial and Corporate Chan*ge, 6(2), 203–245.

De Ferranti, D., Perry, G., Lederman, D., & Maloney, W. (2002). *From natural resources to the knowledge economy: trade and job quality*. Washington: World Bank.

Den norske ingeniørforening og Den polytekniske forening. (1935). *Tidsskrift for bergvæsen/Tidsskrift for kemi og bergvæsen.*

Díaz, J., Lüders. R., & Wagner, G. (2016). Chile 1810-2010. La República en Cifras. Historical Statistics. Santiago de Chile: Ediciones Universidad Católica de Chile.

Domeyko, I. (1872). Instrucción Pública: reseña de los trabajos de la Universidad desde 1855 hasta el presente: memoria presentada al Consejo de la Universiad en session de 4 de octubre de 1872. In *Anales de la Universidad de Chile*, tomo 41, 557-661.

Ducoing, C., Peres-Cajías, J., Badia-Miró, M., Bergquist, A.-K., Contreras, C., Ranestad, K., & Torregrosa, S. (2018). Natural resources curse in the long run? Bolivia, Chile and Peru in the Nordic countries' mirror. *Sustainability* (Switzerland), 10(4). https://doi.org/10.3390/su10040965

Escobar Andrae, B., & Arellano Escudero, N. (2019). Green Innovation from the Global South: Renewable Energy Patents in Chile, 1877-1910. *Business History Review,* 93(2), 379–395.

Escobar, B. (2014). The doctrines and the making of an early patent system in the developing world: the Chilean case. 1840s-1910s. *Working Papers Facultad de Economía y Empresa,* Universidad Diego Portales, 58.

Escuela de Minas de Copiapó. (1918). *Revista minera, sostenida por los profesores de la escuela practica de minas de Copiapó.*

Escuela de Minas de Copiapó. (1957). *Boletin Centenario Escuela de Minas de Copiapó 1857-1957.* Santiago de Chile: Imprenta Artes y Letras.

Frankel, J. A. (2012). The natural resource curse: A survey of diagnoses and some prescriptions. *HKS Faculty Research Working Paper Series*. https://doi.org/10.3386/w15836

Galdames, L. (1934). *La Universidad de Chile 1843-1934*. Santiago de Chile: Prensas de la Universidad.

Grönberg, P.-O. (2003). *Learning and returning: return migration of Swedish engineers from the United States, 1880-1940.* author's doctoral dissertation, Umeå University.

Grönberg, P.-O. (2019). *The Peregrine Profession. Transnational mobility of Nordic Engineers and Architects, 1880-1930*. Leiden: Brill. https://doi.org/10.1163/9789004385207

Habashi, F. (2003). *Schools of mines: the beginnings of mining and metallurgical education.* Québec: Métallurgie Extractive .

Hanisch, T. J., & Lange, E. (1985). *Vitenskap for industrien: NTH, en høyskole i utvikling gjennom 75 år.* Oslo: Universitetsforlaget.

Hiliart, L. (1964). *Braden, Historia de una mina*. Santiago de Chile: Editorial Andes.

Hodne, F. (1981). *Norges økonomiske historie 1815-1970*. Oslo: Cappelen.

Inkster, I. (2003). Patents as Indicators of Technological Change and Innovation — An Historical Analysis of the Patent Data 1830–1914. *Transactions of the Newcomen Society*, 73(2), 179–208. https://doi.org/10.1179/tns.2003.010

Jerez Bravo, V. (1950). *Álbum histórico de la Escuela Universitaria de Minas de Copiapó, 1857-1950.* Santiago de Chile: Escuela Nacional de Artes Gráficas.

Lampe, M., & Sharp, P. (2019). *A land of milk and butter: how elites created the modern Danish dairy industry*. Chicago: Chicago University Press.

Lindgren, M. (2011). *Christopher Polhems testamente: berättelsen om ingenjören, entreprenören och pedagogen som ville förändra Sverige*. Stockolm: Innovationshistoria Förlag Stockholm Nielsen & Norén.

López Soria, J. I. (2012). *Historia de la UNI. Los años fundacionales (1876-1909).* Lima: Universidad Nacional de Ingeniería.

