Project: Opening up Natural Resource-Based Industries for Innovation: Exploring New Pathways for Development in Latin America

CASE STUDY | Aguamarina

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1. Introduction

This report corresponds to the findings of one of the four case studies conducted in Chile as part of the project "Opening up natural resource-based industries for innovation: Exploring new pathways for development in Latin America". One of the types of "alternative pathways" we are interested in are "path-creating" alternatives, i.e. those that start from the needs and experience associated to natural resource sectors, but involve innovative, knowledge-intensive activities that can help develop national technological capabilities.

The actual application of scientific knowledge in industrial problems is something that is difficult to obtain in countries with weak, disarticulated and incomplete National Innovation Systems. Biominery has been performed in Chile for decades already, but the potentials of this technology are still not realized, and some people are already skeptical of its promises. Aguamarina, a young company located in Antofagasta, started working on biolixiviation (bioleaching), but has extended to any problem of the mining sector where microorganisms and biotechnology could improve operations. This case shows that world-class applied scientific research is possible in Chile, that there are capabilities to develop them, and interest in companies to try these technologies and invest in them, especially as they start to see results. At the same time, the productive improvements related to their technologies are not associated to environmental problems. In fact, they usually improve environmental outcomes.

Across this case study report we see the "alternative" as the company Aguamarina, the focus of the study, although we do it always in the context of *path-creation*, i.e. thinking on how this company has managed to be a successful example of a very innovative and knowledge-intensive firm.

The report starts by describing the methodology and the context of biotechnology in Chile, and particularly in the copper mining industry, as well as the history of Aguamarina and what they do. After these introductory sections, we analyze the five main questions of our study:

1. *How widespread has the alternative become?*
2. *How distant is the alternative to the dominant trajectory?*
3. *To which extent is the alternative promising or delivering better outcomes?*
4. In which ways has the availability of internet and/or other ICT technologies contributed to the development of the alternative?
5. Which are the main barriers that block the diffusion of the alternative?

Finally, we present a summary of our findings for these questions.

2. Methodology

As for all the cases under study, we base our work on both secondary information and primary information obtained from interviews to key informants. While the secondary information was fundamental for the previous stage of the project, where we described the dominant trajectory and its problems, in this stage we base ourselves on the primary information and follow a case study methodology (Flyvbjerg, 2006). However, we still use some secondary information for the general description of the case, as well as for contrasting the available information to that obtained from the interviews.

We focus the study on the issues discussed in the Consolidated Paper (Marin and Benavente, 2011) that summarizes our adaptation of the Transitions Framework to study the problems of sustainability and generation of diversity in Latin American economies, starting from natural resources.

We conducted interviews to the founder and CTO of Aguamarina, the laboratory chief, and several other researchers, as well as their counterparts at the mining companies. We complement these interviews with those to other actors that have general knowledge about the way the mining sector works in Chile.

We used the software QSR NVivo 8 to analyze the data collected. We coded different fragments into concepts, research questions, and actors. This allowed us to later produce queries that crossed, for example, research questions with different important concepts of interest, to easily analyze our data but to do it in a very thorough way.

3. Context: Biotechnology in Chile

3.1 Overview of the industry

Biotechnology, according to the UN Convention on Biological Diversity, is defined as *"any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use"*. The first biotechnology firm in Chile, called BiosChile, was established in 1986. For years, Chilean biotechnology firms sold their products (pregnancy tests, reactives, etc.) cheaper than their competitors because the market did not trust national products. They started working on solving domestic problems, and they are currently earning millions of dollars a year. The industry started to grow slowly, but this has accelerated in the last years, and there are currently over 200 entities working on biotechnology, out of which over a hundred are firms dedicated to it, and around 30 of the most important ones are grouped in Asembio (Chilean Association of Biotechnology), founded

in 2004. This association has been actively promoting the Chilean biotechnology industry abroad.

National biotechnology firms are concentrated in the agroindustry (around 40%), human health (around 25%), and the rest is distributed across aquaculture, forestry, foods industry, bioprocesses, mining, and others. Around 60% of the total number of firms are focused on natural resources, and there were a total of over 130 million dollars involved in research in 2009 (Hernández-Cuevas, 2011; ThisisChile, 2009).

An interesting example of products are vaccines for salmons (which can save the sector up to 100 million dollars of yearly losses). One of the firms that developed a vaccine currently has around 160 employees and a turnover of 35 million dollars a year. They reinvest around 5% of this in R&D projects. They took six years and around USD 3 million to develop the vaccine. Other developments by Chilean biotech companies include the development of a system to quickly detect infections in vineyards, and a test for early cancer diagnosis. There is currently a program to accelerate pharmaceutical businesses in Chile, and at least two investment funds with experience in biotechnology.

The State has played a role in the development of biotechnology. In 2003, the president called for the creation of the "National Committee for the Development of Biotechnology", that was later absorbed by the National Council for Innovation and Competitiveness, created in 2008. The Chilean Government's Productive Development Corporation (CORFO, for its acronym in Spanish), through its Innova program, has provided around USD 120 millions of co-financing for over 400 biotechnology innovation projects between 1992 and 2009, almost 60% of it in the last three years (DF, 2010). There have also been other sources of public funding, for not-so-close-to-the-market developments. Important resources have gone to research on bioleaching and biodiesel technologies, and the government has also provided funds for Asembio to promote the "brand" of Chilean biotechnology abroad, focusing on California.

Currently, there are estimates of over a hundred biotechnological companies in Chile, with a total yearly turnover (including products, inputs and equipments) of between USD 100 and 150 million. There is right now a very positive environment for innovation and entrepreneurship in Chile, with many public and private initiatives to promote it and increase awareness of it. This might increase the number of innovative firms in the coming years, however there are still important problems to be faced, such as insufficient venture capital and collaboration levels. Particularly for the biotechnology sector, some of the main challenges are the lack of a critical mass of firms, the vision for internationalizing businesses, lack of experience and exposition, low patenting levels, and lack of experience in technology transfer, to name some (Hernández-Cuevas, 2011).

3.2 Biotechnology in the Chilean mining sector

Biotechnology in the mining sector has revolved almost completely around bioleaching. In 1947 the role of microorganisms in the copper lixiviation process was understood, and commercial exploitation of the technology started in the US in 1950. In Chile, the first trials

were done by Codelco (Chile's state-owned cooper mining giant) in the early 70's, but the first commercial operation started working in 1986: the Lo Aguirre mine, owned by Sociedad Minera Pudahuel. Bioleaching makes it possible to recover copper from very low ore grade minerals[1], and the process is cheaper, less water demanding, and less pollutant than other technologies. The main problems are that there is little control over the process, and the very slow processing speeds (between one and two years).

During the last two decades the technology has greatly increased its presence in the world and in Chile. In terms of research, in 2000 a joint venture called "Alliance Copper Limited" was started by Codelco and Billiton[2] (that contributed with a patented bioleaching technology). There was a pilot plant, but finally the joint venture was dissolved in 2006. Both companies have continued to invest in biotechnology, Codelco through a joint venture started in 2002 with Nippon Mining & Metals called Biosigma (controlled by Codelco). Biosigma –that employs around 15 PhDs– has focused on genetic manipulation, while BHP-Billiton on developing processes improvements, such as airing systems. Jointly, they have invested over USD 20 million in research (Hernández-Cuevas, 2011), and both have received different forms of public support for their research. Besides collaboration between BHP-Billiton and Universidad Católica del Norte, these research efforts have been relatively closed and in-house, more than the usual in the industry.

