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How to improve collaboration between industry, government and universities to face industry challenges: the case of the Chilean Mining Programme 'Alta Ley'

Cómo mejorar la colaboración entre la industria, el gobierno y las universidades para enfrentar los desafíos de la industria: el caso del programa minero chileno 'Alta Ley '

Verónica ROA; Julio GONZÁLEZ [1]; Jorge TORRES [2]

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Content

ABSTRACT:
The paper poses the following research question: how does the Chilean Mining Programme 'Alta Ley' improve collaboration between the mining industry, government and universities to contribute to solving the productivity and sustainability challenges of the industry? To answer the research question we use the triple helix system as the theoretical lens, complemented with policy learning literature. We look at the interaction of actors in a context of industrial development to drive and accelerate innovation. The paper uses a qualitative approach and documentary information from governmental institutions, reports and annuals from firms, regulations, industry articles and newspapers.
Keywords Triple Helix System, Innovation Policy Learning, Industrial Policy, Chilean Mining Industry

RESUMEN:
El documento plantea la siguiente pregunta de investigación: ¿cómo el programa minero chileno ' alta ley ' mejora la colaboración entre la industria minera, el gobierno y las universidades para contribuir a la solución de los desafíos de productividad y sostenibilidad de la industria? Para responder a la pregunta de investigación utilizamos el sistema de triple hélice como objetivo teórico, complementado con la literatura de aprendizaje de políticas. Nos fijamos en la interacción de los actores en un contexto de desarrollo industrial para impulsar y acelerar la innovación. El documento utiliza un enfoque cualitativo e información documental de instituciones gubernamentales, informes y anuales de empresas, reglamentos, artículos de la industria y periódicos.

Palabras clave sistema de triple hélice, innovación política de aprendizaje, política industrial, industria minera chilena

1. Introduction

1.1. Challenges of the Chilean mining industry

Mining is the main productive sector of Chile. It represents 30% of total capital stock, and in the period 1990-2014 it represented 33% of the flows of foreign investments. Between 2008 and 2014 it represented 13% of total GDP and 9% of tax revenue (US$4.9 billion). Taxes paid by mining are equal to the total taxes paid by almost the remaining productive sectors: the average labour productivity in the industry is four times the productivity of the financial sector and six times that of the industry sector. Mining exports have increased significantly since 2004 and accounted for 57% of the amount exported in 2014. Copper is still the main export; in 2014 it was about 50% of the country's total exports (Cantallopts, 2015; Fundación Chile, 2016).

At the global level, Chile is the largest producer and exporter of copper. The country has comparative advantages of having 30% of the worldwide mining stock. The position of Chile in the global mining industry has increased as a percentage of exports. Until 1990, the participation of Chile was 16% of global production; today it is 30% (Fundación Chile, 2016).

Certainly, the decline in the copper prices since 2011 had a negative impact on the growth of Chilean GDP. Between 2011 and 2015 the price of copper decreased by 51%; the question is for how long this will have an effect on Chile's GDP growth. A working paper from the International Monetary Fund argues "the copper price decline is likely to have a durable (although not permanent) effect on GDP growth. While the impact of lower copper prices is the strongest in the first 3 years after the shock, the transition towards the new lower steady- state GDP level generally takes 5–10 years" (Eyraud, 2015, p.15). Economic diversification is crucial to face this situation.

In a comparative study including thirteen countries, Cantallopts (2015) finds that Chile, on average, is located within the top five countries with significant advantages in geological potential, regulatory and legal framework, political stability and tax system. However, it has disadvantages regarding production costs where some factors, such as the labour market, are even below average. Thus, the Chilean mining industry faces productivity and sustainability challenges. In this context, a recent report from Fundación Chile (2016) explains the main resource, technological and innovation challenges of the local mining industry. In terms of resources, the challenges are related to the decline and quality of the geological resource and the intense use of water and energy, which are scarce resources, where the production of copper takes place.

Mining deposits are ageing and the copper grade is diminishing, which means that the percentage of pure copper in a certain amount of mineralised rock is becoming less. Today open pit mines are more intensive and it is more difficult to obtain materials. Mining deposits are being retrieved from ever greater depths, meaning that there is further to go to remove material in a tailing process, and the materials from where the copper is extracted are harder and with more presence of contaminants. Processes are becoming more complex.

At the same time, the mining industry is an intensive user of energy and water. More than 20% of the cost of the industry is explained by energy. Continental water for the operations is scarce. Firms also use seawater, which is more difficult to acquire because of the distance and higher altitude of the resource. Operational costs of the industry have increased 10% per year on average while productivity has reduced by 20%. All of this implies that firms' efforts in maintaining their productivity is increasing. As a result, another challenge corresponds to finding new and better deposits in the future. However, fewer actors are entering the industry and the discovery of these new and better deposits is jeopardised. As is indicated by the industry, consensus is needed for the effective use of the assigned property and give value to the industry.

In terms of technology, Chile faces a unique situation. It is the largest open pit mine industry that will become underground mining. The challenge regarding industry sustainability and increased productivity is to improve the levels of underground mining to large-scale viable deep mining. This is a challenge not seen before in the global mining industry.

In terms of innovation, the articulation of an innovation open ecosystem to boost the development of local providers who are knowledge and technology intensive is needed. As said by the industry, to face these challenges, all industry actors should be involved, and the improvement of the low levels of association and collaboration between them is required. The Fundación Chile report highlights that, since Chile is the largest producer and exporter of copper (representing 30% of the global production of a commodity; it also has a similar worldwide stock), it can play a role linking technological development and innovation in being a platform for the generation of technological innovation.