López, S. M., Molero, J., & Santos-Arteaga, F. J. (2010). Poverty traps in a frictionless world: The effects of learning and technology assimilation. *Structural Change and Economic Dynamics*, 22, 106–115. https://doi.org/10.1016/j.strueco.2010.12.001

Maloney, W. (2002). Missed Opportunities: Innovation and Resource-Based Growth in Latin America. *Economía Journal*, 3 (1) (Fall 2002), 111–168.

Maloney, W. F., & Caicedo, F. V. (2017). Engineering Growth: Innovative Capacity and Development in the Americas. *CESifo Working Paper Series*.

Markussen, I. (1990). The development of writing ability in the nordic countries in the eighteenth and nineteenth centuries. *Scandinavian Journal of History*, 15(1–2), 37–63. https://doi.org/10.1080/03468759008579189

Mehlum, H., Moene, K., & Torvik, R. (2006). Institutions and the Resource Curse. *The Economic Journal*, 116(508), 1–20. https://doi.org/10.1111/j.1468-0297.2006.01045.x

Mellafe, R., Rebolledo, A., & Cárdenas, M. (1992). *Historia de la Universidad de Chile*. Santiago de Chile: Ediciones de la Universidad de Chile, Biblioteca Central.

Mitre, A. (1993). *Bajo un cielo de estaño: fulgor y ocaso del metal en Bolivia.* Serie Biblioteca Minera Boliviana (Vol. 6). La Paz, Bolivia: Asociación Nacional de Mineros Medianos.

Monsalve, M., & Carrasco, J. M. (2019). Globalization and technology in Latin America: The development of Peru's first patent system, 1890-1930. Paper Presented at the European Business History Conference-Rotterdam.

Muñoz, A. (1909). *Enseñanza Universitaria y Técnica de Chile*. Santiago de Chile: Soc. impr. y Litogr. Universo.

O'Rourke, K. H., & Williamson, J. G. (1995). Education, globalization and catch-up: Scandinavia in the swedish mirror. *Scandinavian Economic History Review*, 43(3), 287–309. https://doi.org/10.1080/03585522.1995.10415905

Ovando-Sanz, G. (1975). *La academia de Minas de Potosí, 1757-1970: ensayo documental.* La Paz: Banco Central de Bolivia.

Papyrakis, E., & Gerlagh, R. (2004). The resource curse hypothesis and its transmission channels. *Journal of Comparative Economics*, 32(1), 181–193. https://doi.org/10.1016/J.JCE.2003.11.002

Peres-Cajías, J. A. (2017). The expansion of public spending and mass education in Bolivia: did the 1952 Revolution represent a permanent shock? In L. Bertola & J. Williamson (Eds.), *Has Latin American inequality changed direction? Looking over the long run* (pp. 195–218). New York: Springer.

Ranestad, K. (2018). The mining sectors in Chile and Norway, ca. 1870–1940: The development of a knowledge gap. *Innovation and Development*, 8(1), 147–165. https://doi.org/10.1080/2157930X.2017.1322030

Ranestad, K. (2020). Multinational mining companies, employment and knowledge transfer: Chile and Norway from ca. 1870 to 1940. *Business History*, 62(2), 197–221. https://doi.org/10.1080/00076791.2017.1407313

Salamanca Trujillo, A. (1993). *Facultad Nacional de Ingeniería (1906-1950), Ensayo monográfico.* Oruro: Liberías Latinas Editores.

Serrano Bravo, C. (2004). *Historia de la minería andina boliviana (siglos XVI-XX).* Potosí, Bolivia: UNESCO.

Sociedad Nacional de Minería. (1891). *Boletín*. Santiago.

Sociedad Nacional de Minería. (1910). *Boletín*. Santiago.

Sociedad Nacional de Minería. (1920). *Boletín*. Santiago.

Sociedad Nacional de Minería. (1925). *Boletín*. Santiago.

Sociedad Nacional de Minería. (1934). *Boletín*. Santiago.

Sociedad Nacional de Minería. (1936). Boletín. Santiago.

Sociedad Nacional de Minería. (1940). *Boletín*. Santiago.

Solano Vega, F. (1918). *El Mineral de Potrerillos 1916-1918.* Copiapó: Imprenta Progreso.