Currently, around 10% of total copper production in Chile is obtained through bioleaching (over 500 thousand tons of fine copper). In 2009, there were seven bioleaching operations, controlled by five different mining groups (COCHILCO, 2009). The current technological challenge is to successfully process chalcopyrite through bioleaching, as an estimated 80% of known reserves are found in low ore-grade chalcopyrite deposits (Minería Chilena, 2008). There are optimist and sceptic views about this. Biosigma recently announced an industrial scale pilot that will use their technologies and patented microorganisms to process chalcopyrite, in what might become one of the most important technological breakthroughs in the history of copper mining, but they still have to show that their technology works.

A technology that could compete with bioleaching is lixiviation in high-chloride environments (discussed in our "Sea water" case report), but bioleaching has received much more attention than its potential competitor.

[1] The technology has been used both to process residuals from the traditional processes, and to process minerals with ore grades so low that traditional processes are not useful.

[2] This was before its merger with BHP to form the current BHP-Billiton.

4. Aguamarina

Aguamarina is the name of a semi-precious stone that is usually found in the desert, “so small that one cannot see it, but you know it is there”, just like the microorganisms which are the center of this company’s work. Aguamarina was founded by Pamela Chávez, who after a PhD in aquatic molecular microbiology in Kyoto, postdoctoral work on cellular physiology and heavy metals in Hawaii, and a prolific academic career back in Chile, decided to switch to entrepreneurship. The first company where she participated, after some success decided to move to Santiago, something she did not agree with, and decided to leave her partner. After finding an investor for a new startup in Antofagasta, they started Aguamarina in 2007. A researcher passionate for marine biology, she decided to apply her knowledge and skills in the sector that dominates the economic activity of her region of origin: copper mining.

The company has had most of the important mining groups present in Chile as clients, including BHP-Billiton, Barrick, Xstrata and Antofagasta Minerals, showing that there is an important demand for their research. They started working on bioleaching services, but they have expanded into new product lines, all biotechnology-based solutions for mining companies. They currently employ over 20 people, most of them highly qualified women, in a man-dominated industry. Most of their business has been *creating new solutions or services* for problems that are present in all mining operations. To develop these new solutions, the company has worked both with public funding and with private funding in particular projects with mining companies.

Figure 1 – Top: Aguamarina's team. Bottom: Working at the lab.

One of their defining characteristics is that their solutions are non-pollutant, providing them with an important additional source of value for mining companies: using microorganisms in different ways, they can improve their efficiency and production levels without any harmful environmental effects.

The main areas where Aguamarina has been working are bioleaching, biocorrosion, biorremediation, biorreactors, water treatment and dust control. Most of these lines have a significant potential for lateral migration, first to other mining industries[3], but later to completely different industries that face similar problems.

[3] Different from copper, for example iron.

Figure 2 – Biofilm (that can increase corrosion problems) over a pipeline.

Different forms of networking and alliances have been key for their success, including their relationships with international universities, Endeavor and BHP-Billiton's Cluster Program (see Box 1), to name some of the most important ones.

Box 1: BHP Billiton's Cluster Program

BHP Billiton's Cluster Program deserves a special mention. Some years ago, BHP-Billiton closed their research centers, stating that their core business is not research but mining, and that research services can be acquired in the market. With a different motivation, but consistent with this idea, the Cluster program is born in late 2008 from the realization that in around ten years from now, the sector will face a lack of high-quality suppliers in Chile. The Cluster program aims to identify suppliers with potential to become "world class", but at the same time, to develop innovative technologies together with the company to solve specific operational problems that do not have satisfactory solutions currently available in the market. The Cluster Program takes suppliers through their "World Class Route", to help them become leaders at domestic level and competitive at global level, and collaborate with them to develop technologies that have a large potential in international markets. This collaboration is coordinated by the "project champions" inside the mining operations. Codelco joined the program in 2010, and the government in 2011, through CORFO, with funds to support innovative projects and initiatives to increase the competitiveness of the sector's suppliers[4]. BHP and Codelco aim at developing and reinforcing at least 250 suppliers for 2020.

In the case of Aguamarina, this program made them extend their horizons and really think about "going global", an objective that will likely see some results soon. On the other hand, they are working at the Spence mine (a relatively new operation, which began in 2007) on a project selected through the Cluster Program and another project that was awarded through a different route inside the company. Their counterpart and "champion" inside the company is Juan Larenas, a young engineer with experience in bioleaching and that worked previously at

[4] They have a total of USD 45 million to invest in three years.

BHP's largest operation in Chile, Escondida. Throughout the report, there will be many references to this relationship, both because of its importance for Aguamarina, and because it is in itself an important organizational innovation that can play a role in promoting the development of other *path-creating* alternatives.

After showing concrete results to mining companies, they have not only achieved the difficult feat of validating themselves in the "biotechnology for mining" area, but became the leaders in it. Aguamarina is filling the key void that usually exists between scientific research and industrial needs. On the one hand, they are attentive to scientific developments that could have industrial applications, and on the other, they are getting close every time to the mining operations and their problems. Their scientific knowledge, together with a deep understanding of "what hurts" inside the operations, allow them to develop innovative and effective solutions to some of the most relevant problems faced by the sector. But to get to this point, it was necessary to have both scientific and business knowledge and abilities. As stated by Chávez, she invested almost three years *"in understanding the business"*. She decided to focus on only two or three clients, *"to understand their pains, understand where we had to aim to with our technological developments"*. This was also important for being recognized as a valid counterpart by mining companies. After some initial funding and developments, and this long investment in understanding the sector and its problems, the Cluster Program came in, at precisely the right time to help them define their sales and products strategy –with a global perspective. Valuing their work is something extremely complicated for technological startups, but nevertheless fundamental for their market success.

5. Q1: How widespread has the alternative become?

Following our adaptation of the Transitions Framework, described in the Consolidated Paper (Marin and Benavente, 2011), we describe the diffusion of the alternative in terms of networks, expectations, learning processes and policy initiatives.

5.1 Networks

One of the aspects that differentiate Aguamarina from other actors in the sector is its network of contacts, which includes research centers in Japan, the United States and Germany, as well as government agencies and domestic and international universities. They have also collaborated with Endeavor[5] and engaged in important relationships with mining companies (such as BHP's Cluster Program). The most remarkable characteristic of their network of contacts is that it balances science and business, as well as including contacts with government agencies. They have managed to acquire the necessary knowledge and capabilities from the

[5] Endeavor is a global non-profit entrepreneurship-promotion organization.

right places, and given equal importance to scientific capabilities and business matters (notably technology management), something not usually done by scientists.

We present a brief review of their different types of contacts.

- In terms of **clients**, they have worked with pretty much all large companies, including Codelco, which has had a closed and (practically) in-house bioleaching research group at Biosigma for already 10 years, and with BHP-Billiton, that has also devoted important efforts to developing technologies to improve the process. Other mining groups that they have had as clients include Xstrata, Barrick, Anglo American, Antofagasta Minerals and Teck, in mining operations like Quebrada Blanca, Collahuasi, Los Pelambres, and El Soldado, to name some. They have already analyzed samples from other countries, including mines in the United States, Brazil, and Peru, and are constantly being contacted from abroad because of the know-how they have developed.