According to the latest Global Competitiveness Report, Chile is the most competitive country in Latin America and the Caribbean; also, it is in transition between an efficiency-driven economy to an innovation-driven economy (World Economic Forum, 2015). Since Chilean mining is in transition to a stage characterised by knowledge, technology and innovation challenges, the transition from one stage of the economy to another can be made through the mining industry as the platform of technological innovation.

In terms of policy, Fundación Chile (2016) states that the development of the mining industry in Chile has had an impact on the design of public policies due to the substantial increase in the production of copper over the last 20 years. As it will be seen later in this paper, now that the industry faces important challenges of production and sustainability, this has once again had an impact on public policies.

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2. Policy learning in triple helix systems

Policy learning in a context of industrial policy is related to how policies change and adapt over time in a sector or industry through a process of knowledge accumulation. This is a collective process that involves the participation of different actors. In the literature, policy learning has different conceptualisations depending on who learns, what is learned and to what effect, as Bennett and Howlett (1992) explain. In this paper policy learning means social learning (Hall, 1993) and lesson-drawing (Rose, 1991) where the agents of learning are policy communities and policy networks; policy ideas and instruments are the object of learning to the effect of developing or changing policy programmes or instruments. Understood in this manner, policy learning is a conscious and intentional process; as Hall (1993) indicates, "a deliberate attempt to adjust the goals or techniques of policy in response to past experience and new information" (p.278). For the context of this paper, past experience and new information might come from the local sector or industry where the policy learning process is taking place (the Chilean mining industry), or from other sectors or industries that have progressed in policy issues that may be of interest to the Chilean mining sector or industry (for example, the Australian mining industry); the latter case constitutes lesson-drawing policy learning.

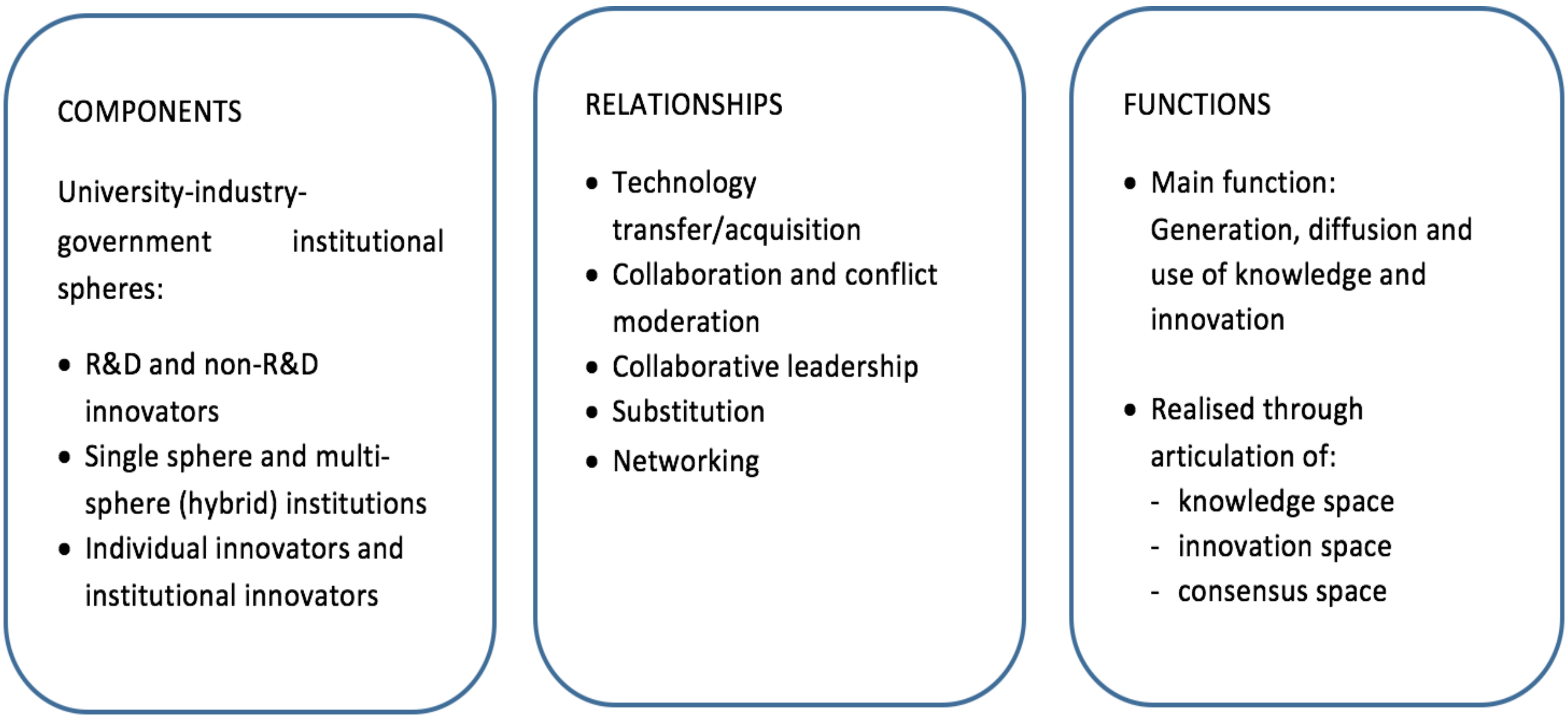
With regard to the agents and context where policy learning takes place, in the case of the Chilean Mining Programme 'Alta Ley', the triple helix system appears as a suitable lens in exploring and explaining the relationships between actors and spaces where learning occurs. The triple helix system is an analytical framework for innovation policy and practice in the knowledge society developed by Marina Ranga and Henry Etzkowitz, both from Stanford University (Ranga and Etzkowitz, 2013).