Statens bergskole. (1966). *Bergskolen 100 år Jubileumsberetning 1866-1966*. Trondheim.

Tveit, K. (1991). The Development of Popular Literacy in the Nordic Countries. A Comparative Historical Study. *Scandinavian Journal of Educational Resear*ch, 35(4), 241–252. https://doi.org/10.1080/0031383910350401

Universidad de Chile. (1913). *Anales*. Santiago.

Universidad de Chile. (1920). *Anales*. Santiago.

Velásquez-Castellanos, I. (2017). La instrucción y la educación en la historia de Bolivia (1900-2017). In I. Velásquez-Castellanos & N. Pacheco (Eds.), *Un siglo de economía en Bolivia (1900-2015). Tópicos de historia económica* (pp. 507–580). La Paz: Konrad Adenauer Stiftung.

Vertova, G. (1999). Stability in national patterns of technological specialisation:some historical evidence from patent data. *Economics of Innovation and New Technology*, 8(4), 331–354. https://doi.org/10.1080/10438599900000014

Villarán de la Puente, F. (2015). *Historia de las patentes e invenciones en el Perú*. Lima: Indecopi.

Ville, S., & Wicken, O. (2013). The dynamics of resource-based economic development: evidence from Australia and Norway. *Industrial and Corporate Change*, 22(5), 1341–1371. https://doi.org/10.1093/icc/dts040

Ville, Simon, & Wicken, O. (2015). The institutional foundations of natural resource based knowledge economies. In M. Badia-Miró, V. Pinilla, & H. Willebald (Eds.), *Natural resources and economic growth. Learning from history* (pp. 294–312). London: Routledge.

Westberg, J. (2019). The Production of Impoverished but Sophisticated Emigrants: Emigration, Human Capital, and Economic Growth in Sweden. In D. Mitch & G. Capelli (Eds.), *Globalization and the rise of mass education* (pp. 193–217). Palgrave.

Wright, G. (2015). The USA as a case study in resource- based development. In M. Badia-Miró, V. Pinilla, & H. Willebald (Eds.), *Natural resources and economic growth. Learning from history* (pp. 119–139). London: Routledge.

Appendix. Foundation of Mining and Engineering Schools from 1700 to 1910

Country	**Type**	**Institution**	**Year of foundation**	**Source**
Germany	Mining Schools	Mining School in Freiberg	1702 (1765)	Habashi (2003)
Czech Lands		Mining School in Joachimsthal	1716	Habashi (2003)
Hungary		Mining School in Schemnitz	1735	Habashi (2003)
Italy		Tunin School of Mineralogy	1752	Habashi (2003)
Norway		**Mining Seminar in Kongsberg**	**1757**	**Ranestad (2018)**
Czech Lands		Mining School in Prague	1763	Habashi (2003)
Slovenia		Mining School in Idria	1763	Habashi (2003)
Germany		The School of Mines in Berlin	1770	Habashi (2003)
Russia		Saint Petersburg Mining Institute	1773	Habashi (2003)
Germany		School of Mining and Metallurgy in Clausthal	1775	Habashi (2003)
Spain		Mining Academy in Almaden	1777	Habashi (2003)
Mexico		Real Tribunal de Mineria	1777	Habashi (2003)
France		Mining School inParis	1778	Habashi (2003)
Mexico		Mining School/ National School of Mining	1792/1867	Maloney & Caicedo (2017)
Germany		School of Mines in Eisleben	1798	Habashi (2003)
Mexico		School of Mines in Guadalajara	1798	Habashi (2003)
Germany		Mining School in Geislautern	1802	Habashi (2003)
France		Mining School in St. Etienne	1816	Habashi (2003)
Germany		Saarbrücken School of Mines	1816	Habashi (2003)
Germany		Mining School in Saarbrücken	1816	Habashi (2003)
Poland		Academy of Mining in Cracow	1816	Habashi (2003)
Sweden		**Mining School in Falun**	**1819**	**Habashi (2003)**
Belgium		University of Liege (mining)	1825	Habashi (2003)
Spain		School of Mines in Madrid	1828	Habashi (2003)
Belgium		Ecole Provinciale des Mines du Hainaut	1837	Habashi (2003)
Austria		Mining school in Leoben	1840	Habashi (2003)
France		Mining School in Ales	1841	Habashi (2003)
Czech Lands		Mining School in Pribram	1848	Habashi (2003)
Mexico		Practical School of Mining and Metallurgy in Zacatecas	1852	Habashi (2003)
Germany		Bochum School of Mines	1854	Habashi (2003)
Chile		**Mining School of Copiapó**	**1857**	**Ranestad (2018)**
Germany		School of Mines in Zwickau	1862	Habashi (2003)
United States		School of Mines in Columbia College, New York	1864	Wright (2015)
Germany		Essen School of Mines	1868	Habashi (2003)