- On the other side of the "supply chain", **suppliers** have not been particularly relevant for their work. They do the research in house, the only thing that they buy are some analysis, which are standard, and can be obtained from domestic or international suppliers (Korea for example), depending on prices and available capabilities. In terms of their human resources, it is much better to buy these than to dedicate their limited time to do them.

- In terms of **competition**, they do not have much. There are few biotechnology companies focused on the mining sector, and the products Aguamarina is working on are highly innovative at world level, making them the only choice for mining companies. Chávez has been an active participant of Asembio, and is currently its official representative in the Antofagasta Region.

The fact that there are not many similar companies in Chile means that looking abroad is necessary both for inspiration and for discussion of results. For instance, they are constantly checking scientific production, and there are cases where something read on a scientific paper inspired a totally different use for a microorganism in the mining sector. In terms of discussing results, there are contacts with Japanese and American universities. For example, issues related to the search for life in Mars being studied by astrobiologists at the University of Southern California are very similar and complementary to the work of Aguamarina on bioleaching monitoring. This is because the conditions in Mars are similar to that in the Chilean Atacama desert. One of the public funds for innovation that they were awarded also includes an internship in California to work with laboratory equipment not available in Chile.

In terms of business, one of the most important contacts is Endeavor, which is in fact the entry into a global network of high-impact entrepreneurs. Chavez remarks *"feeling alone"* in the process of starting the company, and *"wished there were more"* to be able to discuss problems and learn. This *"feeling alone"* made her worry much more about every step in her way, and Endeavor, as well as her studies in business and innovation in Chile and abroad (at Columbia University) have been fundamental in avoiding common mistakes. Together with Endeavor, the company has participated in and organized seminars about research and entrepreneurship

in Antofagasta, and obtained important international contacts, such as potential venture capital investors and connections at the MIT and Stanford universities.

And besides business studied and contacts abroad, an important development in Aguamarina has been bringing graduate students from top US universities for internships in the company, to work with them on issues such as business models and marketing. The company also hired an expert from the Boston Consulting Group to help them with their branding and marketing strategies. Although these have come from abroad, in Chile there is interest in learning from Aguamarina, and a local university is studying them as a business case.

Finally, researchers from the company recently published chapters in two internationally edited volumes on Biohydrometallurgical Processes and Marine Cosmeceuticals, inserting the company in the academic community.

Firms that want to develop technology together with mining companies should look at successful cases like this one, not to try to replicate their networks, but to understand which collaborative linkages could be important for their own success.

Regarding the networks around biotechnology in Chile in general, the industry has been growing fast, but a critical mass of firms has not yet been achieved, and lack of collaboration is still an important problem for the sector (Hernández-Cuevas, 2011).

5.2 Expectations

The future for Aguamarina seems promising, the main worry being having too much work to do. They are currently at a critical point, running several pilot projects, and apparently most of them have already shown positive results. The company must be ready and have a plan to ensure that they will be able to keep on working and delivering on time if all or most of their research lines and projects are successful. The idea of this risk shows up both when talking to people inside the firm and to their counterparts.

At the same time, there are more and more contacts with foreign companies, including several non-disclosure agreements already signed. The company is considering models of independent business units to manage their technology portfolio internationally, but they stress that they still have much space to grow in Chile.

Thinking on the longer run, technologies related to biocorrosion or dust control, for example, have a very wide range of industrial application. There are concrete opportunities of adapting the technology to mining of other minerals, as well as some very specific and unexpected examples of adapting the technologies developed for mining companies to the needs of other sectors. For example, the technology developed to monitor bioleaching processes can be used in microalgae growing, and these microalgae are being used to produce biodiesel. This application has already been tested at industrial scale.

Beyond Aguamarina, and regarding bioleaching in particular, there are mixed views on the sector. Some are already very sceptical of its real potential, considering how much money has been invested and how little actual results there are. For the rest of the biotechnology-based solutions for the mining sector, there are bright prospects, but the sector is conservative and needs to see very concrete results before having faith in new technologies. Beyond mining, biotechnology in Chile seems to be heading towards health and agroindustry issues. Together with the growing scepticism around bioleaching, this poses a challenge for biotechnology in mining, which must show that it can produce effective solutions for the problems of the mining sector. Aguamarina seems to be contributing in this direction.

Although recognizing the fact that *"it is not easy to develop technology in Chile"*, at Aguamarina they think that more and more similar companies will be able to appear in Chile, especially if there are examples that show good results. BHP's Cluster program might be a good way to promote the development of this kind of suppliers. And there is no reason to think that there are not other potential "Aguamarinas" that on the margin might spring out with the demonstration effects of the first successful examples, as well as the support from this kind of initiatives. With Codelco and the government joining BHP-Billiton in this long term effort to develop "world class" suppliers, the scale and potential of the initiative increased significantly. With many of the problems being common for all companies, it makes sense for them to work together in the development of innovative suppliers that will in the end benefit all of the sector, and in fact there is at least one more important mining group that is considering joining the program. But of course that the rest of the context must be considered: if some of the general bottlenecks and problems that affect the Chilean National Innovation System (such as difficulty and costs of financing) are removed, these initiatives should be even more successful.

5.3 Learning processes

The balance of scientific knowledge, understanding business, and working at industry rather than university-pace has been key for Aguamarina.

On the one hand, it is possible to go through the slow and relatively certain way of thorough scientific understanding of the biological phenomena of interest, and on the other extreme, there is the engineering like, applied approach of learning through quick trial and error. To be able to develop effective biotechnological innovations, science is key, but mining companies value speed and results more than scientific understanding. Maybe the largest difference between the research performed at Aguamarina, and that performed at universities with similar microorganisms, is the pace of work. Aguamarina is praised because they have been able to deliver results quickly, closer to trial-and-error than scientific learning, focusing on the applied problems rather than on scientific inquisition. Comparing their situation to university researchers, they feel that being "subsidized" by their university positions, they do not have the pressure to be constantly showing results as they do, to keep a relatively constant flow of income. But it is also important to mention that there are research projects funded internally

by the company, as part of their learning processes, which can later turn into products and services.

The company has found itself forced to learn to speak the language of engineers, for example to collaborate with a group of American engineers that were working with one of their clients, but also to be able to collaborate successfully with the people that will be working daily with their products. This first step involved the scientists becoming familiar with the reality and problems of mining operations, but there is a next step, not yet fully developed, where the research company needs to have more full-time engineers inside the company and spending time on the mines, at least according to some of their counterparts. There is an issue of balancing the effort between the mining company and the supplier, sometimes there is still a gap between the researchers' ideas and what they can implement in practice by themselves. This can be seen on issues such as the design of pilot plants, but also in details like being able to independently move around the mine, details that may nevertheless make the difference for the engineers in the mine when choosing with whom to work. But all the faces of the problem must be considered: from the perspective of the supplier, it can be dangerous to focus so much resources on maybe only a few clients. This is a classic problem of transaction costs, how much of the work is done by the supplier and how much by the mining company: how to reduce transaction costs (of which many can be traced to learning and acquired knowledge), while preserving the independent identities of client and supplier. There is a large middle ground between microbiology and mining engineering, and both actors need to expand their knowledge bases to be able to communicate and work effectively.

Besides technical learning, the learning in terms of business knowledge at Aguamarina needs to be highlighted. Scientists in general are sceptic and wary of managers and everything business-related. But in the case of Aguamarina, its founder has not only pursued studies on innovation and management at a local university and at Columbia, but has also brought experts to work with them. Students from prestigious American business schools and business consultants have came for internships with them, working on issues like business models, marketing and pricing. And the most remarkable thing is that the other scientists in the company fully understand the importance and potential of these visits. They do not see time spent with them as wasted away from their research, but as *"an investment"* necessary for the success of the company: *"they come to help us position ourselves as a brand"*.