The triple helix university-industry-government relationships are a well-known model with a wide theoretical development and empirical applications. The origins of the model go back to the 1990s with the studies of Professor Henry Etzkowitz (Stanford University) and Professor Loet Leydesdorff (University of Amsterdam). In these origins are two key articles: 'Technology transfer: the second academic revolution' by Etzkowitz in 1993, and 'The Triple Helix: university-industry-government relations: a laboratory for knowledge-based economy development' by Etzkowitz and Leydesdorff in 1995. These articles reflect on the move from an industrial society, where a strong industry-government relationship was present, to a knowledge society, where universities take a more leading role in a triadic relationship between industry and government. As indicated by Ranga and Etzkowitz (2013, p.238):

> "the triple helix thesis is that the potential for innovation and economic development in a Knowledge Society lies in a more prominent role for the university and in the hybridization of elements from university, industry and government to generate new institutional and social formats for the production, transfer and application of knowledge".

Coordination is required to achieve an effective relationship between triple helix actors. The authors state that the triple helix literature has mainly been developed from two complementary perspectives: the (neo-) institutional perspective and the (neo-) evolutionary perspective. Both perspectives stress the view and underline a systemic dimension since they focus and highlight interactions of social systems characterised by action and communication. However, neither of these perspectives "provides an explicit analytical framework for conceptualising Triple Helix interactions as innovation systems" (p.240). To fill this gap, the authors propose an analytical framework to study triple helix systems from an innovation system perspective, describing the components, boundaries of the components, the relationships among the components and the functions of the triple helix systems. Figure 1 below summarises this:

Figure 1: A Synthetic Representation of Triple Helix Systems



Source: Ranga and Etzkowitz (2013)

For the purposes of this paper the functions of the triple helix systems become more relevant in explaining the nature, design and implementation of the 'Alta Ley' Programme. Therefore, a focus on the formation and functioning of this triple helix system is made. Ranga and Etzkowitz (2013) explain that the main function of a triple helix system is the generation, diffusion and use of knowledge and innovation, and that this function is achieved through the articulation of the knowledge, innovation and consensus spaces. The formation of these spaces is the result of the interactions of the university, industry and government spheres.

The knowledge space brings together the competencies of the actors for the creation, use and diffusion of knowledge that are essential in strengthening the knowledge capacity of the triple helix system. In the innovation space, the role of hybrid organisations is more prominent in the development of innovation and innovation capacity in the system. In the consensus space, actors of the triple helix system come together towards collaboration; alignment of interests and conflict moderation become essential in achieving shared targets.

The degree of involvement of the industry, university and government spheres can be different, and this would explain the substitution of roles or functions between the spheres; that is, when a sphere is weak or underperforms, other spheres take on the role or perform the function of the weak sphere. This implies that the spaces interact with each other in a non-linear process, and that directions and transitions of the spaces depend on context circumstances and the stage development of the system. Four stages in the development of a system can be identified:

i. The genesis of the system, with the idea of a new system development, for example, an industrial or regional one;
ii. The implementation of the system, performing new activities and developing infrastructure to carry out the idea, for example, developing specific infrastructure and relationships between producers and suppliers of an industry or sector;
iii. The consolidation and adjustment of the system integrating the activities, infrastructure and functions of the components of the system to improve its efficiency; and,
iv. Self-sustaining growth and renewal of the system through the identification of new areas of growth and development of the system.

As said before, for an effective operation of the triple helix system, the organisation of its components (i.e. spheres or actors), relationships and functions is required. That is, coordination is essential for the effective operation of a triple helix system. As suggested by Woolthuis et al. (2005), coordination failures are the result of poor interaction among actors of a system. This weak, or lack of, interaction might lead to a lack of shared vision of the future and a lack of research effort and investment for innovation. As the following sections present, the nature of the 'Alta Ley' Programme precisely seeks to straighten out the coordination failures of the Chilean mining industry.

2.1. Policy learning of industrial policy in Chile as the context of 'Alta Ley' programme

The context of 'Alta Ley' Programme links with the Chilean economic model based on natural resources and the sophistication and diversification in the exports of the country. Bitrán (2015a, 2015b) indicates that the Chilean economic model, based mainly on natural resources, is now declining. This means that the potential growth of the country has decreased due to the limited capacity of traditional sectors to continue growth. Economic sectors based on natural resources such as mining face resource and environmental restrictions: the quality of the resources is deteriorating and there is an increased scarcity of basic factors for production such as water and energy. On the other hand, Chile has a limited sophistication and diversification of good exports. In the Sophistication of Exports Index (EXPY), Chile ranks lower (9.43 in 2012) than other Latin America countries (Brazil, 9.67; Colombia, 9.57; Costa Rica, 10.18; Mexico, 9.75, and Dominican Republic, 9.75) (Bitrán, 2015b). According to the World Bank, "estimating the level of technological sophistication embodied in a country's export portfolio (EXPY index) gives an indication of the country's economic development" (World Bank, 2013 p.39). In the same way, Anand et al. (2012) demonstrate that the sophistication of goods exports has an impact on a country's growth economy. In the case of Chile, the country's export basket contains few products; the majority of them are commodities, 60% being from the mining industry. Since the growth of the GDP in the long term is explained to a large extent for the sophistication of exports, it is expected to have a slow GDP growth if the country continues to produce greater amounts of the same products (Bitrán, 2015b).

In that regard, the Executive Vice President of the Chilean Agency for Economic Development (CORFO), Eduardo Bitrán, explains the need to promote a growth model oriented to sophisticate and diversify the Chilean economy, as well as to increase the level of innovation in firms and sectors. According to him, this implies a move from static comparative advantages linked to industries based on natural resources to a stage in which more knowledge in products and services is incorporated. That is, to move from static comparative advantages to dynamic advantages, namely, to produce sophisticated technological goods and to add value, differentiation and sophistication in exports. In order to move from static comparative advantages to dynamic advantages, it is necessary to incorporate more innovation and technology in the development strategy of Chilean firms and organisations (Bitrán, 2015a, 2015b). This is a call for policy learning to innovation to provide, as Bitrán (2015b) states, i) horizontal incentives to innovation and entrepreneurship, and ii) strategic focus in sectors and technologies of high growth potential, with the aim of increasing productivity and sophistication of sectors with coordination failures that prevent taking advantage of opportunities.