United States		Mining & Metallurgy College, State University of California	1864	Habashi (2003)
United States		School of Mines, University of Nevada	1864	Habashi (2003)
United States		School of Civil and Mining Engineering, University of Kentucky	1866	Habashi (2003)
United States		School of Civil & Mining Engineering, West Virginia University	1867	Habashi (2003)
United States		School of Mines and Metallurgy, University of Missouri	1870	Habashi (2003)
United States		Colorado School of Mines	1870	Habashi (2003)
Australia		School of Mines in Ballarat / Australian Institute of Mining and Metallurgy	1871/ 1891	Ville and Wicken (2015)
New Zealand		Otago School of Mines	1871	Habashi (2003)
United States		State Agricultural College (mining)	1871	Habashi (2003)
Australia		Mining School in Bendigo	1873	Habashi (2003)
Japan		Imperial College of Engineering (mining)	1875	Habashi (2003)
Brazil		Ouro Preto School of Mines	1876	Habashi (2003)
United States		School of Mines and Mine Engineering	1877	Habashi (2003)
France		Mining School in Douai	1878	Habashi (2003)
Canada		Mining Engineering in McGill College, University of Toronto	1878	Maloney & Caicedo (2017)
United States		Freeland mining & Mechani- Drifton	1879	Habashi (2003)
Australia		Mining School in Bairnsdale	1880	Habashi (2003)
United States		School of Mines, University of North Dakota	1883	Habashi (2003)
United States		Michigan Mining School	1885	Habashi (2003)
United States		School of Mines in Rapid City	1885	Habashi (2003)
Colombia		School of Mines in Meddelin	1886	Habashi (2003)
United States		School of Mining & Metallurgy, University of Alabama	1887	Habashi (2003)
Chile		**Mining School of La Serena**	**1887**	**Habashi (2003)**
Chile		**Mining School of Santiago**	**1887**	**Habashi (2003)**
Australia		Mining School in Adelaide	1889	Habashi (2003)
United States		New Mexico School of Mines	1889	Habashi (2003)
Canada		Hailebury School of Mines	1883	Habashi (2003)
United States		College of Earth & Mineral Sciences	1890	Habashi (2003)
United States		School of Mines in Philadephia	1890	Habashi (2003)
United States		School of Mines, University of Desert	1891	Habashi (2003)
United States		School of Mines and Metallurgy, University of Minnesota	1892	Habashi (2003)
China		Wuchang Mining and Engineering College	1892	Habashi (2003)
Canada		Kingston School of Mining and Agriculture	1893	Habashi (2003)
United States		School of mining, University of Washington	1893	Habashi (2003)

