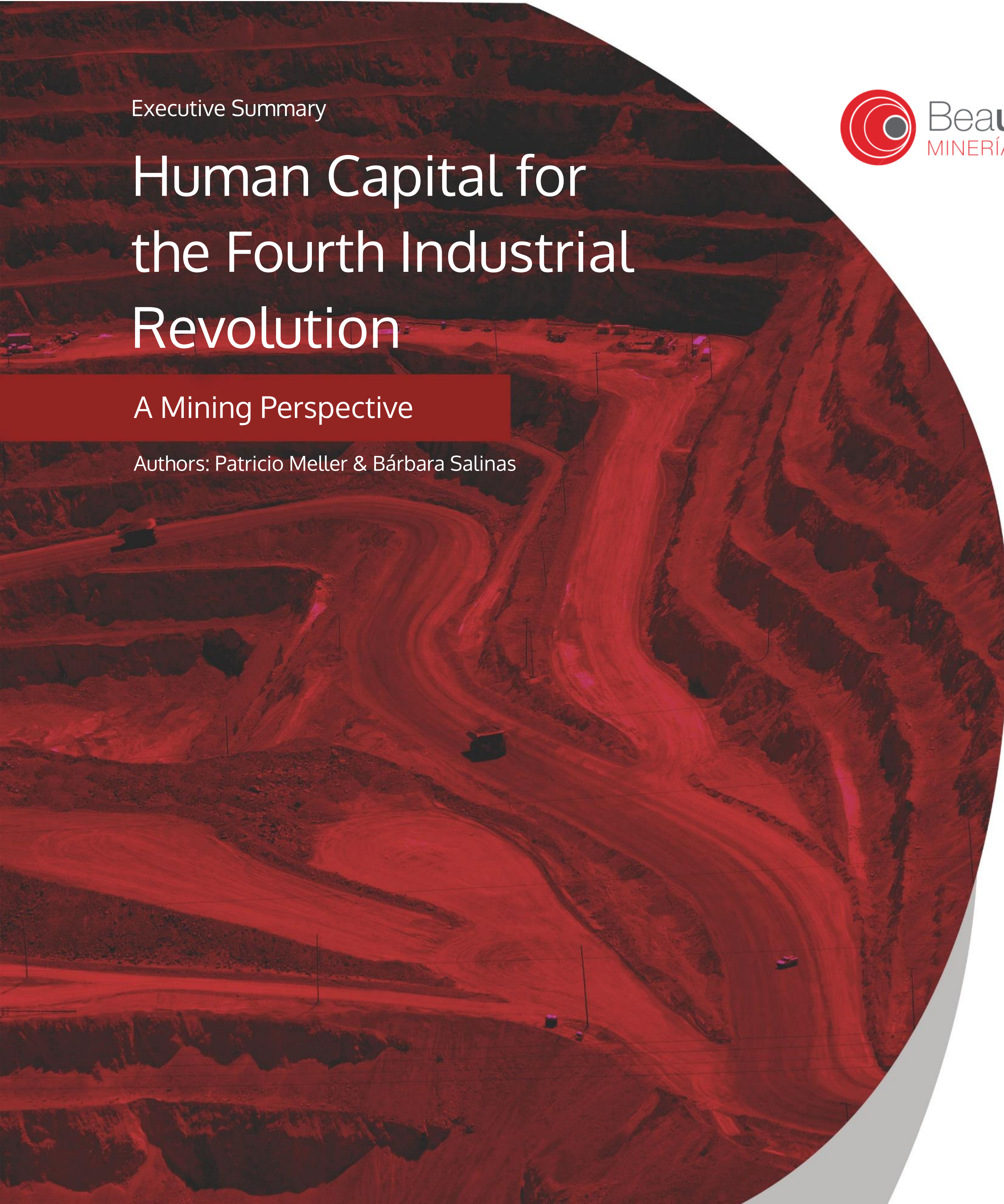
Executive Summary

Human Capital for the Fourth Industrial Revolution

A Mining Perspective

Authors: Patricio Meller & Bárbara Salinas



Studies in Mining, Technology and Society Series

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Beauchef Minería

This is a program created at the Faculty of Physics and Mathematics at the University of Chile. Its mission is to become a think tank that achieves steering functions and support for public policies in the mining sector. The purpose is to contribute towards increasing the competitiveness of the mining industry in Chile, to participate in the strengthening and coordination of the innovation ecosystem and to increase the visibility of the activities carried out at the Faculty of Physics and Mathematics in a national and international scope.

As an important part of its work, Beauchef Minería organises colloquia and studies on topics of high interest for the mining industry, highlighting the activities that the Faculty undertakes on mining R&D&i.

Human Capital for the Fourth Industrial Revolution
A Mining Perspective

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Foreword

The Fourth Industrial Revolution is driven by digital transformation, automation, robotics, IoT (Internet of Things), big data and artificial intelligence; it is shaping all industries worldwide. On the one hand, it is expected that, as in previous revolutions, it will enable us to improve our quality of life. However, there is concern about the rapid changes that will occur and the possibility that it may generate large negative effects, such as higher unemployment and increasing inequality between countries and among high and low income people. Undoubtedly, there are apprehensions across the world about how to surf this mega technological wave.

There is no doubt that human capital is a key element in facing this process properly and, certainly, those countries and industries with professionals trained in new technologies will be able to adapt more efficiently to the technological tsunami that is flooding us.

In this context, the present study is of crucial importance as it identifies key aspects that must be addressed by Chile and its mining industry in order to be part of this new technological era.

"Human Capital for the Fourth Industrial Revolution: A Mining Perspective" tackles - in a clear and precise way - the gap between Chile and developed countries in relation to the human capital required for the multiple technological innovations that are taking place in the 21st century. It also offers an accurate analysis of the technological trends relevant to the mining sector of the future, identifying short, medium and long-term challenges in the field of human capital.

At Beauchef Minería we hope that this study will add to the discussion of these topics in our country, with the main objective of contributing towards increasing the competitiveness of the national mining industry, cooperating with the strengthening and harmonisation of its ecosystem of innovation and with proposals on strategic issues for the development of this key sector for Chile´s economy.

Javier Ruiz del Solar
Executive Director of Beauchef Minería

Human Capital for the Fourth Industrial Revolution
A Mining Perspective[1]

Authors: Patricio Meller & Bárbara Salinas

Introduction

Although Chile has improved its economic indicators and its citizens' quality of life, there is still a large gap in relation to developed countries regarding the human capital required for the multiple technological innovations that are taking place in the 21st century. This is the problem that inspired this study and that has generated several of the questions that we will try to address. However, we must keep in mind that sometimes the queries are more relevant than the answers.

What type of human capital will increase Chile's chances of becoming a part of the Fourth Industrial Revolution?

The forms of addressing the topic of human capital have evolved as Chile's economy has developed. A hundred years ago, we often wondered as to when Chile was going to become a developed country. Nowadays, the questioning is more related to the method that we will use to reach this goal. Given the characteristics of our economy, there are discussions on whether copper can transform Chile in a developed country. Why copper? The answer lies in the fact that Chile is small in everything, except in copper. If we compare ourselves with China, a country that surpasses us in practically all the economic indicators, in this particular field we are far greater.

Another concept worthy of our attention is that we are living the Fourth Industrial Revolution based on the digital transformation, robotics, nanotechnology, bio-genetics, along with numerous combinations between these four technologies. Chile was an outside spectator of the last three technological revolutions as they occurred: the steam engine in the 18th century, electricity and oil in the XIX century and computers in the 20th century. We have this new revolution just in front of us and we expect not to be left out again. Yet, how are we to make Chile a part of the Fourth Industrial Revolution?

There is a hypothesis that says that the "world is flat", that information and knowledge are available everywhere (Friedman, 2005). Almost everybody has a cell phone today, and each of these phones has more capacity than the computers that existed when humans landed on the moon. In theory, with this technological potential anybody could invent anything, anywhere. However, while information, knowledge and technology may well be available everywhere, why is Chile not on the cutting edge of innovation?

Thus, the following question arises: what type of human capital will increase Chile's chances of becoming a part of the Fourth Industrial Revolution? In order to answer this question, we propose two key assumptions: (1) We need more doctors in science and technology and (2) copper will aid us as a technological innovation platform.

This study tries to answer the questions previously mentioned with the objective of putting this issue on the public debate agenda and constructing an analysis that is useful for the public sector, universities, research centres and mining companies.