Within this policy learning process the development of the Productivity, Innovation and Growth Agenda was vital. The Productivity, Innovation and Growth Agenda was an initiative of the current government to face the country's productivity challenge, which is considered to be the primary cause of the gap between Chile and developed economies. Through 47 measures, the agenda proposes actions to advance towards a production transformation in order to diversify the economy producing new goods, developing new industries and creating new innovation poles. To achieve this, the measures are organised into four strategic goals:

- to promote the productive diversification;
- to drive high potential sectors;
- to increase the productivity and competitiveness of firms; and
- to generate new impetus to the exports (Gobierno de Chile).

Within the Productivity, Innovation and Growth Agenda, the Chilean Agency for Economic Development (CORFO) assumes a new role regarding productive policies. The mission of CORFO is "to improve the competitiveness and the productive diversification of the country by encouraging investment, innovation and entrepreneurship; strengthening, in addition, the human capital and technological capabilities to achieve a sustainable and territorially balanced development" (Corfo.cl (a), 2016). In this new role, CORFO promotes not only neutral policies but also targeting policies. Neutral policies are broad horizontal policies focused on the promotion of firms and entrepreneurship for the whole economy, whilst targeting policies are policies oriented to sectors or clusters that lead to technological changes and to the economic and institutional environment as a whole (Bitrán, 2015a).

In this context, CORFO, the Ministry of Mining and the Ministry of Economy and coordinated by Fundación Chile, created the National Strategic Programmes of Smart Specialisation. Inspired by European experiences, the Strategic Programmes of Smart Specialisation are aimed at encouraging national productive sectors, with high growth potential through a strong public-private alliance, to boost the creation of social capital. They seek to establish a new strategic approach to productive development. The Executive Vice President of CORFO states that "it is crucial to build social capital to solve coordination failures and achieve a shared vision to ensure the [sustainability of sectors]" (Corfo, 2015). These programmes promote coordination and collaboration between different actors within an innovation system. Lessons from Europe might be transferred to the Chilean context to help sectors with coordination failures overcome their productivity and sustainability challenges.

In Chile, these programmes were developed to diagnose opportunities and gaps in a sector with high potential of growth, to agree actions among actors in order to take advantage of the opportunities and to fill the gaps through the design and implementation of technological roadmaps (Bitrán, 2015a). International experiences demonstrate that Strategic Programmes of Smart Specialisation strengthen the public and private collaboration to solve coordination failures from transaction costs, asymmetries of information, and non-tradable services with economies of scale. Coordination failures require targeting policies to support innovation in sectors and increase their productivity and sophistication of their goods.

According to Bitrán (2015b) Strategic Programmes of Smart Specialisation promote three principles: they increase the productivity of sectors, improve the sophistication and diversification of goods for the exports, and stimulate inclusive and sustainable development of sectors. This encourages the development of a quadruple helix system where a participative approach between triple helix actors (state-academia-industry) plus NGOs, citizens and workers at industry, regional and national levels, together with their consensus to build governance, is needed. The development of a quadruple helix system requires, first, the implementation of a balanced triple helix configuration that characterised a knowledge society. At the end of 2015, seven National Strategic Programmes of Smart Specialisation were developed. The National Strategic Programme of Smart Specialisation for the mining sector was called 'Alta Ley'.

3. The Chilean mining programme 'Alta Ley' as the consensus space to contribute to the productivity and sustainability challenges of the industry

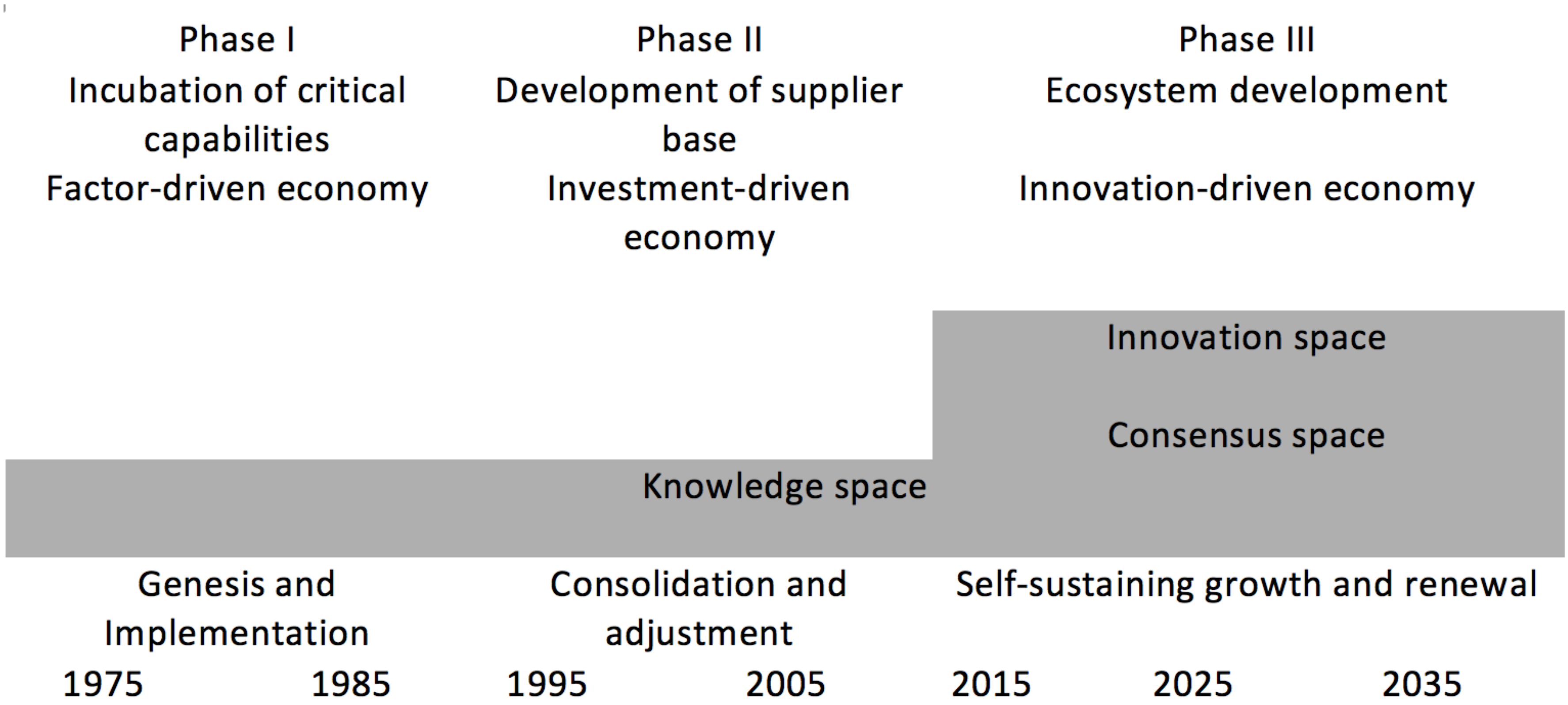
3.1. The evolution of the Chilean mining industry