Another learning-related aspect of this case is the development of highly-skilled human capital, at the scientific and technical levels. Just like the techniques learned to do basic science can be adapted to work on applied problems, the knowledge acquired on applied problems of copper mining can be used to work with other industries that could use biotechnology to improve their processes and/or reduce their environmental impacts.

Finally, it is important to mention that scientific publications can be an important source of ideas. One of Aguamarina's currently most promising technologies was born from reading an article about a specific bacterium, being used in a completely different process, which was later acquired and adapted at their laboratory for a use in the mining sector.

Aguamarina is ahead of the average technology supplier on the three areas of knowledge discussed, and has gone through important and effective learning processes in all of them. There is much to be learned from the way things have been done at Aguamarina in this respect.

5.4 Policy initiatives

In contrast with the other three cases that we studied, here public instruments to support innovation have played a relevant role in Aguamarina's success. There are at least four different instruments that have been used by the company: Innova, FONDEF, the tax incentive for private R&D, and a subsidy for hiring highly-qualified researchers in private firms.

'Innova', located inside CORFO, groups most of the government subsidies to promote innovation (rather than basic science). Aguamarina has had at least two projects, a recent one on biocorrosion, and another one on a monitoring technology for bioleaching. The former uses traditional corrosion measurement techniques, together with microbiological analysis techniques, to evaluate the impact of the microorganisms that induce corrosion. The latter had ample media coverage, and in the two years of execution obtained very good results, and *"the investment will be much more than recovered"*. Currently bioleaching operations (and lixiviation operations in general) perform in a very "artisanal" and empirical way, without much information, compared to the highly controlled and understood process of flotation. To change this, they developed a system to remotely control bacterial activity. This can replace the slow (10 days at least) processes of obtaining samples and sending them for analysis, improve response time to changes in their conditions, finally increasing output and optimizing the use of inputs. With a subsidy of around US$550.000, they first produced fluorescent clones of the bacteria (see Figure 3), and then developed a device that can count these fluorescent bacteria in real time and without affecting the process.

Figure 3 – A picture showing fluorescent bacteria on a piece of mineral.

FONDEF projects, on the other hand, are developed by firms together with universities, and are not as close to industrial application as Innova projects. They have worked on FONDEF projects (including at least one related to marine biology, for scientific more than business

reasons), and through them they have had access to some specialized laboratory equipment. However, in the company they feel more comfortable with Innova projects, which end up in concrete products after a relatively short time, there is no need to interact with a university, and they can work directly with their clients.

As stated by the initial investor of Aguamarina, *"we would not exist today without CORFO, it is very difficult to perform applied research in Chile without the support of the State"*. Besides initial financial support, public funding plays another role: it can help to stabilize income flows, as mining companies usually take very long times to make payments effective.

Regarding the tax credit for R&D expenditures, Aguamarina became a certified center in June 2011 (firms need to work with certified research centers to obtain the benefit). Firms can have a tax benefit of up to 46% of the investments in R&D projects performed together with Aguamarina. However, at mining companies, they confess that in practice this does not make a difference: the projects are still small in terms of investment for large mining groups, and technical teams only need to argue with technical reasons why they want to work with a certain supplier, and funds for the projects will be released, regardless of the mining company being a certified center or not. This policy might have more impact in other sectors that do not handle the volume of resources that large mining companies do. But this does not mean that the benefit is not being used, there are several projects that will recourse to the benefit, from at least two mining groups.

Finally, a very large subsidy to hire researchers in firms, which has received surprisingly little interest from the industry in general, was used by Aguamarina to finance the first years of at least two of their PhD's. This company will probably represent a very good example of the potential of this subsidy, and hopefully will move other firms to use it.

For the development of mining suppliers in general, the previous government's innovation strategy included targeted support for the mining sector (including the development of suppliers), but this selective innovation strategy was discarded by the government that took office in 2010. However, in 2011 the government, through CORFO, joined BHP-Billiton and Codelco in the Cluster Program, providing funds for competitiveness of suppliers in general as well as for the development of innovative technological solutions.

6. Q2: How distant is the alternative to the dominant trajectory?

Considering that this is a path-creating alternative, it is not simple to compare it to the dominant regime. The comparison is not "parallel" to the regime, in terms of describing an alternative pathway that achieves similar objectives through different means. Instead, it produces something completely different, and as such, most dimensions are radically different from the regime's, and |not always directly comparable. More than speaking of scalar distances between the two in each dimension, we will describe them for the case of the alternative.

6.1 Guiding principles

As discussed on the other cases, the ultimate motivation for mining companies is always maximizing production levels, and they prefer to use proven technologies. On the side of Aguamarina, besides the traditional motivations behind any entrepreneur, such as seeking profits and self realization, there is another important aspect: the core of their business is conducted by researchers, that love science, but all of them give immense value to the possibility of applying their scientific knowledge and abilities into applied industrial problems. In their view, the reason why there are not more scientists following this path is not the traditional looking down on applied work by scientists, but rather a lack of demand from the private sector. There might be a change in the present and future generations of scientists, of giving more value to entrepreneurship and working on applied industrial problems. Other cultural differences related to richer and really collaborative relationship between individuals and firms are discussed in section 6.6.

Mining companies also like to say that they are innovators and have unique technologies. When there is a possibility of developing a technology that will certainly not negatively affect their production, and could improve it (or reduce costs, pollution, or risks of accidents), they will invest in it, as many times these are also small investments for these companies. On the other hand, scientists interested in applied work will happily accept scientific challenges that will have observable economic results. There is an interesting intersection between the application of science and the needs of firms, that when the conditions that are discussed in this report are met, can give rise to the development of *path-creating* alternatives like this one.

The guiding principle that can summarize Aguamarina's philosophy is *"understanding [the particular problem] from the pain, the real needs, and ideally jumping ahead five or ten years in what they are going to need"*. In this way, they have been able to find areas where miners have a problem, understand it, and apply their scientific capabilities to develop innovative solutions for them. They also use design thinking methodologies and give importance to issues like product usability.

But the main difference in terms of final motivations is that mining companies are only trying to maximize profits. While Aguamarina is a firm that looks for profits, its work is motivated by their love for science and research, but particularly for applied and *industry-useful* research.

Figure 4 – Aguamarina researchers taking samples to look for microorganisms and studying them.

Particularly among biotechnology researchers, there are also different orientations behind their work. Some try to find or create some kind of "super bacteria" that will work under any conditions. At Aguamarina in contrast, for each client, they try to find a bacteria that is already adapted to their conditions. This requires customizing their solutions for each client, and on-site search for samples, as shown in Figure 4.

6.2 Products

With the help of Aguamarina, mining will still be producing the same types of products, except that they will be able to do it in more efficient and less pollutant ways. These technologies themselves are highly innovative products –unique in the world– that help solve different problems of the mining process. This is a stark contrast with the product of the dominant regime: copper, a commodity.

Aguamarina's technologies have the potential of each becoming a "business unit", that could adapt the technology for the mining of other minerals as well as other industries that could use similar microbiological solutions, and export these technologies.