[1] This study is part of the activities developed by Beauchef Minería during 2018. The authors appreciate the comments and suggestions made by Javier Ruiz del Solar, Rodrigo Cortés, James McPhee, Alejandro Jofré, Luis Vargas, Álvaro Egaña, Alejandro Ehrenfeld and Paul Vallejos. As usual, the authors are solely responsible for the content of this report.

I. Advanced Human Capital and the Fourth Industrial Revolution

The technological revolution, the exponential increase of information and digitisation, make human capital essential for the incorporation of new technologies.

Human capital is fundamental for economic development

Human capital (HK) represents the education, skills and abilities of an individual. In theory, people who want to increase their income should assign time and resources to increase their productive capacity. This explains why people invest so much in higher education. Therefore, education has become the main mechanism for addressing the inequality and social mobility issues.

However, formal education is not the only mechanism for gaining HK. Work experience, interactions with other people, cultural and family environment, and acquired tacit knowledge all increase HK.

Nowadays, HK has stopped solely being considered as an individual's solution for increasing the level of income; HK has become a key factor for the competitiveness and the economic and social success of countries. The technological revolution, the exponential increase of information and digitisation, make human capital essential for the incorporation of new technologies.

Universities have the responsibility of generating the supply and types of HK that companies demand. Additionally, they should interact more with the productive sector in order to be familiarised with its problems. This requires greater interactions between business executives and academics, which creates a virtuous circle for both. Several studies have shown that collaboration between universities and the private sector is key so that doctors can subsequently be hired by companies[2]. Hence, many developed countries have implemented public policies that encourage these collaborative alliances[3].

[2] Durette et al. 2012; Etzkowitz (2003); Benito, M. & Romera (2013).

[3] Borrel Damian et at. (2015).

Are political leaders, academia and the CEOs of companies prepared to make the most of the potentials associated with the Fourth Industrial Revolution?

Chile cannot forgo on the Fourth Industrial Revolution

The industrial revolutions have been responsible for the increase of economic growth rates and the living standards around the world. Currently, we are living the Fourth Industrial Revolution, characterised by advances in biotechnology, robotics, nanotechnology, artificial intelligence, etc. What makes it different from the previous ones is the speed at which the changes are occurring, its widespread coverage and depth, and its systemic impact. As a consequence, the world is being modified to the extent that it is challenging our ideas about what it means to be a human (Schwab 2016).

Are political leaders, academia and the CEOs of companies prepared to make the most of the potentials associated with the Fourth Industrial Revolution?

Productive companies will have to boost deep organisational changes; CEOs must understand the new technologies in order to insert them into their operations and processes. According to Deloitte (2017), very few executives venture on investing in modern technologies, since this implies leaving their comfort zones and adopting new business models to face challenges with unpredictable consequences.

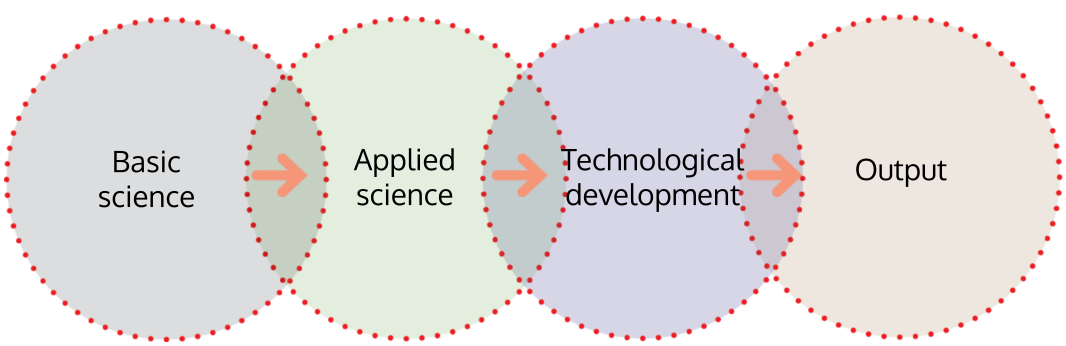
Developed countries recognise the importance of specialised HK in the field of innovation. For this reason, they have promoted various initiatives to increase the participation of specialised HK in the productive sector. Nevertheless, in Latin America, companies invest little on R&D (Research and Development), which is partly explained by their lack of technological capability[4] (capacity + skill).

Companies are the ones that tend to develop and use technology. In spite of that, research centres and universities are essential for carrying out R&D. In order to generate a transfer of technology, it is necessary for companies to have the internal specialised HK in order to put this R&D into operation.

A new way of generating innovation: the dual model

The linear model of innovation corresponds to sequential stages where basic science is a requirement for technological innovation. This model has influenced public policies for the funding of basic science, while companies must invest in the development of applied science and technological development.

[4] See Meller y Parodi (2016).



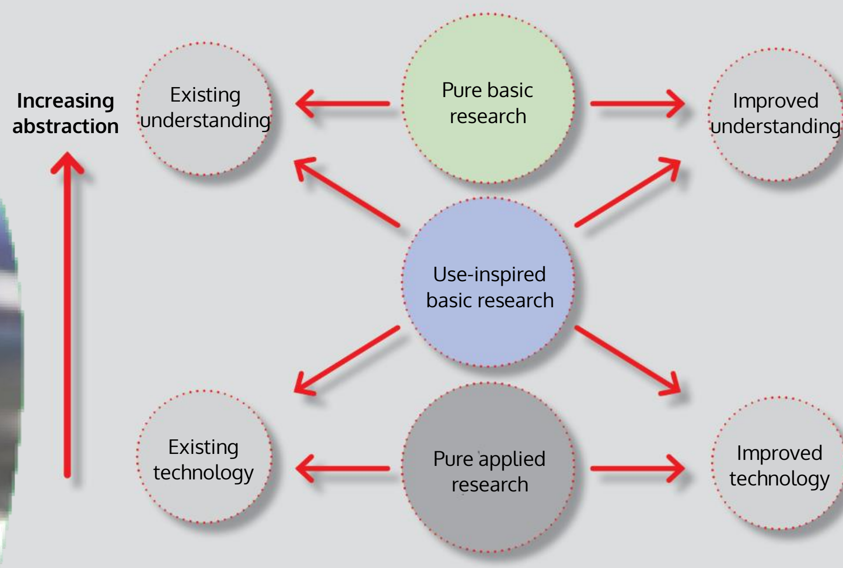


Later, the Dual Model was born (figure 1), which brings together the interactive, yet autonomous paths, of scientific understanding and technological know how. That is to say, both science and technology can evolve independently on their own, regardless of what happens with the other. However, there can also be reciprocal bi-directional and interdependent influences inspired by applied science.

This new concept of technological development suggests a combination of basic and applied science that must be financed by the State and the private sector.

Despite this paradigm shift, the "linear model" of the relationship between science and technological innovation is not obsolete. Science remains fundamental for knowledge development and must be financed by the State so that it is able to fulfil its role.

Figure 1: Dual Model



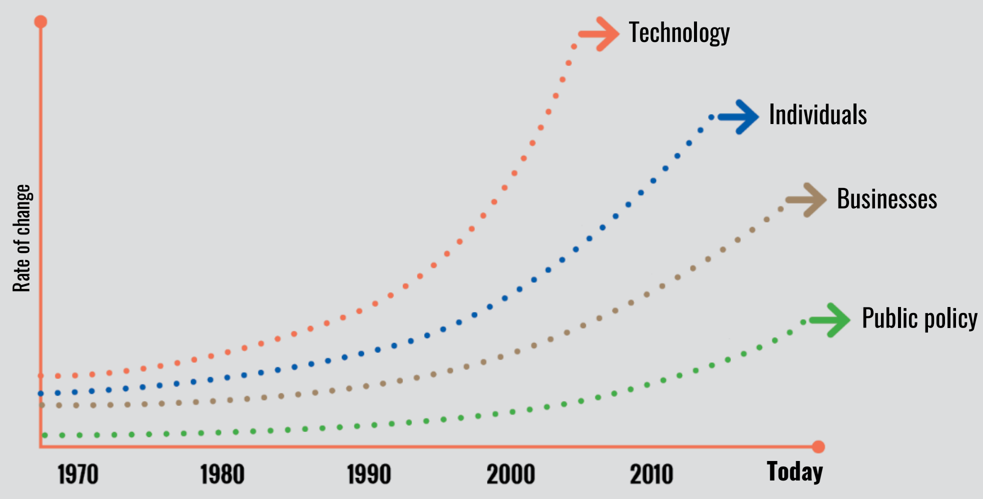
Source: Adapted from Stokes (1997)

Technology advances so fast that it causes adaptation problems

In figure 2, curve 1 reflects the exponential change of technological progress. At the start of this century, technology reached an extraordinary level, which was impossible to be assimilated by people (curve 2), companies (curve 3) and public policies (curve 4). Moreover, it is estimated that it took almost 15 years for individuals to reduce the gap, which to this day has yet to be closed. Companies have taken even longer, with approximately 20 years of delay, due to the need for planning, restructuring, outlining goals, evaluating risks and costs, etc. Finally, public policies, such as minimum wage, labour training, taxes, foreign trade, education, etc., show approximately a 30-year difference in adapting to technological improvements.