The evolution of the Chilean mining industry (Figure 2) exemplifies the transition from a knowledge space to the consensus and innovation spaces in the self-sustaining growth and renewal stage of the industry. At the genesis and implementation stages of the industry (1975-1995), the knowledge space is characterised by the development of a competitive productive activity from a comparative advantage given by the abundance of high-value minerals endowment. Access to advanced technology was given mainly from overseas. Then, at the consolidation and adjustment stage of the industry (1995-2015), the knowledge space is characterised by foreign investment that allowed a significant increase in the production. The advanced technology comes from overseas, but also local suppliers start to develop capabilities to improve their technology. The formation of the consensus space is identified by the establishment of a long-term shared vision, and the development and implementation of the technological roadmap for the industry at the self-sustaining growth and renewal of the industry. This also initiates the innovation space of the industry where the aim is to develop an innovation ecosystem based on dynamic advantages.

Phase I	Phase II	Phase III
Incubation of critical capabilities	Development of supplier base	Ecosystem development
Factor-driven economy	Investment-driven economy	Innovation-driven economy
		Innovation space
		Consensus space
Knowledge space		

Genesis and Implementation	Consolidation and adjustment	Self-sustaining growth and renewal
1975 1985	1995 2005	2015 2025 2035

Figure 2: The evolution of the Chilean mining industry



Source: Own elaboration based on Ranga and Etzkowitz (2013) and Fundación Chile (2016)

3.2. Design of the programme

As stated previously, the Chilean Mining Programme 'Alta Ley' was initiated by the Chilean Economic Development Agency (CORFO), the Ministry of Mining and the Ministry of Economy and coordinated by Fundación Chile. The programme was launched in January 2015 and is part of the National Strategic Programmes of Smart Specialisation that develops within the Productivity, Innovation and Growth Agenda of the government. The goal of the 'Alta Ley' Programme is to develop an industry of goods and services based on science and technology with application in mining. This would then address the challenges of productivity of the mining industry through a robust ecosystem of innovation in an associative way between the industry, suppliers, the scientific and academic sector and the state. The 'Alta Ley' Programme aims to develop 'virtuous mining' that, from the challenges of productivity and sustainability, creates technology, human capital and innovation. This would then allow Chile to enter in global technological waves, developing world-class suppliers, attracting investment, developing R&D and linking universities and research institutions with the most important technological and productive challenges of the country. This implies the strengthening of productivity, competitiveness and innovation in the national mining industry and its suppliers in order to drive the development of the country (Revista Técnicos Mineros.com, 2015; Programa Alta Ley.cl, 2016).

As this paper argues, the 'Alta Ley' Programme coordinates the interactions between the triple helix system, the state, the industry and academia, to improve collaboration in order to achieve the objectives of the Programme. This role of coordination complements the new role assumed by CORFO and described in the previous section: the formation of private-public alliances to develop a vision of strategic selectivity and remove barriers in order to increase the sophistication and productive diversification of sectors.

As the methodology of the National Strategic Programmes of Smart Specialisation indicates, the first step in this policy learning process for mining corresponded to the design of the 'Alta Ley' Programme. Within the design, the first phase was to develop and validate a long-term shared vision of the mining industry among relevant actors (i.e. the components or actors of this triple helix system), to, in a second phase, develop a technological roadmap of the industry that specifies objectives, proposals and identifies specific challenges to achieve the proposed long-term shared vision. This vision was developed for 20 years ahead, up to 2035. A third phase corresponds to the implementation of the designed technological roadmap that, at the moment, is in an early stage.

The design of the 'Alta Ley' Programme is well documented in the 2016 report From Copper to Innovation: Technological Roadmap 2015-2035 by Fundación Chile. This section of the paper mainly draws upon that report.