Aguamarina produces not only innovative technological solutions. While they do this, they also train highly qualified applied researchers on biotechnology, and generate information that can be used by future entrepreneurs and other actors. Mining companies, suppliers, and policymakers can learn from examples of successful young technological supplier like this one.

6.3 Technology

The core of Aguamarina is microbiology and biotechnology. They started working on services for bioleaching, an area with potential because many mining operations have bioleaching operations and there was much space for improving the processes. However, bioleaching is also characterized by the technology being developed in a relatively closed and secret way by Codelco and BHP-Billiton, and certain scepticism by some executives after significant

investments and little improvements. But besides successfully supplying technologies to improve bioleaching processes, they have expanded into other areas, starting from the fact that knowledge on microbiology can be used to solve many of the problems faced by mining companies.

They are specializing on the problems of the mining sector. Specialization helps them develop more and better products, but eventually the technologies and abilities developed will be adapted to other productive sectors. Biotechnology is one of the "general purpose technologies" that will be key in the next technological revolution, producing radical changes – and opportunities– across all of the economy in the coming decades (Pérez, 2008). This is why it becomes so important for a country like Chile to take advantage of the fact that natural resource-intensive industries have great potential to demand biotechnology-based knowledge. This knowledge demand can be used to develop technological capabilities that could be key for diversification and economic development.

In terms of in which parts of the productive process their technologies come into play, mining companies are conservative in what constitutes ensuring production levels. This means that it is difficult to think that operations would be interrupted to try out a new technology, but this doesn't mean that the technologies they are trying with Aguamarina would have little impact. They might be used in non-core parts of the process, but nevertheless have potential for increasing productivity in different ways, while also obtaining better environmental and safety outcomes. And at these operating scales, small improvements in productivity translate into millions of dollars. People at BHP stress that they will not simply invest in research for the sake of it in the Cluster Program, but work with suppliers on promising technologies that could have important positive impacts on their operations.

Particularly with bioleaching, Aguamarina has oriented its efforts towards developing technologies that will be complementary to the efforts being developed in-house by mining companies. They have found these opportunities through their guiding principle described in section 6.1, *"understanding bioleaching from the pain"*. Aguamarina works with their clients in different stages (e.g. laboratory, design, scaling-up), and subsequent private investment depends on the success of each stage.

If we consider the "social technologies" (Nelson and Sampat, 2001), the institutions that regulate interaction between actors, we find that Aguamarina is an exception in the sector and in Chile in general. The company has managed to create rich collaborative relationships with their clients, fundamental for the proper development of innovative solutions to their problems.

6.4 Industrial structure

BHP and Codelco's Cluster Program is an interesting organizational innovation that could foster the development of many other knowledge-intensive suppliers, which at the same time that learn to collaborate with large mining companies to develop innovative solutions, are prepared by the program to become "world-class" and internationally competitive. This program is

somehow paying for the costs of coordinating mining companies with potential technology suppliers, and in this way removing the coordination problem that may prevent potential suppliers to develop.

While the rest of the industry does have a similar discourse about developing suppliers, actually executing policies in that direction is something completely different. In fact, it seems like the fact that Codelco joined the program was influenced by the arrival of a very high executive from BHP to Codelco in 2010.

And apparently inside the different mining groups there can be heterogeneity regarding the propensity to innovate, associated with the organizational culture that dominates each mine. In some operations people are more willing to try things –that do not affect production– and to have deep collaborative relationships with suppliers. On the other hand, the supplier must have a culture and way of working (especially the speed and long term perspective) which fits with that of the mining company, and making this match might be part of the explanation of some of the success stories of the Cluster Program.

It is interesting to see that there is a certain degree of competition across the mining companies that are trying out technologies with Aguamarina. We heard about a case where a company that was recommended to work with Aguamarina by another company (from a different mining group), ended up trying first a technology that both wanted to try, because they already had a particular intermediate input that was difficult to obtain. This produced a certain jealousy on the part of the recommenders.

Besides institutions like the Cluster Program, which can help find and develop *path-creating* alternatives, it is important to highlight the fertile insertion of Aguamarina in the Chilean Innovation System and the rest of the world. It is a firm that has managed to obtain human capital, public and private funding (besides the projects funded by the clients), and made links to other entrepreneurs in Chile and abroad, as well as high-level research centers. All of these are difficult and take time, effort and mutual trust, and it is encouraging to see an entrepreneur that has been able to form such a comprehensive and functional network of contacts.

The fact that Aguamarina does not have many connections to national universities is consistent with what is happening with mining companies, as hinted by the quantitative analysis and confirmed by the interviews. Mining companies have been significantly reducing their relationships to them. Universities work on problems that are still far from industrial application, and this is not likely to change under the current model. Mining companies need researchers to be much closer to them, investing time in understanding their problems, and want to work with people who move at the same speed as they do, *"the speed of 'yesterday', everything is day to day, everything was needed for yesterday"*. This is very far from the way university research works in Chile (and in fact, most of patent applications related to

bioleaching, for example, have came in similar parts from Biosigma, BHP and suppliers, and only an 11% from universities[6] [Minería Chilena, 2008]).

Finally, comparing Aguamarina with Biosigma, which does R&D in genetic manipulation to improve the bioleaching process, the models are very different. Although far from the standard in the industry, Biosigma has always been pretty closed and secretive to the rest of the sector. But this does not mean that the closed model does not work. In fact, Biosigma recently announced that they will try at industrial scale a technology that could represent the most important breakthrough in decades, but they still have to convince the sector –and Codelco– that their technology works.

6.5 Knowledge

As described on other sections of the report, the success of Aguamarina would not have been possible without three different types of knowledge: scientific knowledge on microbiology, knowledge about the mining process, and knowledge on business issues. The first has been acquired through academic studies and experience, the second through the close collaboration with different mining companies, and the third, through academic studies and visits from interns.

There are several PhD's working at Aguamarina, and employees are encouraged to study masters and PhD programs and going back to the company. In fact, they have funded the PhD studies for some people, who are doing their dissertations at the company. The academic world is also important in terms of being an important source of ideas and knowledge that can later be –quickly– adapted to solve industrial problems. The development of internal projects only as part of their learning processes is also an important source of learning and potential products and services.

On the other hand, there is operational knowledge, that needs to be acquired from the clients, but suppliers like Aguamarina will necessarily need to have some in-house employees that can fill in the gap between researchers and engineers.

Aguamarina has been using their scientific knowledge to find the best microorganisms that are already adapted to a client's environmental conditions, and if necessary modify them to better serve a particular purpose. But the precise way to implement these solutions will be tailored to what the operation demands, considering the needs and problems of those that will be using the technology. It is interesting to note that inside Aguamarina, it is common to have "cross-fertilization" of ideas between different research lines, showing that similar techniques can be adapted to different situations.

As described in section 5.1, business knowledge comes from Chavez's studies on innovation and business at a Chilean university and at Columbia Business School. Besides this, graduate

[6] It is possible that Biosigma's share has grown in the last years, due to its increased patenting activity.

students have worked on their dissertations at Aguamarina, and an expert from the Boston Consulting Group is currently working on their marketing strategy. Careful organizational preparation for each step in the growth of the firm is something *very* distant from the usual behavior of mining suppliers and most firms in Chile. Some things are even more complicated for technology suppliers than other firms, like, for instance, valuing their products and pricing strategies. That is why the fact that Aguamarina has taken business issues seriously –studying, learning from other cases, taking advantage of their contacts through Endeavor, for example– deserves to be stressed.