Given the great uncertainty surrounding the emergence of future technology, it is important that professionals develop digital, data analysis and computer knowledge along with soft skills, such as critical thinking, creativity, coordination and team leadership, interdisciplinary thinking, flexibility, adaptation, solving unknown problems, etc. Therefore, we have to strengthen the skills that robots, essentially, cannot develop (Muro et al., 2017).

Figure 2: Lags caused by the technological transition



Source: Adapted from Deloitte (2017)

II. Human Capital in Chile

It is essential for engineers and doctors in science to be involved in the Fourth Industrial Revolution and thus contribute with their knowledge. The current stage of technological innovation is characterised, among other things, by the generation of large amounts of information, as well as by the use of digital and/or automated technologies. Engineers and doctors in science have comparative advantages for thriving in this environment.

It is essential for engineers and doctors in science to be involved in the Fourth Industrial Revolution and thus contribute with their knowledge.

In the following segment, we can see what has occurred in the evolution of new engineers and doctors during the last decade. As shown in table 1, between 2007 and 2017, more than 61,000 engineers entered the Chilean labour market. Since this study is focused on mining, it is important to highlight the notorious increase of mining engineers. While the total of engineering graduates doubled in this period, the mining engineering graduates increased by 1000%. This could be generating a saturated market, as it seems there may be a surplus of mining engineers in Chile.

Why is there a great expansion of mining engineers? Is it something generated by the demand of mining companies? In 2007, four universities taught this discipline, with the participation of 56 graduate students. In 2017, 12 universities offered this course, with the impressive amount of 578 graduate students. The evidence shows that mining engineers are the ones with the highest income, which makes it an appealing option. However, when many universities increase their vacancies tenfold, it is worth asking what the rate of current unemployment among mining engineers is.

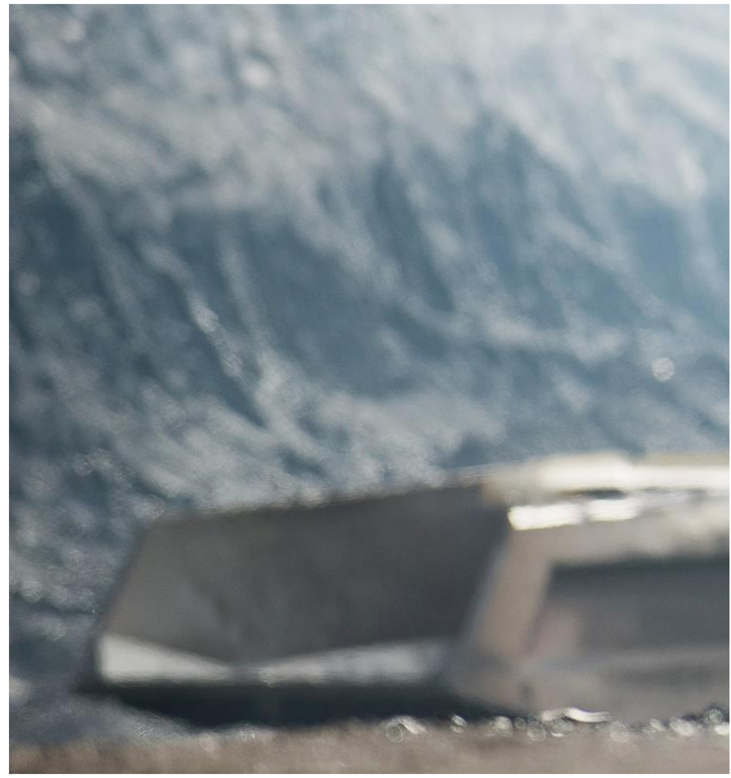


Table 1:
Engineering and Mining Engineering Graduates in Chile (2007-2017)

Year	Engineering graduates	Mining Engineering graduates
2007	4,068	56
2017	7,704	578
Total 2007 2017	61,366	2,684

Source: Own elaboration on data from Ministerio de Educación (2018)

In Chile there are few doctors within the relevant technology sectors

In Chile, 10,592 people hold doctoral degrees (year 2014), of which 2,130 (20%) belong to the fields of engineering and technology and 3,236 (30%) to natural science[5].

There are fundamental disciplines for technology development that are lacking specialised doctors. Table 2 shows the amount of doctors who pursued their doctorate in different fields. Computing, with only 36 doctors is a key sector for productivity, economic growth and innovation. Environmental engineering and environmental biotechnology have merely 50 doctors each, a very low number considering that climate change and the scarcity of natural resources are issues that have a great impact on countries and the welfare of their citizens. There are yet to be any doctors graduated in nanotechnology. Nevertheless, there may be other doctors from different backgrounds who could be working in this domain.

Some developed countries, such as the United States, Canada and Australia, have between 10 and 20 times more doctors compared to the relative amount that exists in Chile. For every million inhabitants, Chile has 596 doctors, while the United States has 12,633, Australia 6,046 and Canada 5,300 (table 3).

[5] This number differs from the information provided by the Ministry of Economy, Development and Tourism (2016), since the OECD classification considers within the natural sciences some areas that in Chile are taught by faculties of engineering. In this study, we have changed the classification.

Table 2: Doctorate holders by field doctorate degree (2011 y 2014)

Science Classification	2011	2014
Medical engineering	14	29
Environmental engineering	56	50
Environmental biotechnology	21	50
Nanotechnology	3	0
Computer and information sciences*	14	36

Source: Own elaboration on data from Ministerio de Economía Fomento y Turismo (2016) y Ministerio de Economía Fomento y Turismo (2015).
* This area is classified as a natural science according to the OECD classification. However, for this study, it has been integrated into Engineering and Technology, as in Chile this career programme is often offered by faculties of engineering.

Table 3: Doctorate holders in Australia, Canada, Chile and the USA

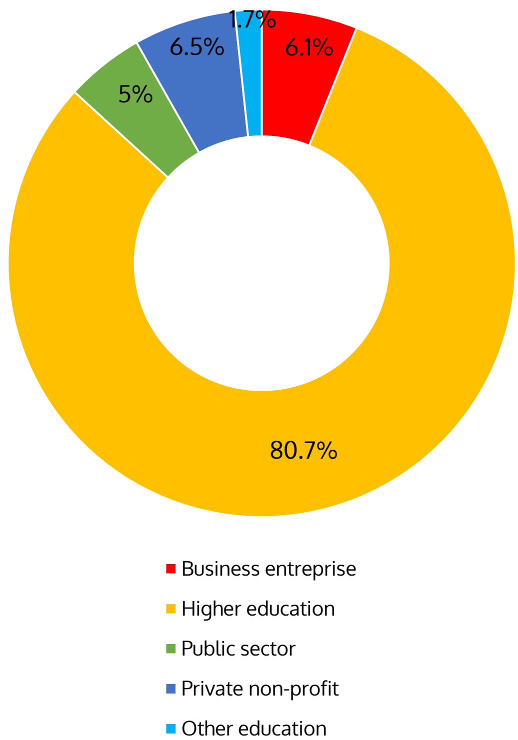
Country	Doctors	Doctors per million population
Chile (2014)	10,592	596
Canada (2011)	208,480	6,046
Australia (2011)	118,396	5,300
USA (2017)	4,096,000	12,633

Source: Own elaboration on data from Statistics Canada (2011); U.S. Census Bureau 2017; Ministerio de Economía (2016); Group of Eight (2013).

In Chile, productive companies almost do not hire doctors: 81% work in universities, while only 6% are employed in the private sector (figure 1).

Some developed countries, such as the United States, Canada and Australia, have between 10 and 20 times more doctors compared to the relative amount that exist in Chile.

Chart 1: Doctorate holders by sector of employment (2014)



Source: Own elaboration on data from Ministerio de Economía (2016)

In Chile, R&D is not valued

Chile invested $ 613,476 (CLP) million in 2016 in R&D, which represents only 0.37% of GDP. Compared to the rest of the OECD countries, Chile stands at the bottom of the ranking (OECD 2016).