United States		Montana School of Mines	1893	Habashi (2003)
Australia		Zeehan School of Mines and Metallurgy	1894	Habashi (2003)
United States		School of Mines of the Oregon Agricultural College	1899	Habashi (2003)
Ukraine		Dnepropetrovsk Mining Institute	1899	Habashi (2003)
Australia		Mining School in Charters Towers	1900	Habashi (2003)
United States		School of Mines, University of Oklahoma	1902	Habashi (2003)
Australia		Western Australia School of Mines	1902	Habashi (2003)
Bolivia		**Practical School of Mining**	**1906**	**Salamanca (1993)**
United States		Mining Trade School, Univer-Platteville	1907	Habashi (2003)
France	Enginee-ring	Ecole Royale des Ponts et Chaussees	1747	Habashi (2003)
Istanbul, Ottoman Empire		Imperial Navan Engineers' School	1773	Habashi (2003)
Paris, France		Ecole Polytechnique	1794	Habashi (2003)
United States		West Point	1802	Maloney & Caicedo (2017)
Prague, Bohemia		Polytechnishes Institut	1806	Habashi (2003)
Graz, Austria		Technische Hochschule (Johanneum)	1811	Habashi (2003)
Vienna, Austria		Technische Hochschule	1815	Habashi (2003)
Cairo, Egypt		School of engineering	1816	Habashi (2003)
Troy, New York		Rennselaer Polytechnic Institute	1824	Habashi (2003)
Moscow, Russia		Institute of Technology	1825	Habashi (2003)
Baden, Karlsruhe		Technische Hochschule	1825	Habashi (2003)
Bavaria Munich		Technische Hochschule	1827	Habashi (2003)
Stockholm, Sweden		**Teknologiska Institutet**	**1827**	**Habashi (2003)**
Dresden, Saxony		Technische Hochschule	1828	Habashi (2003)
London, England		University College	1828	Habashi (2003)
Saint Petersburg, Russia		Saint Petersburg Institute of Technology	1828	Habashi (2003)
Gothenburg, Sweden		**Chalmers University of Technology**	**1828**	**Habashi (2003)**
Warsaw, Poland		Warsaw Polytechnic	1828	Habashi (2003)
London, England		King's College	1829	Habashi (2003)
Copenhagen, Denmark		Technical University of Denmark	1829	Habashi (2003)
Moscow, Russia		Polytechnic School	1832	Habashi (2003)
Darmstadt, Hesse		Höhere Gewerbeschule	1835	Habashi (2003)
Mons, Belgium		Ecole Polytechnique	1836	Habashi (2003)
Stuttgart, Württemberg		Technische Hochschule	1840	Habashi (2003)
Hanover, Hanover		Technische Hochschule	1847	Habashi (2003)
Helsinki, Finland		**Helsinki University of Technology**	**1849**	**Habashi (2003)**
Brno, Moravia		Technical University of Brno	1849	Habashi (2003)

Zürich, Switzerland		Eidgenössische Technische Hochschule	1855	Habashi (2003)
Calcutta, India		Bengal Engineering College	1856	Habashi (2003)
Milan, Italy		School of engineering	1863	Habashi (2003)
Delft, The Netherlands		Technische Universiteit	1864	Habashi (2003)
Cambridge, Massachusetts		Massachusetts Institute of Technology	1865	Habashi (2003)
Montreal, Canada		Ecole Polytechnique	1873	Habashi (2003)
Brussels, Belgium		Ecole Polytechnique	1873	Habashi (2003)
Rio, Brazil		Polytechnical School of Rio	1874	Maloney & Caicedo (2017)
Peru		**School of Civil Construction and Mining Engineers (Mining and civil engineering)**	**1876**	**López Soria (2012)**
Colombia		National School of Mining in Antioquia (Irregular operation)	1877	Maloney & Caicedo (2017)
Berlin, Prussia		Königliche Technische Hochschule	1879	Habashi (2003)
Ohio, Cleveland		Case Institute of Technology	1880	Habashi (2003)
Georgia, Atlanta		Georgia Institute of Technology	1885	Habashi (2003)
São Paolo, Brazil		Escola Politecnical Universidade de São Paulo	1894	Habashi (2003)
Salvador, Brazil		Escola Politecnical, Universidade Federal de Bahia	1897	Habashi (2003)
Kiev, Ikraine		Polytechnic Institute	1898	Habashi (2003)
Saint Petersburg, Russia		Saint Petersburg Polytechnic Institute	1899	Habashi (2003)
Argentina		Civil Engineering in three universities	Last quarter 19th century	Maloney & Caicedo (2017)
Tomsk, Russia		Tomsk Technological Institute	1900	Habashi (2003)
Novo Cherkassk, Russia		Novo Cherkassk Polytechnical Institute	1907	Habashi (2003)
Pittsburgh, Penssylvania		Carnegie Institute of Technology	1905	Habashi (2003)
Halifax, Nova Scotia		Technical University of Nova Scotia	1907	Habashi (2003)
Trondheim, Norway		**Norwegian Institute of Technology**	**1910**	**NTH (1920)**

Sources: Detailed in the table.