Comparing to the dominant regime, here scientific knowledge plays a key role while it is secondary on the regime. The operational knowledge needed by the alternative is part of the core knowledge of the regime, which needs to be transferred to and understood by the supplier to work effectively on solving mining companies' problems. Finally, the business knowledge that is relevant here is quite different from that on the regime. Mining firms are experts in evaluating and developing large mining projects, but the business aspects of this are very different from starting up a technology supplier.

Regarding intellectual property, what they patent are the processes they develop, independently of the particular microorganism. The same patented processes are used for different clients, but adapted to their particular environments and the microorganisms living within it. They also document their results, so that when they need to adapt their process to the particular bacteria available in the environment of a new client, they already have an important and organized knowledge base which allows them to speed results up.

The starting point in their negotiations is that *"everything that is done at Aguamarina remains at Aguamarina"*. The first thing that is signed is always the confidentiality agreement, including this principle and the lack of exclusivity for clients, however there may be provisions giving special conditions to clients that collaborate and invest their resources in developing a technology.

6.6 Culture and values

As explained in section 6.1, the guiding principles are the willingness in Aguamarina to understand their clients and use their science to help them, and the desire for mining companies to improve in certain outcomes, as long as production is not jeopardized. The culture behind each side is important for these guiding principles to be more than simply principles and materialize in collaboration and innovative technologies.

According to our interviews, there are –at least among scientists in related fields– many young scientists interested in applied work, but it is not clear that this is the case across most scientific disciplines that could eventually produce applied work. Some researchers see their work at Aguamarina as *"their first real job"*, actually looking down at their previous academic work. At the same time, it is important that these scientists value not only doing applied research, but also the potential impact than appropriate business strategies and planning can have. The importance of close contact with clients, understanding their problems, and

producing results fast, are defining characteristics of the company, which are highly valued by their clients. Pamela Chávez, Aguamarina's founder, has clearly managed to transmit her vision to her people and develop an organizational culture that is coherent with her views.

On the side of mining companies, it is important to have more young than old people at decision making levels, empower these young engineers, and also to have young counterparts at supplier companies. This appears to have two important effects: companies with younger people (as is the case at BHP's Spence) seem more eager to try new technologies, and in general it is much simpler and faster to get from a conversation about an idea to an actual pilot test of a technology. A second difference is the kind of relationships that can be established with suppliers, when these have also young people in control. For example, higher levels of trust and informality are possible, and things like asking for urgent shipments of supplies, without any formal document backing the request up, are now possible. Or the mining company professionals are willing to listen to the supplier if they tell them that they are doing something wrong. These are just two examples of how relationships can be different between younger professionals, more willing to collaborate. In cases where a constant and rich exchange is needed, as for developing new technology, these kind of fluent and collaborative relationships have much more potential to succeed. Both sides understand that they will be better off building a long term, win-win relationship. This has not always been the case in relationships between mining companies and suppliers, and is probably not yet the norm in the sector either.

On the other hand, too much young people can have a negative side: higher rotation levels because of career expectations, as well as long and complicated strikes have both occurred to "young" mines.

7. Q3: To which extent is the alternative promising or delivering better outcomes?

Following the classification used in the Chilean sectorial report, we will describe alternatives that improve productive, economic, environmental or social outcomes. Firm-level *productive* improvements are considered because some of the main problems of the dominant regime are associated to productive restrictions, and these are fostering the development of alternative pathways. And at the same time, some of these alternatives oriented at reducing productive problems produce important improvements in the outcomes we are interested in (environmental, social, and economic). The *economic* problems we studied are related to the long term dependence of the Chilean economy on copper exports, and the need for developing technological capabilities.

7.1 Productive

Aguamarina's products and services all aim at improving outcomes for mining companies, without having adverse environmental impacts.

The bioleaching monitoring technology reduces processing times significantly (from around 500 to 300 days), increases output, and optimizes the use of different inputs.

Dust reduction solutions have important productive impacts: With dust under control, there is less need to stop blasts, increasing production levels. At the same time, it is positive in terms of the relationship with communities, and it reduces costs thanks to huge water savings: currently, areas of the mine need to be watered to control dust (the problem is so serious that it can produce visibility problems for truck drivers). Using Aguamarina's technology, watering can go down from three times a day to once a week.

Other technologies, like the control of biocorrosion, and others which are not even though of today, will surely result in positive improvements in the company's productive processes.

7.2 Economic

The first and already realized positive outcome is the demonstration effects that a firm like Aguamarina can have. It is an excellent example that shows that world-class applied scientific research can be developed in Chile, producing innovative science-based solutions for industrial problems. Domestic entrepreneurship and knowledge-intensive suppliers for mining companies are a real possibility. It is important for other potential technology companies to look at successful cases like this one, to understand how they have inserted themselves into the scientific, entrepreneurship, and mining worlds. Academia and the public sector should also look at these cases to improve their approach to entrepreneurship and technological businesses.

There is still not much direct competition for Aguamarina, and particularly, no one has left the company to found their own companies, at least not yet. Regarding mining companies, they are absolutely focused on production and are not interested in the commercialization of the technologies they develop. Suppliers should take advantage of this, and work together with mining companies to develop new technologies, and then exploit commercially these technologies and their newly acquired capabilities.

In fact, the potential for exporting knowledge to other countries, other mining industries, and even completely different industrial sectors, is a very real possibility, and Aguamarina has already several contacts in all of these directions. Some examples are the interest of the Chilean Air Force in biocorrosion control, or the use of technology developed for bioleaching monitoring in the microalgae-based biodiesel industry. There are also advanced negotiations in Brazil, Spain and China to adapt and develop technologies for mining companies.

Biotechnology is a general purpose technology, with economy-wide applications and enormous future prospects, that is why developing capabilities in this area can be so important for developing countries. Eventually, people formed at the company could start their own businesses and specialize on other industrial sectors. Transferring technology is not automatic, it demands an additional effort –including learning again how the sector works and its needs– but similar knowledge and techniques are needed. In fact, inside the company, it is common to find "cross-fertilization" of ideas and techniques across different research lines.

In terms of patenting, at least seven patent applications by Aguamarina are being processed at the time. What they patent are the processes they develop, and not the microorganisms. These processes can later be adapted to different clients and situations. Most or all of the knowledge created remains property of Aguamarina. There are some contradictions on whether mining companies have tried or not to keep intellectual property developed with Aguamarina for themselves. But the fact is that developing technologies is not the mining companies' business –as they have explicitly stated– and that sometimes solving a particular problem can be so important that who owns the solution is not that relevant. Nevertheless, mining companies might sometimes retain certain privileges in the use of the patented technologies.

In a different but important positive economic development, Aguamarina is creating demand for advanced human capital. Because of demonstration effects, this demand will hopefully be compounded by other companies that follow their example.

Aguamarina shows that even while there are many challenges, it is possible to develop innovative and environmentally friendly solutions for the mining sector, and technological start-ups can be successful doing this. Mining companies are willing to try new technologies, and there are different policy instruments to support this kind of applied research firms. Of course that many more things are needed, including a strong entrepreneur that can convince her team and a group of clients of her view and capabilities, but the conditions for successful technological entrepreneurship exist. Across this case report we discuss the factors that appear as key for explaining Aguamarina's success, that hopefully will be replicated by other firms.

7.3 Environmental

One of the distinguishing features of this company is that all of their technologies are "green", they do not have negative environmental outcomes, and some of their technologies are actually used to reduce some forms of pollution (like biorremediation or dust control).