In Chile, the State is the main investor in R&D, with 46.5% of the total investment, while companies only contribute with 36%. In addition, there is scarce funding from companies to universities (only 3.4%) despite the fact that they are often the ones that benefit the most from the development of innovation and new technologies[6].

[6] Santelices & Lund (2013)

In Chile, the personnel dedicated to R&D work mostly in the higher education sector (table 4). One of the main concerns is that in Chile research is mainly led by universities, whose interests may differ from the private industry. Moreover, companies employ only 6.5% of the doctors working in R&D, which undoubtedly affects the development of technological innovation. In this regard, it should be noted that the sequential mechanism for generating innovation is that universities undertake R&D and companies carry out the innovation, transfer and scaling. Universities can only produce prototypes and patents, however, those in charge from taking them and transforming them into products and systems are companies[7].

[7] Javier Ruiz del Solar, executive director of Beuchef Minería (pers. comm).

Companies employ only 6.5% of the doctors working in R&D, which undoubtedly affects the development of technological innovation.

Table 4: R&D personnel employed by private companies and universities (full time equivalent)

	% of the total of each category	
	Business entreprises	Universities
Doctorate holders	6.5%	79.5%
Masters	19.8%	55.7%
Bachelor	40.8%	49.6%

Source: Own elaboration on data from Ministerio de Economía Fomento y Turismo (2018)

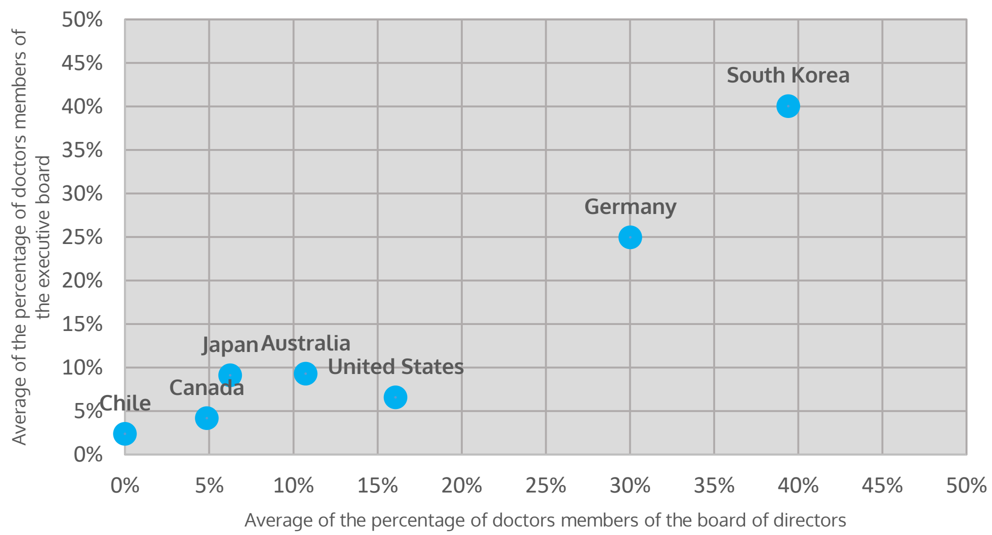
The interesting role of doctors in developed countries

Let us compare the role of doctors in Chilean firms with the number of managers and directors with doctoral degrees in the leading companies of Germany, South Korea, Japan, Canada, the USA and Australia[8]. Figure 2 shows the average percentage of doctors on the board of directors and executive boards of each country. South Korea leads the ranking, with about 40% of the members of both boards being doctors. In Germany, 30% of the board of directors and 25% of the executive board hold a doctorate degree. Similar figures have been presented in other studies[9].

Chile is very far behind those countries, with 0% of the directors and only 3% of the managers being doctors. In summary, in developed countries there are doctors in both, the executive and director boards of enterprises, while Chile registers only isolated cases. The lack of doctors in these types of jobs can be detrimental to innovation and local technology development. There is empirical evidence showing that companies whose CEOs hold doctoral degrees have a 24% higher number of patents and a 46% higher number of quotes than companies whose CEOs don't have advanced degrees (He 2014).

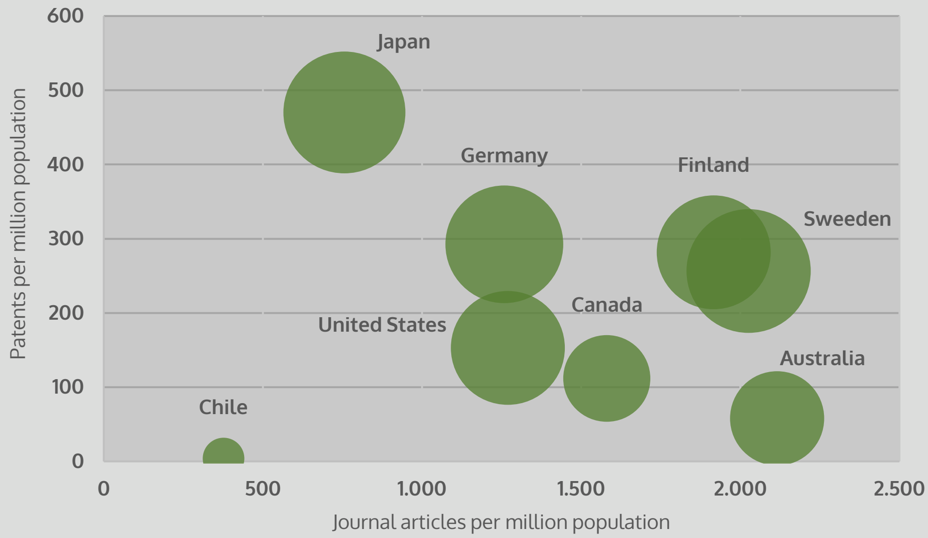
[8] Germany, South Korea and Japan were added because they are leaders in technological innovation.
[9] Couston & Pignatel (2018); Cyranoski et al. (2011).

Chart 2: **Managers and director with doctoral degree in the leading companies of the world (2018) – 24 from developed countries and 6 from Chile**



Source: Own elaboration on data from the websites of the companies considered for this study, Linkedin and Bloomberg. Chilean entreprises: Antofagasta Minerals, Cencosud, Celulosa Arauco, Copec, LATAM y Falabella. Foreigner entreprises: Amazon, Apple, General Motors, Google, Walmart, Toyota, Allianz SE, Bayer, BMW, Daimler Chrysler, Deutsche Post, Deutsche Post, Deutsche Telekom, E ON, SAP, Siemens, Barrick, Brookfield, Power Corporation, Hanwha, Posco, Samsung, BHP, Rio Tinto, Wesfarmers.

Chart 3: Patents and journal articles per million population (2013-2017)*
Size of the bubbles correspond to R&D expenditure as percentage of GDP



Source: Own elaboration on data from World Bank (2013), OECD.stat y UN (2017).
* The data available regarding the journal articles is from 2013, whereas the data concerning the patents is from 2017.

In developed countries there are doctors in both, the executive and director boards of enterprises, while Chile registers only isolated cases.

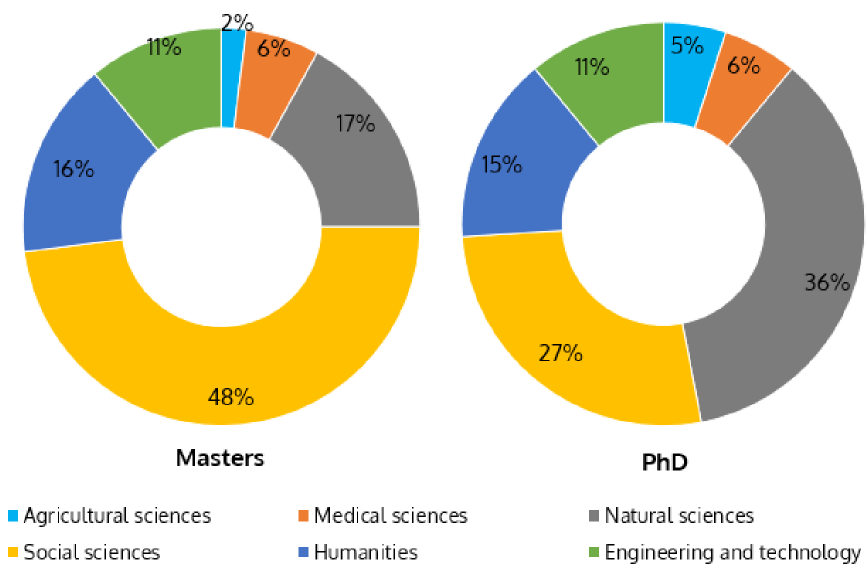
What is the role of doctors in Chile?