In the consensus space the discussions and evaluation of opportunities, challenges and obstacles of the mining sector lead to the development and validation of the 20 year shared vision. This space allowed for the convergence of interest of actors and the construction of collaborative relationships based on dialogue and common understanding. The Mining and Development Committee of the National Council for Innovation Development was the entity that developed the agenda 'Mining: A Platform for the Future of Chile'. Within this agenda a vision to the year 2035 was established, with strategic challenges and priorities to consolidate the aspirations of the industry, reinforce its leadership at the global level and generate a virtuous circle of innovation. The Board of the 'Alta Ley' Programme then decided that the construction of the technological roadmap for the industry would be based on the vision established for that agenda, particularly in the areas and themes related to innovative mining. Within the vision, it was declared that by 2035 Chilean mining would have increased exports, reduced costs, would have developed world-class suppliers who export technologies and services intensive in knowledge, achieved a leader position at the global level regarding sustainable mining, reduced the demand for fresh water and energy, created collaboration among relevant actors based on trust, and accomplished standards with regard to community and labour.

The development of the vision was made through a participative process with triple helix public and private actors such as mining producers and supplier firms, researchers, consultants and personnel from government. For the identification and prioritisation of technological challenges, 50 interviews were conducted with personnel from the industry. This information was analysed using two principles: impact and mainstreaming. This means that overcoming the identified challenges should have a significant impact in the industry to achieve the proposed shared vision, and that the identified challenges should be cross-wise problems in the industry. The prioritised challenges were then grouped into five core themes or key pillars: tailings, foundry and refinery, mining operation and planning, concentration of minerals, and hydrometallurgy. Complementing these key pillars, three enabler pillars were defined: human capital, suppliers and innovation, and intelligent mining. For the identification of the industry's technological challenges and the prioritisation of the five key pillars, there was a systematisation of previous international experiences, specifically the 2004 and 2006 Copper Technology Roadmap from the Australian Minerals Industry Association (AMIRA).

For the design of the technological roadmap a set of workshops were conducted to work on each of the core themes or key pillars. These workshops followed the methodology for developing a technological plan developed by Cambridge University. This methodology was chosen because it promotes participation and collaboration between actors of the system to achieve shared solutions and plans of actions to face together the challenges of a sector. The workshops had direct support from an international consultant from the Institute of

Manufacturing at Cambridge University. In addition, a team from Fundación Chile was trained to develop capabilities on this methodology. The team acted as facilitator of the meetings using a complementary approach to diagnose the mining sector.

For each key pillar a baseline was developed and the participants used this as the starting point to make a technological plan for each pillar. These plans identified challenges, solutions and R&D areas to implement them. The participating actors of this triple helix system were representatives of mining firms, public sector, universities, from technological centres and experts on each pillar. More than 90 participants took part in the set of workshops. Also, 70 interviews with key actors, 3 technical meetings with experts, 1 workshop to prioritise the challenges and 63 organisations were involved. Later, the results of each phase in the development of the technological roadmap for the industry were validated for the Board of the 'Alta Ley' Programme, followed by a workshop meeting session of the Board where the members validated and prioritised the challenges and solutions identified for the industry.

The indicators of the Programme to 2035 were developed at two complementary levels. The first level strengthened the productivity and competitiveness of the industry with the aim of achieving an accumulated production between 130 and 150 million metric tonnes of copper and other minerals, and having 80% of the mineral production of the country in the two first quartiles of costs of the global production. The second level focused on the development of local capabilities with the aim of developing at least 250 world-class supplier firms and achieving US$4,000 million of exports in goods and services related to mining. Collaboration and coordination of private and public actors of a triple helix system are required to achieve these indicators.

The report by Fundación Chile specifies that a technological roadmap has an internal and external function. The internal function relates to the construction or shape of a common future for the industry through consensus to identify technological problems and challenges; this is a consensus space. The external function relates to the provision of information to stimulate collaborative work, for example, between universities, technological centres, the private sector and consultancies; this is within the knowledge and innovation spaces.

As stated previously, the technological roadmap for the Chilean mining industry developed within the 'Alta Ley' Programme in the context of the Strategic Programmes of Smart Specialisation: it was inspired by the experience of the Australian Minerals Industry Association (AMIRA). However, the policy transfer policy suggests, as Fundación Chile (2016) indicates, differences between the two roadmaps:

- The Australian technological roadmap was focused on the development of a roadmap for the largest mining firms, whilst the technological roadmap for the Chilean mining industry, in addition to that, presents a country strategy around mining emphasising the role of copper for the development of Chile as a knowledge society;
- The Chilean roadmap argues that the insertion of Chile in the globalised world and knowledge society requires the development of local innovative capacity and capabilities, and the generation of technological innovations. A strong argument for the roadmap is that copper can be used as a platform to foster innovation in Chile. Within this, the exploitation of copper deposits involves important technological challenges, and the responses to these challenges may generate exportable expertise and innovation. Thus, the Chilean roadmap highlights the importance of boosting the Programme of World-class Suppliers linked to largest mining firms. This supplier programme can be seen as a mechanism to generate and diffuse innovative capacity through different regions in the country;
- The Chilean roadmap identifies key challenges for Chile that the Australian roadmap did not perceive regarding the tailings and their territorial impact, especially in the central zone of Chile, the use of non-conventional and renewable energies, strategies to mitigate the carbon footprint, strategies to have competitive foundries and refineries in Chile, and the evolution and competitiveness of the exploration activities in Chile.

This is not the first time that Chile looked to Australia for a policy transfer process. A past emblematic experience was the development of the Qualifications Framework for mining in 2012; this contains requirements for the various occupational skills profiles of Chilean metal mining. This is a sectoral initiative to facilitate the connection between the training offered and the skills required by the industry, according to the quantity and quality that is demanded. The Framework organises the profiles and competencies of the main processes of the value chain of Chilean mining in skill levels and progressive learning paths. It was developed as an adaptation of the Australian Qualifications Framework and for this the policy transfer process, an agreement and collaboration between the Chilean Mining Competences Council and the Australian SkillsDMC, was established (Consejo Minero.cl, 2016).