The bioleaching process in particular is less environmentally problematic than traditional lixiviation or flotation, but it cannot be used on all minerals (notably not in chalcopyrite), and is currently used only to treat marginal resources still available after the traditional processes.

Dust control has the double benefit of reducing dust pollution in nearby communities, and reducing fresh water usage by mining companies. As stated before, the need for dust watering can go down from three times a day to once a week.

7.4 Social

As in the other cases, the improved social outcomes are not many besides those related to pollution: dust pollution reduction, reduced water consumption, and possibly reduced pollution in other processes through different technologies. In sum, they are an important contribution to a less pollutant mining sector.

Another remarkable thing about Aguamarina is its share of women employees. While not explicitly practicing positive discrimination, the company's open culture and working environment has lead women and handicapped researchers to realize their potential at the company. This is not the norm for Chilean companies, which usually discriminate these groups in a negative way.

8. Q4: In which ways has the availability of internet and/or other ICT technologies contributed to the development of the alternative?

The technologies that have been key for Aguamarina are related to biotechnology and microbiology, although ICTs have played a supporting role in some specific areas.

Aguamarina has analyzed samples sent from the United States, Brazil, and Peru, and results have been sent through the Internet. The internet has been important to be connected to the rest of the world as in any industry. In this case this has been relevant for example to discuss results with experts at universities abroad, or to be quickly aware of the latest scientific research.

But a great part of their success, and a difference with other suppliers, is their availability and willingness to visit clients on site: face-to-face interaction has been much more relevant than electronic communication.

9. Q5: Which are the main barriers that block the diffusion of the alternative?

For the barriers that are manifest in this case, we will comment on them in two levels: the specific case Aguamarina, and its relationship with the general concept of innovative technological suppliers in the mining sector. The reason for this is that we are interested in the diffusion of this type of firm and research. While we focus on particular cases to study how path-creating alternatives develop, the broader idea of path-creation is to develop dynamic comparative advantages starting from the experience in natural resources.

9.1 Capabilities

In the particular case of Aguamarina, excessive success is a potential problem. As highlighted by one of their mining counterparts, Aguamarina *"is comprehensive and takes all challenges, without being the classic firm that takes all challenges and in the end drowns and make no advances"*. But they are currently at a key stage, with many pilot tests, and if all succeed they might have problems to keep delivering quick results as they have been doing up to now.

Clients also expect an even deeper work with them, with Aguamarina hiring more engineers and having them permanently on site. They do not have all the required capabilities to get from their ideas to actual pilot tests of them. Nevertheless, Aguamarina is way ahead of other (potential) suppliers in this respect. Knowledge-related transaction costs are in general a barrier that complicates the development of innovative product between technology suppliers and mining companies. Although this is related to the lack of capabilities to do applied research in general, it is a different problem, which commonly acts as a limiting factor for *path-creating* alternatives.

Regarding the Cluster Program, there are suppliers that instead of taking advantage of the opportunity to receive support to increase their competitiveness and become "world-class", find it hard to comply with its requirements and prefer not to participate in it. The relative ease to make money with the mining sector in Chile might discourage more effort by suppliers, who turn to indulgence instead of thinking on improving and exporting their products and services. This problem is not only of capabilities but might also be cultural, not enough companies are thinking globally or daring to take the necessary steps for internationalization.

In terms of business capabilities, Aguamarina is way ahead of most firms in Chile: *"What is routine, normal for us, is not common, especially in mining-related startups"*. The academic rigor of a researcher in natural sciences has been put to work on the realm of business planning and strategy, with very positive results. Most other firms instead, *"do not know how to price their products, do not have a global vision, and do not visualize the real value of what they do"*. Formal studies on innovation, business issues and technology management as well as support from organizations like Endeavor, might help raising this obstacle.

9.2 Economics

In this case economic or financial restrictions do not seem important, all the opposite, this is a case of successfully securing funding from different types of sources. The only problem mentioned were the long times that mining companies take to issue invoices and then to make payments effective, up to several months. Having several sources for financial resources, including government subsidies, venture capital, and private projects, is important to have a relatively secure flow of funds to keep the firm up and running. However, what this case shows is that when things are done properly, funds can be obtained.

What is an economic obstacle is that there are not enough entrepreneurs and firms demanding researchers to conduct applied work. According to what we were told by some young researchers, their peers are interested in that kind of fast-paced but rewarding work, but most end up in academia because there is no demand for them outside of it. As discussed in section 3, biotechnology in Chile has grown significantly in the last years, but there is still not enough "critical mass" of firms.

There were also mentions to some firms being "paralyzed" by a sort of public innovation funds assistencialism; they expect to work constantly on government funds, and do not go out there to look for other sources of funding for their projects.

9.3 Vested interests

The lack of significant changes in the core aspects of the mining process is associated to technical complexity and conservativeness from mining companies that do not want to put production levels at risk. But vested interests from technology providers do not seem to be important. In fact, if there is a technology that would improve certain aspects, and with certainty would not affect production, mining companies will adopt it. Particularly, *"mining companies are always open to clean technologies that improve production"*.

There might be vested interests in currently favoured suppliers, or universities that have been performing certain biological analysis. But mining companies are careful with suppliers that try to obtain large short term profits from them, and do not hesitate on switching when they see that their current suppliers are providing them with expensive and low quality services. But for this it is important that the new suppliers are able to demonstrate their capabilities and show that they can do better.

On the other hand, rich collaborative relationships between mining companies and suppliers, like those that Aguamarina tries to build, can in fact result in important sunk investments for companies, and could later turn them into the incumbents with the vested interests themselves.

What could indirectly be a problem of vested interests might come from the academic profession, which wants to keep or increase their resources and their control over them, is

well organized, and has lobbying capacity. They can influence national budget in their favor, in detriment of nascent firms that need support to start doing applied research.

9.4 Politics and power

The only barrier that seems related to the distribution of power is the differences in organizational cultures in mining companies. When responsibilities are more widely distributed, and most positions –including executive and technical ones– are in the hands of empowered young –or at least open to change– individuals, firms are more agile and ready to collaborate with suppliers and try out innovative technologies.

9.5 Infrastructure

While not strictly infrastructure, an important problem is the tendency of companies to move to Santiago as they are successful. One of the key factors in Aguamarina's results has been being based at Antofagasta, close to their clients, ready to visit them at once when they need it. On the other hand, also because of the centralization that dominates the national economy, there are some logistic problems for scientific companies that want to be away from Santiago, for example some inputs need to be brought in trucks from Santiago, and laboratory equipment needs to be sent to Santiago for repairs.

9.6 Institutions

Incentive design *inside* mining companies might be a problem to fruitful collaboration with suppliers to develop technology.

Successful innovations need collaboration, and in the mining sector this is usually between mining companies and suppliers. But while for the suppliers developing technologies might be part of their core business and have important incentives to do it, it is not the same for mining companies. Their core business is to produce minerals, and everyone inside the companies has objectives and is evaluated according to production levels. Therefore, for employees of the mining company, dedicating time to other things (i.e. helping suppliers develop a new technology) might act against their best interest. Even if these technologies could eventually improve their results, they would be assuming a disproportionate amount of the risk associated to the innovation (vis-à-vis the company).

In terms of national institutions, such as labour market, regulations, and government incentives, Aguamarina does not complain, and in fact state that they have received much public support.