In Chile, there is a trend towards publishing academic articles instead of generating patents. This happens mainly because of the university promotion system and the incentives given by the State to obtain funding for research. Therefore, more importance is giving to published academic articles (WOS ISI magazine).

Chart 3 shows the relationship between patents and the publication of articles for different countries. The size of the bubble is determined by the percentage of GDP spent on R&D. Chile appears last in the production of patents, with only four being registered per million inhabitants, while Japan surpasses the rest of the countries with 470 patents, followed by Germany having 292. The United States, Canada and Australia produce relatively fewer patents, but far outnumber Chile. On the other hand, when comparing the academic published articles, the gap between Chile and the rest of the countries is not so extreme. Additionally, there is a relationship between R&D expenditure and the publication of articles and/or the registration of patents.

Social sciences receive 3 times the amount of doctoral grants and 4.5 times more scholarships for master's degrees than engineering. This distribution seems inconsistent with the needs of the country

Chart 4: Masters and PhD scholarships by field of study (2017)



Source: Own elaboration on data from CONICYT (2017)

In short, Chile's efforts to promote R&D are insufficient. This is of concern if we generally want to remain competitive, particularly in mining. The copper industry offers endless possibilities for the country’s development, as long as suitable incentives are introduced. The abundance of natural resources is essential as a platform for generation of innovation and technological development[10].

The distribution of scholarships in Chile is inconsistent with the country's needs for inserting itself in Industry 4.0

The majority of Becas Chile doctoral scholarships are awarded to the fields of natural sciences (35%), followed by social sciences (29%) and humanities (16%). On the other hand, engineering and technology have only 10%, medical sciences 6% and agricultural science 5% (graph 4). Social sciences receive 3 times the amount of doctoral grants and 4.5 times more scholarships for master's degrees than engineering. This distribution seems inconsistent with the needs of the country, where engineering and mining are key economic activities. Mining accounts for 10% of GDP and more than 50% of exports. Therefore, encouraging HK that develops innovation for this sector should be a priority.

CONICYT (2017) defined three priority areas in 2017 for master's scholarships: water resources, resilience to natural disasters and digital transformation.

[10] Meller & Gana (2015)

Although this is an improvement, it is still insufficient. Only 75 scholarships are assigned to these areas and this scheme does not consider key disciplines for boosting technological development according to Industry 4.0, such as robotics, nanotechnology, among others. In addition, environmental fields are not taken into account, which is worrisome considering the scarcity of natural resources and the security risks involved in supplying them, together with climate change, where engineers and scientists are fundamental for generating innovations for reducing these negative effects[11].

"Appropriate planning has not been done to determine how many doctorate holders are required in Chile, nor how many are being generated, let alone the number that will be used for research" (ANIP 2016). Although CONICYT created the Attraction and Insertion of Advanced Human Capital Program (PAI) in 2009, its coverage is insufficient. In a World Bank & OECD (2011) report, the Chilean policy of attraction and reintegration of postdocs graduates was criticised, as it is based on punishing those who do not return instead of rewarding their homecoming and supporting them in their job search process.

[11] Academia de Ingeniería de Chile (2018)

"Appropriate planning has not been done to determine how many doctorate holders are required in Chile, nor how many are being generated, let alone the number that will be used for research" (ANIP 2016).

In Australian and Canadian mining there are up to 80 times more researchers per million metric tons of copper (MTC) than those registered in Chile.

Chilean mining has a small-specialised labour force

Of the total personnel working on R&D in Chile, only 249 are concentrated in the mining industry (5%), while of the total of researchers[12] only 85 are working in this sector (3%) (table 5). In Australian and Canadian mining there are up to 80 times more researchers per million metric tons of copper (MTC) than those registered in Chile.

Additionally, the number of workers with a bachelor's degree or more advanced education is larger in the Australian mining industry than in Chile. In addition, in the former country, the training expenditure per employee is six times higher than in its south American counterpart (Council of Competencies Mining Companies 2017; Australian Mining 2013).

[12] Includes all persons employed directly in research, measured as full-time equivalent.

Table 5: Researchers employed in the mining industry in Chile and in reference countries (2016*)

Country	R&D personnel in the mining sector	Researchers in the mining sector	Researchers / MTC
Chile	249	85	15
Australia	3,668	1,194	1,200
Canada	1,333	665	950

Source: Own elaboration on data from OECD.stat
*2016 or latest date available

Why should Chilean companies hire more doctors?

Doctors have appropriate skills for companies, such as the ability to resolve complex difficulties, research skills, the capacity of identifying and defining problems, aiding in tasks with data uncertainty and being generators of information and disseminators of knowledge (Durette et al., 2014; Couston & Pignatel 2018; Advisory Council for Science Technology and Innovation 2009).

For companies to be inserted into the Fourth Industrial Revolution, it is fundamental that their CEOs and directors understand and value the importance of innovation. As was previously pointed out, enterprises that hire managers with doctoral degrees will have more patents, and will obtain a greater number of citations. This leads to more innovation and greater relevance. At the same time, companies that support innovation have more incentives for hiring more doctors.

In general, the majority of businesses—including Chilean firms—do not hire doctors for the following reasons (Couston & Pignatel 2018; Benito & Romera 2013; Fixari & Pallez 2005):

1. Companies hire people that can adapt quickly to their tasks and generate short-term ideas and proposals.
2. Corporations believe that it is not so important to innovate, as it is less expensive and risky to import new technologies.
3. Universities are disconnected from the industry and companies have no information of the teaching content and research focus of the doctorate programmes.
4. Firms are not aware of the contribution doctors might bring to their organisations. They do not have business structures that adequately welcome doctors[13].
5. Companies prefer to hire professionals with master's degrees, who can adapt more easily to their culture and practices. Doctors can be very critical and disruptive.
6. There is a certain degree of arrogance among some doctors, who may look down on people with non-doctoral degrees: technicians, professionals, and masters.
7. Doctors tend to work individually. They are used to interacting only with other doctors.

[13] Javier Ruiz del Solar, executive director of Beuchef Minería (pers. comm).

III. Technological Trends Relevant to the Mining of the Future

In order to determine the HK that will be needed, first we must identify the technologies that are being adopted by the leading mining companies. We use three complementary methods.

Method 1:
Determining global trends for the mining of the future

The first classification is based on the type of technology, where we have identified five important areas: productive technologies, information technologies, environment, operational safety and energy efficiency. Here we will briefly describe some of them.

- **Productive technologies**

These types of technologies are fundamental for the mining sector. Although a great diversity of innovations can be found in this category, the main ones are the following[14]:

1. **Autonomous and remote equipment:** automation is the smart management of a system through the use of technology, in such a way that its operation can happen without human intervention. Leading mining companies are using this technology in drilling and blasting, trucks, remote hammers, trains, boat cargo, etc. These machines improve the productivity, reduce costs, improve workers security and decrease pollution.

2. **Systems automation:** the objective is to achieve, through the analysis and use of large volumes of information, the organisation of a totally interconnected system, from the mine to the port. The pioneering company in these technological advances is Rio Tinto, which has an integrated operation centre in Perth (Australia) from where they control and monitor the operations of the mine. CODELCO has also implemented this type of technology in its operations. At El Teniente there is an Integrated Operations Centre (CIO), which allows monitoring processes, managing teams remotely and making integrated decisions[15]. More recently, División Ministro Hales has also incorporated an integrated operations centre, obtaining excellent results.

3. **Drones:** Can be used to calculate volumes, monitor drilling, optimising the management of traffic, design roads, etc.

[14] Matysek & Fisher (2016); McKinsey (2017); CSIRO (2017) y Deloitte (2018).
[15] CODELCO (2010).