3.3. Early implementation of the programme

As indicated previously, the 'Alta Ley' Programme intends to promote 'innovative mining' from where it is expected that the industry will improve its competitiveness and productivity, and at the same time builds the conditions for the emergence of a robust R&D and innovation ecosystem with local knowledge and capabilities (Fundación Chile, 2016). To help in the construction of this innovation ecosystem, targeted instruments to the mining sector were developed through CORFO's calls in the early implementation of the 'Alta Ley' Programme. These instruments were aimed at boosting technological development, innovation and collaborative work in R&D activities among triple helix actors. This section highlights these instruments, adding one instrument from CONICYT.

As established in the technological roadmap, a key pillar corresponds to tailings and a prioritised issue is related to the need of having more, better and timely information about the performance of tailing deposits that are more responsive to communities and the authority. Thus, the first instrument from CORFO, called 'Development of Technological Instruments for the Monitoring of Tailing Deposits', is aimed at developing a monitoring system to supervise the physical and chemical stability of tailing deposits using the best available technologies, and developing innovative mechanisms for the measurement of critical variables to provide quality and reliable information in real time to mining firms, communities and authorities. This would help to strengthen the operational management of the mining industry, improving the communication among actors and providing responses to possible emergency situations. CORFO funds up to 50% of the total cost of the programme with a maximum of 4 million Chilean pesos for this instrument; this is equal to US$6 million approximately. It is expected that this instrument will contribute to the declared inclusive and sustainable mining made in the technological roadmap by the industry (Corfo.cl (b), 2016).

Another prioritised issue within the key pillar tailings is related to the need to know the mineral (beyond copper and molybdenum) content in tailings and promoting strategies for their recovery and commercialisation, developing technological capabilities and new suppliers in order to diversify the offer of products and services related to mining. Thus, the second instrument from CORFO, called 'Recuperation of value elements in tailing deposits', is aimed at identifying and quantifying the existence of high value mineral content in the tailings in order to promote the adoption and development of processing technologies to capture the value of those minerals, developing technological capabilities and new suppliers that diversify the offer of products and services related to mining, and at the same time generate positive environmental externalities. CORFO funds up to 70% of the total cost of the programme for this instrument, with a maximum of 2 million Chilean pesos; this is equal to US$3 million approximately (Corfo.cl (c), 2016).

A third instrument from CORFO, called 'Technological Development Creation and Adoption of International Standards for Mining Interoperability', aims to provide an enabling platform acting as a driving force for the digitalisation of the mining industry. The idea is to design and implement international standards to promote the coordination of productive processes of the industry, strengthening efficient and secure mining operations through standardised and interoperable world-class solutions. The implementation of these standards requires the participation and compromise of mining productive firms and suppliers, the strengthening of networks and alliances with applied R&D centres and standards organisations. CORFO funds up to 60% of the total cost of the programme for this instrument, with a maximum of 4 million Chilean pesos; this is equal to US$6 million approximately (Corfo.cl (d), 2016).

As CORFO (2016a) states, the three instruments described above are framed as Technological Programmes and require a technological manager responsible for the development of the programme. This actor should have technological management capabilities such as experience in technology transfer, management of R&D projects, intellectual property rights, and be a technological leader on mining, to have a team of specialised human capital to achieve the objectives of the programme, transfer and diffuse knowledge, and to have experience in working with technological centres and relevant firms in the sector. In addition, these programmes require partners who will complement the technological capabilities on applied R&D and innovation for the development of the programme, and an interested party (or parties) who is interested in the use of the results of the programme, for example, organisations that demand products and services to be developed in the programme. Among the fundable activities of these three CORFO instruments are infrastructure for applied research, technology transfer, innovation and entrepreneurship activities, the development of prototypes, patentability studies, technological monitoring and foresight activities, search of technological alliances and training activities for applied research, technology transfer, innovation and entrepreneurship.

Another CORFO instrument corresponds to the call 'Strengthening and Technology Capacity Building Enabling for Innovation'. This instrument is targeted to technological centres, universities or firms and is aimed at validating technologies under real conditions. It is expected that this instrument will contribute to filling technology gaps in the mining sector by enabling testing spaces that allow testing technologies under real operating conditions, or equivalent to those found in mining operations. It will have properly instrumented systems to measure and verify critical process variables, with standardised test protocols adopting international best practices and will be executed by highly qualified human personnel. Among the fundable activities are hiring professionals and researchers with Master's or PhD degrees, training for personnel in the areas of applied research, technology transfer, innovation and entrepreneurship, and the purchase of equipment to develop R&D and innovation activities. The projects can have a national or meso regional scope. For the national scope CORFO funds up to 9,700 million Chilean pesos, which is equal to US$14,500 million approximately. For the meso regional scope CORFO funds up to 9,700 million Chilean pesos, which is equal to US$9,300 million dollar approximately (Corfo.cl (e), 2016).

At the same time, the Scientific and Technological Development Support Fund (FONDEF) launched the first call of technological innovation on mining prioritising funds for this sector. FONDEF belongs to the Chilean National Commission for Scientific and Technological Research (CONICYT), and works within the framework of the National Innovation Strategy of the Government of Chile. Its mission is to promote ties and partnerships among research institutions, corporations, and other entities to develop applied research projects that can improve Chile's competitiveness and the quality of life of its population. This call from FONDEF is aimed at giving financial support for the development of scientific and technological projects in mining with economic potential and social impact. It is also aimed at encouraging research in mining and increasing the quantity of researchers investigating mining themes. It is expected that the results of those projects are achieved, evaluated and validated within a short-term period (CONICYT, 2016).