9.7 Cultural

As discussed in section 6.6, Aguamarina has characterized itself for appreciating applied work, business ideas, and closeness with clients. None of these are the norm across researchers. It is necessary to have more scientists with those ideas, as well as entrepreneurs that create firms which follow a similar philosophy.

Another problem is the centralization of the Chilean economy, which might be blamed for the relative importance that suppliers give to being in Santiago compared to being close to the problems. And as discussed in section 9.1, another cultural problem is that most suppliers are not thinking, much less acting, globally.

The role of younger professionals and the relationships that can be established[7] seem to be important characteristics of this case. The lack of these might be an important limiting factor in other cases.

On the side of mining companies, they need to fully embrace the discourse of collaborating with suppliers to develop technologies, and really invest time and resources in this, something that not all companies are doing.

10. Summary

In this report, we covered our main research questions for the case study of Aguamarina, a biotechnology company that has been developing innovative solutions for different challenges faced by copper mining companies. Interested in its experience as a successful path-creating alternative, we discussed all of the project's questions in terms of this particular company, but we also related them to what could happen with similar alternatives.

In terms of its diffusion, Aguamarina's networking is remarkable, especially because the company has been able to tap on the right sources and develop rich relationships with different types of actors that have been key to its success. The company has worked with most large mining groups, has very high level global academic connections, as well as business contacts that have helped them travel through this road. The future looks bright for the company, with several pilot operations showing good results, and possibilities to export their technologies and applying them in other mining sectors or completely different ones, like biofuels. For innovative technology suppliers in general, expectations are also good, with Codelco and the Chilean government joining BHP-Billiton in their effort to promote the development of "World Class" suppliers for the sector. In terms of learning, three complementary areas have been important to explain this company's results: science, industry, and business. Scientific understanding is key to their work, but it must be complemented with an engineering-like understanding of the day-to-day problems, and they must act more in an engineering than academic way, to deliver quick and effective solutions. Learning through trial-and-error has been very important, but the scientific world is still an important source of knowledge and ideas. There is a complicated issue associated to knowledge-related transaction costs: how much the company must increase the scope of its knowledge base towards more engineering and applied work, as clients demand. At the same

[7] This is described in detail in Section 6.6.

time, learning about business and technology management has been an important aspect of this story, allowing the company to evolve successfully through different stages. The learning of individual employees is also relevant, as they could eventually adapt it to do applied work on other economic sectors or in competing companies. Government support has been an important source of funding for some of their projects, and the company has also made use of a subsidy to hire researchers in firms.

There are two guiding principles behind this case: for mining companies, improving production without worsening other outcomes. For Aguamarina, it is the motivation of young scientists that want to do applied work that has an impact on industry. To achieve this, they have followed the principle of *"understanding the pain"* faced by their clients, to provide appropriate solutions. Aguamarina started because of the business potential around bioleaching services –particularly working on technologies complementary to those developed by mining companies– but has expanded to other areas where biotechnology can serve the mining process, and that had not been explored before. The specialization in the mining sector helps them develop better solutions, but the technologies and knowledge developed will certainly be applied on other areas of the economy. In terms of industrial structure, more than Aguamarina, it is interesting the role that could be played by the Cluster Program, of which Aguamarina has benefited, both with support to become "World Class" and with a contract to develop a technology in close collaboration with a mining company. Heterogeneity in organizational cultures even across mines operated by the same groups is also something to take into account, it shows that any generalization about the culture of the sector should be considered carefully. In this case we see an agile and flexible technology supplier that has managed to establish very rich collaboration relationships with some mining companies, something that is not the norm in the sector. As discussed regarding learning processes, three kinds of knowledge have been important: scientific knowledge on microbiology (the company has even sponsored some people's PhD studies), applied knowledge on mining problems (obtained through a close collaboration with clients), and understanding of business issues and technology management (that comes from formal studies and consultancies from experts). Most entities that attempt to do "hi-tech" are not savvy in the last two, which have been key for Aguamarina. Suppliers are especially lacking knowledge on management and business issues. Finally, what is interesting in terms of culture and values, is the relevance given by researchers to applied work (even mentioned by some as *"their first real job"*), and the importance of establishing a new kind of relationship between mining companies and suppliers, a more fluent and informal one, where the company can listen to suppliers, and suppliers really want to build long term, "win-win" relationships with mining companies. These relationships seem to be more likely to occur when younger professionals are involved.

From the perspective of mining companies, the technologies developed by Aguamarina can improve their production levels, and sometimes do it while reducing different types of pollution at the same time. There are no negative aspects for companies, only positive ones. In terms of social improvements, besides Aguamarina's positive work environment for usually discriminated minorities, the social benefits are indirect, and associated to the reduction of dust and other forms of pollution. Environmental improvements can be significant, through,

for example, the reduction of dust pollution and water usage, or an increased reliance on less pollutant technologies, like bioleaching. But where there is more potential for improved outcomes is the economic realm, as should be expected from a *path-creating* alternative. Aguamarina is a clear example of biotechnology developed to solve problems of natural resource-based industries. In Chile, there were successful examples of biotechnological firms, but not particularly in copper, where the technology was circumscribed to bioleaching. The patented technologies developed by Aguamarina can be exported to other copper producers, adapted to other mining industries, and even migrated to unrelated ones, such as biofuels, where there are already some interesting developments. The potential of biotechnology as a "general purpose technology" is something that can be easily confirmed. At the same time, the company is educating a new generation of microbiological scientists, in a culture of working closely with the industry to solve their problems. And besides the hypothetical possibility of these researchers starting up new companies, cases like Aguamarina can produce strong demonstration effects and promote the development of more applied research firms, especially if the company is deeply involved in networking and diffusion at a regional, national and international level, as it is. And a notable fact about all of these economic improvements, is that they are *not* associated to negative, but to *positive environmental outcomes*.

ICTs have been important for Aguamarina's international connections, including the discussion of scientific results and sending the results of laboratory analysis performed for international clients. But the face-to-face relationship with their mining clients is much more important for understanding their success.

Barriers to diffusion were discussed both for Aguamarina in particular and for similar companies in general. For Aguamarina, there is a risk of *too much success*, and not being able to respond appropriately if all of their current projects have successful results. Mining companies would also appreciate that Aguamarina could hire more engineers to rely less on them for certain things. For technology suppliers in general, more of them should take the challenge of the Cluster Program, and more of them should care about technology management, strategic planning and internationalization strategies for their firms. In terms of economic barriers, Aguamarina is an example that, from different sources, funding for this kind of work can be secured. What are missing are more entrepreneurs that follow, to achieve a critical mass of biotechnological firms. Vested interests do not seem to be a problem, as mining companies act in a pretty rational way and switch suppliers if that will be good for them. On the other hand, this could be more difficult when they have had a significant investment in time and money with a particular supplier, as a richer relationship cannot be simply acquired from the market, so firms like Aguamarina may, hypothetically, end up representing vested interests. What could be dangerous vested interests are those of the academic profession and their lobbying to tilt public funding towards basic science and away from applied research. Another relevant aspect is the design of incentives inside mining companies, so that people involved in the operations do engage in productive collaboration with suppliers. Regarding cultural barriers, some of the characteristics of Aguamarina that have been important for their results, and that are not always shared by other suppliers, are staying in Antofagasta instead of going to Santiago, really appreciating applied work and

making an effort to understand their clients and their problems, as well as giving real importance to business planning and technology management. The role of young professionals and more fluent and informal relationships between companies also appear to be important.

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