- **Information technology**

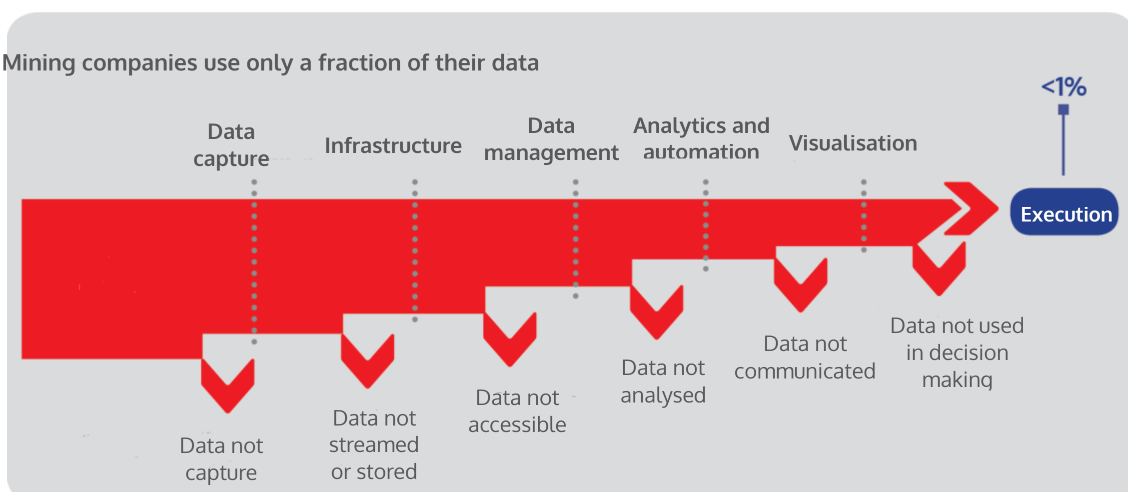
This corresponds to the use of sensors, computers and telecommunication equipment for storing, recovering, transmitting and manipulating data or information. "Much of the value creation in mining will shift from how well the operation moves material to how well it collects, analyses, and acts on information to move material more productively"[16].

Mining companies produce large quantities of data, however, less than 1% of this information is used in the production process for developing predictions and improving strategies. Throughout the process, several failures are responsible for this inefficiency (figure 3).

[16] Durrant-Whyte et al. (2015).

Mining companies produce large quantities of data, however, less than 1% of this information is used in the production process for developing predictions and improving strategies.

Figure 3: Data used by mining companies



Source: Adapted from Durrant-Whyte et al. (2015).

- **Operational safety**

Despite the fact that the mining sector has one of the lowest accident rates in Chile, it has the highest accident mortality rate. If we compare this to other relevant countries, Chile suffers 21.6 deaths per 100,000[17] of its protected workers, while the United States has 9.8[18] and Australia 2.7[19].

Therefore, it is important to develop innovation in this field. There are three technological trends in this category.

1. **Robotisation:** there are robots that can replace humans and carry out dangerous tasks. Operators can manage the machinery from safer and cleaner places through real time images and videos.

[17] Comisión Nacional de Productividad (2017).
[18] Centers for Disease Control and Prevention (2015).
[19] Safe Work Australia (2018).
[20] Mining Magazine (2018)

2. **Monitoring sensors:** can detect and report real-time safety data, such as the condition of machinery, air quality, geolocalisation, soil stabilisation, and the health and safety of workers[20].

3. **Ventilation systems:** high temperatures can cause workers health problems. Therefore, we must design complex ventilation systems that keep the temperature at optimal levels.

- **Energy efficiency**

The transition towards an energy mix based on Non-Conventional Renewable Energies (NCRE) is unavoidable. Therefore, the sooner the companies adapt, the more competitive they will be once this change becomes inevitable. In addition, an energy mix based on NCRE would generate a supply regardless of fossil fuel price fluctuations.

Energy self-sufficient mines can reduce their carbon emissions by up to 28% when using a system that combines solar energy—storage with batteries—and diesel generators. In short, it is also a great opportunity to reduce costs and improve the energy supply quality[21].

In Chile, renewables have increased their share of the overall energy mix, currently accounting for 20.4% of the installed electricity generation capacity (equivalent to 5,095 MW). As a matter of fact, 12% of the nation's energy comes from solar and wind. It worth noting the important increase of solar power, which went from 0 MW in 2012 to 2,358 MW of the installed energy generation capacity[22]. Additionally, energy prices in recent tenders have dropped significantly. In 2017 a record average price of 32.5 US$/MWh was reached[23].

Chile is already working in this area. CORFO created the Solar Energy Industry Development Committee with the purpose of boosting this industry in the country. On the other hand, a CORFO project aims to produce hydrogen based on solar energy to power the trucks of the mining industry.

- **Environment and community**

The environmental impacts caused by mining are widely known by the population, which has caused a change of perspective within the industry. The relationship with communities has been modified, forcing companies to have a "social license to operate". Therefore, having a permanent and effective communication with communities has become essential when developing new projects.

[21] Energy and Mines (2017)
[22] CNE (2018)
[23] CNE (2017)

Method 2:
Collaborative programs

1. **Collaborative R&D programmes:**

In developed countries, the private sector works collaboratively with universities[24], while in Latin America they prioritise alliances with clients, without including academia[25].

The collaboration between the private sector and universities is beneficial for both. For universities, it allows them to develop an interdisciplinary teaching scheme and deliver innovative solutions for complex problems, while responding to the industry needs. On the other hand, companies have access to scientific and technical knowledge, which are essential for overcoming their own challenges.

Rio Tinto has realised how important it is to create these partnerships. With this purpose, the company inaugurated the Rio Tinto Center for Mine Automation (RTCMA) in conjunction with the University of Sydney, a project that has delivered satisfactory results since 2007. Despite the fact that in Chile some R&D centres work in collaboration with the industry, there is not a solid and stable alliance throughout time. Considering that mining projects have a medium and long-term horizon, it is key to have centres that work permanently over time, which are capable of continuously and steadily solving the industry challenges. For example, the Advanced Mining Technology Center (AMTC) of the University of Chile, a research centre focused on developing multidisciplinary research for the mining sector, is leading the way in developing projects in conjunction with the industry in Chile. It responds directly to the needs of the sector and seeks solutions to concrete problems, so there is a constant interaction between each entity in order to achieve beneficial solutions for both. This stems from the source of its financing, which has reached an expected balance, composed of one third of funds from

In developed countries, the private sector works collaboratively with universities, while in Latin America they prioritise alliances with clients, without including academia.

[24] Borrel-Damian, Morais & Smith (2015)
[25] Agosin et al. (2010)

Not even in times of crisis has the mining industry been willing to collaborate.

the Associative Research Program (PIA) of CONICYT Basal Centres, one-third from competitive funds for R&D and a third that comes directly from the mining industry (more than $ 1,500 million annually).

2. **Collaboration within the same industry:**

The mining sector is known for being non-cooperative. In Chile, the sector has not even been willing to collaborate on mutual benefit projects, as is the case with desalination plants, where they could gain advantage from economies of scale by having a large desalination plant shared by several companies instead of each one working with its own.

Not even in times of crisis has the mining industry been willing to collaborate. In 2015, the mining sector caused the greatest environmental disaster of Brazil. When the Fundão tailings of Samarco (managed by Vale and BHP Billiton) released 40 billion litres of water with sediments and toxic substances, contaminating the water supply, decimating the local fauna and provoking a mudslide that caused the death of 19 people and the loss of more than 500 homes[26].

Faced with this catastrophe, the industry did not show interest in developing further partnerships, which could develop ideas to prevent future disasters or preventative measures in case anything like that were to happen again. In January, this year, a tailing from the same company, Vale, caused an even worse environmental disaster, leading to the death of hundreds of people.

In contrast, the oil sector has taken measures under similar circumstances. In the U.S.A., the Deepwater Horizon plant from BP exploded causing the spill of 4.2 million of barrels of oil in the Gulf of Mexico and the death of several workers. This catastrophe triggered the big oil companies to collaborate towards planning a reaction protocol in case of similar accidents. Chevron, ConocoPhillips, ExxonMobil and Shell started the initiative by contributing US$1 billion each to create a non-profit organisation, that would carry out this project: The Marine Well Containment Company (MWCC). Currently, it is made up of 10 companies; Anadarko, Apache, BHP Billiton, BP, Equinor and Hess joined the four founders[27].

[26] The Guardian (2016)
[27] Marine Well Containment Company (2019)

Method 3:
Specific technological trends of productive processes

Through the analysis of the production line, we will examine the technological innovations that are generating real changes in how the processes are carried out. Here we will emphasise automation and digitalisation.

Boston Consulting Group addresses this issue. As you can see in figure 4, the process begins with exploration and ends at marketing and commercialisation of the product. The most relevant innovations are associated with information technologies and automation. Leading mining companies in innovation have invested in automating their processes to reduce costs, improve the safety of workers and efficiency.

This schematisation shows that the most revolutionary change is the development of Smart Mining. We briefly analyse each stage.