The areas of the projects to be proposed are those that involve the key pillars of the 'Alta Ley' Programme (i.e. tailings, foundry and refinery, mining operation and planning, concentration of minerals and hydrometallurgy). The projects should start from a previous result, which is already validated at the level of proof-of-concept, model or prototype in a small scale or laboratory, and might come from previous research such as theses, internal projects from universities or projects funded with public or private resources. Proposed projects must be framed on:

i. Pre-competitive R&D projects, which are ones of scientific and technological research with the aim of providing results to generate product, process or service innovation with impact on markets; or
ii. R&D projects of public interest, which are ones of providing innovation results for the benefit of the Chilean community or important sectors of the Chilean community that cannot be appropriable for individual actors (Conicyt.cl, 2016).

Eligible organisations for this call are non-profit organisations such as universities, technological R&D, public or private centres and other organisations that perform scientific and technological activities. In the pre-competitive R&D projects, the actors involved should be a beneficiary organisation and a partner organisation. In the case of R&D projects of public interest another organisation (such as ministries, municipalities, foundations and trade associations) that would be responsible for the application of the project's results to the final addressees is also required; this would involve the transfer and diffusion of the project's results. To increase the project's effectiveness it is possible to include international organisations such as universities and technological centres, experts or international firms in the development of the projects. In this targeting call, FONDEF increased the subsidy given by 10% compared to FONDEF's regular calls. Also it funds up to 80% of the total cost of the programme with a maximum of 220 million Chilean pesos, this is equal to US$330 million , and the funding from the partner firm or organisation is just 10% of the total cost (in a regular call, it is 20%) (CONICYT, 2016).

Finally, it is important to mention that there are other CORFO instruments that promote collaboration between the industry and the university: voucher for innovation, technological contracts for innovation and human capital for innovation. Voucher for innovation is an instrument for the linking between firms and knowledge suppliers' organisations. The aim of this instrument is to contribute to the development of innovative solutions to productive or competitive problems or challenges of firms through the collaboration between that firm and a knowledge supplier organisation. The expected results would be the boosting of collaboration between firms and knowledge supplier organisations, obtaining significant improvements in processes, developing new or improved products with a positive impact on the productivity or competitiveness of firms, and to incorporate technological and innovative capabilities within firms (CORFO, 2016a).

In the case of contracts for innovation, they seek to promote a collaborative link between firms and knowledge provider organisations to solve a challenge or take advantage of an opportunity. In this collaborative relationship the firm originates a challenge with R&D and innovation components based on a need or opportunity. This challenge or opportunity is addressed together with a knowledge provider organisation that can be a national or international university or an R&D centre. A broker role is necessary to facilitate the relationship between the firm and the knowledge provider organisation; this role can be internal or external to the firm. The expected results are collaborative work and formation of alliances, transfer of knowledge and technologies (technological and innovative capabilities), the use of R&D and innovation in the business strategies, and the development of new products and processes (CORFO, 2016d).

The aim of the human capital for innovation instrument is to contribute to the strengthening of R&D and innovation capacities in firms through the insertion of highly-qualified professionals, for their participation in the solution of R&D and innovation challenges with the aim of increasing the productivity and competitiveness of the firms that were hired. These professionals should have a Master's or PhD degree in the areas of science, technology and innovation (CORFO, 2016b).

So far these instruments have not taken a sectoral approach, however, it is not possible to dismiss the notion that they will focus special calls for the mining industry in the future.

4. Conclusions

Industrial policy learning in Chile is developing targeting policies to support sectors with high growth potential. At the end of 2015, and inspired by European experiences, seven National Strategic Programmes of Smart Specialisation were defined to solve coordination failures of prioritised sectors. The idea was to increase the productivity of these sectors and at the same time improve the sophistication and diversification of goods for exports, together with the stimulation of an inclusive and sustainable development of the sectors. For the mining sector, the 'Alta Ley' Programme is the Strategic Programme that promotes the operation of a triple helix system. In this it is expected that the state, industry and academia spheres will contribute to the transition towards a knowledge society economy in which the mining industry is used as the platform of technological innovation to generate the emergence of a robust R&D and innovation ecosystem with local knowledge and capabilities. The first phase of 'Alta Ley' corresponded to the development of a long-term shared vision of coherent public-private action. This was followed by a second phase, by the design of a technological roadmap for the industry. The third phase corresponds to the implementation of the designed technological roadmap that, at the moment, is in an early stage.

The process of deliberation to achieve the vision and elaborate the roadmap created social capital that allowed consensus about the future of Chilean copper and other minerals. The convergence of objectives documented in a roadmap allows for the orientation and prioritisation in decisions on public investments; at the moment these are focused on the development and strengthening of collaborative R&D and technological capacity, the development of standards and advanced human capital.

The Chilean mining industry is now in a self-sustaining growth and renewal phase; this is characterised by a consensus space where a shared long-term vision and the development and implementation of a technological roadmap for the industry was developed. It is expected that the consensus space is the basis for an innovation space where the dynamic advantages of the industry are exploited.

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1. Academic, PhD in Science, Technology Policy Studies and an MSc in Public Policies for Science, Technology and Innovation from SPRU-University of Sussex (United Kingdom). Department of Technologies Management. Universidad de Santiago de Chile. veronica.roa@usach.cl

2. Academic, PhD in Social and Political Processes in Latin America from Universidad ARCIS (Chile) and a Master of Education specialising in Curriculum and Community Education from Universidad de Chile (Chile). Department of Technologies Management. Universidad de Santiago de Chile. julio.gonzalez@usach.cl

3. Academic, PhD Candidate in Social Economy from Universitat de València (España) and Master's degree in Industrial Engineering from Universidad de Santiago de Chile (Chile). Department of Technologies Management. Universidad de Santiago de Chile. jorge.torres@usach.cl

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