1. Exploration and planning: The use of big data will decrease exploration costs. The advances in computing and other technologies have overcome many of the challenges that the professionals had when generating, classifying and analysing data.

2. Extraction and processing: Robots and artificial intelligence can carry out—in an autonomous or assisted manner—operations, such as perforations, blasting, loading, transport, rescues, etc. Also, they allow predictive equipment maintenance and the use of spare parts, reducing failures and costs. Moreover, the latter parts will be in the future manufactured through 3D and 4D printers, avoiding waiting periods and reducing costs.

Figure 4: Examples of new and emerging technologies

	Exploration and planning	Mining and processing	Supply chain and logistics	Marketing and trading
Already in use	**Big Data** • “Digital twin” (advanced simulation tool • Precision planning and operations scheduling	**Real-time data** • Remote operations • Predictive maintenance	**Logistics** • Trains from mine site to port • Cargo ships managed globally	**Block chain** • Product provenance documentation • Information access for costumers
Close to commercial use	**Interconnected sensors** • Drones with InSAR sensors performing in situ scanning	**Advanced analytics** • Integrated processing system • Product tracking and continuous communication	**Quantum computing** • Integrated supply chain planning • Route optimisation and interaction	**Market intelligence** • Digital channels that expand arbitrage opportunities

Source: Adapted from Durrant-Whyte et al. (2015).

3. **Supply chain and logistics:** In Latin America, there are structural and productivity problems in logistics. This is due to a lack of public-private collaboration and the limitations in adapting technologies such as the IoT, cloud computing, etc. (Manchon 2018). In developed countries, a special emphasis is placed on the supply chain and logistics within the production processes. In the year 2017, Rio Tinto inaugurated an autonomous train that connects the mine with the port.

4. **Marketing and commercialisation:** Despite the fact that the average Chilean consumer does not pay attention to the origin of the goods they purchase, in developed countries people are increasingly aware of the environmental impact and respect towards communities. This has promoted the use of environmental logos, which will soon also include the mining sector.

The lower part of figure 4 shows the technologies that are not yet fully integrated, but are soon to be incorporated. Noteworthy are the use of interconnected sensors, advanced analysis (integration of processes, product tracking and continuous communication), quantum computers (logistics and route optimization) and market intelligence.

In short, the evolution of computers, sensors, data analysis, and artificial intelligence techniques will further strengthen the integration of automated processes within the mining industry[28]. It is estimated that in the future (long term) mining will be almost fully robotised and nearly all operations will be remote[29]. Process optimisation will be carried out in offices with experts looking at data panels and applying analytical models. It is difficult to predict what the mining of the future will look like, but what we can see is that digitisation and automation will be increasingly relevant.

What kind of human capital will the mining of the future need?

Experts say that this technological revolution will require more professionals in science, technology, engineering and mathematics[30]. However, what skills should they develop to adapt to the technological changes? In the case of engineers, the teaching methods must evolve, as the system used in most Chilean universities has not changed and they continue giving academic conference lectures with little interaction instead of encouraging critical thinking and applied learning[31].

On the other hand, the OECD has estimated that the average Chilean worker has a 55% probability of having their tasks automated[32]. That is, the workforce will change enormously and professionals will have to develop new skills. The ability to generate statistical models, algorithms and being capable of interpret-

[28] Matysek & Fisher (2016)
[29] Boston Consulting Group (2018)
[30] PricewaterhouseCoopers (PwC) (2015)
[31] Academia de Ingeniería de Chile (2018)
[32] Nedelkoska & Quintini (2018)

It is estimated that in the future mining will be almost fully robotised and nearly all operations will be remote.

ing them will be essential. Administration restructuring will be crucial and vertical hierarchies will have to be streamlined to generate a more dynamic organisation. Big Chilean mining companies have on average two additional hierarchical levels compared to those of USA, Australia, Sweden and Canada[33].

In the medium term, the way we extract and process minerals will not be modified substantially. What will really change is who carries out this task (robots or people).

Regarding the mining sector, in the medium term, the way we extract and process minerals will not be modified substantially. What will really change is who carries out this task (robots or people). A lot of information will be generated in each stage of the production process, which will require a good understanding of what is happening while making decisions in real time may produce a great increase in efficiency. We will divide the analysis in short and long term.

[33] Comisión Nacional de Productividad (2017)

- **Short term:**

Sensors will play a fundamental role. Different types of professionals will be needed in each phase to develop this technology (Alvaro Egaña, director of ALGES laboratory of the AMTC):

1. **Sensor manufacturing:** Electrical, mining or mechanical engineers are apt for this job. The ideal scenario would be to have a multidisciplinary system with shared academic programmes. If we need to create a sensor with a non-existent material, a doctor will be required, but if we want to copy and adapt the technology from other countries, an engineer with a multidisciplinary perspective will be sufficient.

2. **Positioning and operation of the sensors:** A technician can do it, however, in more complex cases an engineer will be required. In this case a new speciality may evolve, something similar to the functions of a medical technologist: a professional who does not need to be a doctor but must be able to read and understand exams. For sensing technologies, we need a similar profile. A new speciality might arise in undergraduate school or a master's degree coordinated by two departments.

3. **Data capture:** Those who normally carry out this task are electrical engineers.

4. **Data processing:** The goal is to convert data in something that is comprehensible by analysts. They have to know why they are doing it, what they want to get and what the expert needs to know. Therefore, you need a specialist that could be a professional with a master's or doctorate degree.

5. **Data analysis:** qualified experts are needed in data analysis. Given the complexity of this work, engineers or scientists with doctoral degrees are required, who are also capable of modelling and making decisions.

Egaña stresses that experts will not be replaced, since it is not possible to create smart systems trained to make fundamental overall decisions. As these stages are becoming more complex, what will change are the skills that professionals should have, given that the process will be geared towards decision-making with a much higher level of abstraction.

For this reason, to face the Fourth Industrial Revolution it is essential to promote the development of analytical skills. However, Chile is far from achieving this, a failure that must be addressed from high-school education.

If Chile were faced with a sudden change of the technology used in the mine industry, university research centres could be a good solution for adaptation, as long as they have professionals from different disciplines, i.e., interdisciplinary interaction is fundamental. Universities will not be able to modify their academic programmes quickly and spontaneously, since they are very resilient to change. However, they can create collaborative centres that could be a good temporary solution.

> To face the Fourth Industrial Revolution it is essential to promote the development of analytical skills. However, Chile is far from reaching this, a failure that must be addressed from high-school education.

- **Long term:**

In the long term, the analysis becomes more complex, since the level of uncertainty is very high. "Jobs will change, markets will change, and the skillset needed will change. We are educating young people for jobs that don't exist, using technologies that haven't been created to solve problems we have not identified"[34]. Faced with this doubt, engineers should develop non-technical skills, such as self-learning, leadership, commitment, feedback and communication.

Given the long-term nature of the mining sector, it is even more complex to plan the adjustments to these changes. Technological advances that are at the forefront today will perhaps be obsolete in five years. So, how can companies develop flexible plans if the decisions they make have a time frame of even more than 20 years? There is clearly a disparity between the life cycle of mines and that of technologies and digitisation, which is altering the operation of the sector[35].

[34] National Academies of Sciences Engineering and Medicine (2018).
[35] PwC (2017)

It is necessary to define the reference framework in which Chile will position itself regarding the future technological innovations, before considering the specialised HK that will be trained by universities. First, it is fundamental to define whether Chile is going to transform itself in a technology producer or importer. Once establishing this, it is important to determine how to develop applied research in Chile. First, it is necessary to calculate how much the country will invest in R&D and then assess, according to the available resources, how many professionals will be needed. Today, the country uses the opposite model, investing in educating doctors without having a budget for the research they are supposed to carry out, and later on they have to develop their own research and look for financing (Paul Vallejos and Alejandro Ehrenfeld, AMTC researchers).

Simultaneously, companies have to integrate highly qualified professionals into their organisations whereas universities must strengthen their R&D applied centres. Both should coordinate the development of new technologies and projects. What is the bottleneck to generate this interaction? In Chile there is very little investment in R&D and research centres require more researchers, but with enough funding and flexibility to face the inherent risks and uncertainties of innovation.

It is fundamental to define whether Chile is going to transform itself in a technology producer or importer.

Additionally, it is necessary to ensure continuity in public policies. Mining is a long-term planning and investment sector, where technology decisions that are made today will have repercussions in more than 30 years. The problem is that in Chile five years is already seen as "long-term" and R&D funding policies can be subject to large changes depending on the political cycle. Rio Tinto invests in research centres that will provide solutions in a 20-year period, while in Chile the mining companies expect results from one year to the next, which is more like the job of a consultancy company than a research centre.

AMTC researchers believe that Chile lacks a mature ecosystem of innovation. When a researcher generates a prototype, they need a provider company to take this idea and transform it into a marketable product. In Chile there are not enough firms doing this work, i.e., a technological ecosystem does not exist. In consequence, the mining industry does not trust local innovators. Even though research centres can provide successful solutions, nobody can guarantee they will have continuity over time. There is no company willing to develop this product, update it and provide the overhaul and maintenance service.

In short, the uncertainty regarding future technology means that professionals will have to be able to think in a multidisciplinary way, connect ideas and build information; these global competencies will shape our world and the way we live and work together (OECD 2017). On the other hand, mining companies import technology because there is no local

The uncertainty regarding future technology means that professionals will have to be able to think in a multidisciplinary way, connect ideas and build information.

technology supplier, providing permanency in the delivery of the products and services that are generated locally. Until the necessary investment is made to generate the right conditions that allow the development of the ecosystem of innovation in Chile, it is very difficult to determine what kind of specialised professionals we will need.

We know that "we can’t predict the future, of course, but we believe the conversation about what the future might look like to be an important one”[36].

[34] PwC (2017)

References

Academia de Ingeniería de Chile, 2018. Visión de Futuro de la Ingeniería y de los Ingenieros en Chile, Santiago.

Advisory Council for Science Technology and Innovation, 2009. The Role of PhDs in the Smart Economy.

Agosin, M. et al., 2010. La Era de la Productividad: Cómo Transformar las Economías Desde sus Cimientos Banco Interamericano de Desarrollo, ed.

ANIP, 2016. Becas Chile, CONICYT y la nula existencia de programas de inserción. Available at: https://anip.cl/tag/becas-conicyt/.

Australian Mining, 2013. Mining industry spends $1.15 bn on training: report. Available at: https://www.australianmining.com.au/news/mining-industry-spends-1-15-bn-on-training-report/.

Banco Mundial & OCDE, 2011. Revisión de Políticas Nacionales de Educación: Programa Becas Chile.

Benito, M. & Romera, R., 2013. How to Boost the PhD Labour Market? Facts from the PhD System Side, Madrid.

Borrel-Damian, L., Morais, R. & Smith, J.H., 2015. Collaborative Doctoral Education in Europe: Research Partnerships and Employability for Researchers, Brussels.

Boston Consulting Group, 2018. The New Technology Frontier in Mining. Available at: https://www.bcg.com/publications/2018/new-technology-frontier-mining.aspx.

Centers for Disease Control and Prevention, 2015. Statistics: All Mining. Available at: https://www.cdc.gov/niosh/mining/statistics/all-mining.html.

CNE, 2017. Valor de la energía más bajo en la historia de las licitaciones en Chile. Available at: https://www.cne.cl/prensa/prensa-2017/11-noviembre-2017/valor-de-la-energia-mas-bajo-enla-historia-de-las-licitaciones-en-chile/.

CNE, 2018. Capacidad Instalada de generación [base de datos]. Available at: https://www.cne.cl/estadisticas/electricidad/.

CODELCO, 2010. Este es el primer paso para la minería del siglo XXI. Available at: https://www.codelco.com/este-es-el-primer-pasopara-la-mineria-del-siglo-xxi/prontus_codelco/2011-05-06/205829.html.

Comisión Nacional de Productividad, 2017. Productividad en la Gran Minería del Cobre, Primera Ed., Santiago: Editorial Universitaria S.A.

CONICYT, 2017. CONICYT Define Áreas de Interés Prioritario Para Magíster Becas Chile 2018. Available at: http://www.conicyt.cl/becasconicyt/2017/11/21/conicyt-define-areas-de-interes-prioritario-para-magister-becas-chile-2018/.

Consejo de Competencias Mineras, 2017. Fuerza Laboral de la Gran Minería Chilena 2017-2026: Diagnóstico y Recomendaciones.

Couston, A. & Pignatel, I., 2018. PhDs in business: Nonsense, or opportunity for both? Global Business and Organizational Excellence, 37(2), pp.49–58.

Cyranoski, D. et al., 2011. The PhD Factory. Nature, 472, pp.276–279.

CSIRO, 2017. Mining Equipment, Technology and Services: A Roadmap for unlocking future growth opportunities for Australia.

Deloitte, 2017. Rewriting the rules for the digital age: 2017 Deloitte Global Human Capital Trends.

Deloitte, 2018. Tracking the trends 2018. The top 10 issues shaping mining in the year ahead.

Durette, B., Fournier, M. & Lafon, M., 2012. Compétences et employabilité des docteur.

Durette, B., Fournier, M. & Lafon, M., 2014. The core competencies of PhDs. Studies in Higher Education, 41(8), pp.1355–1370.

Durrant-Whyte, H. et al., 2015. How digital innovation can improve mining productivity. McKinsey & Company, (November).

Energy and Mines, 2017. Mining Sector Embracing Microgrids: Hybrid Systems Reduce Energy Costs & Environmental Impact. Available at: http://energyandmines.com/2017/09/mining-sector-embracing-microgrids-hybrid-systems-reduce-energy-costs-environmental-impact/.

Etzkowitz, H., 2003. Innovation in innovation: The Triple Helix of university-industry-government relations. Social science information, 42(3), pp.293–337.

Friedman, T.L., 2005. The world is flat: A brief history of the twenty-first century, New York: Farrar, Straus and Giroux.

He, Z., 2014. Are CEOs With a Ph.D. More Innovative?

Fixari, D. & Pallez, F., 2005. Propositions pour favoriser l'emploi des docteurs: Rapport du groupe de travail sur l'emploi des docteurs- FutuRIS Président : Jean-Claude Lehman.

Manchón, F., 2018. Los Corredores Logísticos y la Transformación Digital como Catalizadores del Comercio y la Integración Regional. En Conferencia CAF: Productividad e Innovación para el Desarrollo. Bogotá.

Marine Well Containment Company, 2019. Membership. Available at: https://www.marinewellcontainment.com/about-us/membership/.

Matysek, A.L. & Fisher, B.S., 2016. Productivity and Innovation in the Mining Industry, Canberra.

McKinsey, 2017. Beyond the Supercycle: How Technology Is Reshaping Resources.

Meller, P. & Gana, J., 2015. El Cobre Chileno Como Plataforma de Innovación Tecnológica. 1era Edici., Santiago: CIEPLAN.

Meller, P. & Parodi, P., 2016. La Importancia dela Capabilidad Tecnológica en el Mundo Global, CIEPLAN, ed., Santiago de Chile.

Mining Magazine, 2018. IoT sensors to improve mine safety. Available at: http://www.miningmagazine.com/sustainability/news/1332076/iot-sensors-to-improve-mine-safety.

Ministerio de Economía, Fomento y Turismo, 2016. Resultados Desagregados CDH. [base de datos]. Available at: https://www.economia.gob.cl/2016/04/22/segunda-encuesta-trayectoria-de-profesionales-con-grado-de-doctor-cdh-ano-de-referencia-2014.htm

Muro, M. et al., 2017. Digitalization and the American Workforce.

National Academies of Sciences Engineering and Medicine, 2018. Adaptability of the US Engineering and Technical Workforce: Proceedings of a Workshop, Washington, D.C: The National Academies Press.

Nedelkoska, L. & Quintini, G., 2018. Automation, skills use and training, OECD, Paris.

OECD, 2016. Gross Domestic Spending on R&D. Available at:
https://data.oecd.org/rd/grossdomestic-spending-on-r-d.htm.

PwC, 2015. A Smart Move.

PwC, 2017. We need to talk about the future of mining.

Safe Work Australia, 2018. Fatality statistics by industry. Available at:
https://www.safeworkaustralia.gov.au/statistics-and-research/statistics/fatalities/fatality-statistics-industry.

Santelices, B. & Lund, F., 2013. Innovación con Base Científica: Observaciones para el Análisis y la Formulación de Políticas Públicas. In B. Santelices et al., eds. Innovación Basada en Conocimiento Científico. Santiago: Academia Chilena de Ciencias, pp. 289–301.

Schwab, K., 2016. The Fourth Industrial Revolution, World Economic Forum.

Stokes, D.E., 1997. Pasteur's quadrant: Basic science and technological innovation. Brookings Institution Press.

The Guardian, 2016. Samarco dam collapse: one year on from Brazil's worst environmental disaster.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