PERSPECTIVE

The role of productivity and innovation in periods of low prices in the copper mining industry

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GEM

Paving the Way for the Future of Mining

INDEX

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INTRODUCTION

The fall in copper prices poses a series of challenges for the mining industry.

In order to reduce the impact on margins, mining companies are focusing their efforts on reducing their costs. However, marginal operations are often forced to close, while others lower their production levels.

In this new Perspective, we analyze the characteristics of those mining companies that manage to survive the fall in prices and what are the challenges in these market circumstances.

This is especially relevant, since different economists and institutions such as the International Monetary Fund (IMF, 2022) foresee a significant probability of a world recession in the short term (2023), which would generate a negative shock in the demand for different commodities, including copper, putting downward pressure on their prices (Bloomberg, 2022; Hellenic Shipping News, 2022).

The price of copper, like other mineral commodities, has historically experienced different trends, which are associated with market fluctuations and structural breakdowns (such as economic crises, wars, pandemics, etc.), which, however, have always been dominated according to the so-called market fundamentals (supply and demand).

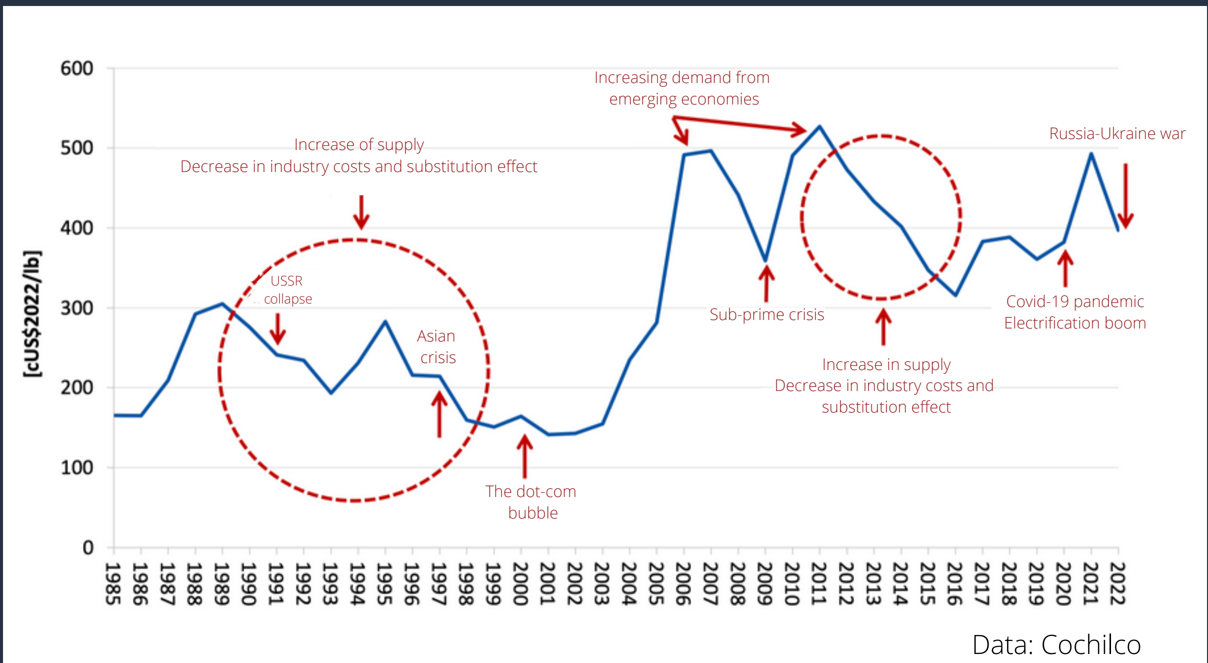
A look at the historical evolution of the price series of this commodity shows that the high volatility of prices has been marked by different historical events or facts that have affected the supply and demand balance of this industry and consequently, its price. The historical review of the 1985-2022 period indicates that eight milestones have significantly marked the copper market in the period in the following order of time:

(1) Decline in industry costs and substitution effect, (2) Collapse of the Soviet Union (USSR), (3) Increase in supply (incorporation of mega-deposits), (4) Asian Crisis and Dot Com Bubble Crisis, (5) Increase in demand from emerging economies (particularly China), (6) Subprime Crisis, (7) Covid-19 Pandemic and, finally (8) Rise of electrification (including electromobility).

Figure 1 shows the evolution of the average annual copper price recorded on the London Metal Exchange on a real basis (in 2022 currency[1]), together with the 8 milestones previously mentioned.

It is worth noting the significant drop in the copper price observed in the year 2022, which is 19% decrease in relation to the average annual price in 2021.

Figure 1 - Structural breaks in copper prices, 1985- 2022



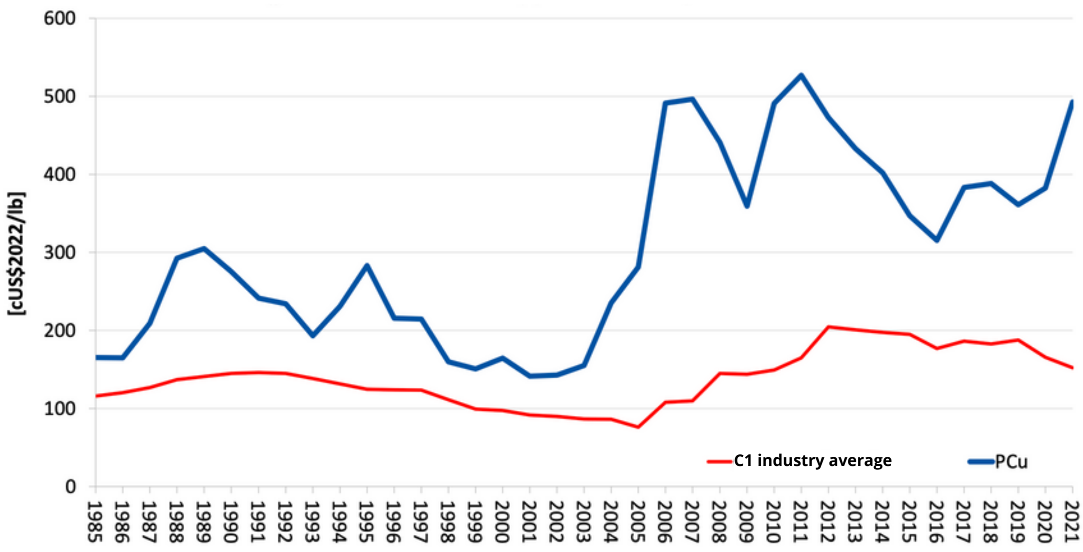
When the price of copper falls, mining companies typically adopt different measures to adjust their costs. In this way, the industry seeks to minimize the impact on margins that the reduction in revenues would imply.

These measures typically include:
(1) reduction of exploration activities and expenditures, (2) closure of high-cost operations, (3) discontinuation of contracts, (4) suspension of innovation projects, among others.

[1] The U.S. Producer Price Index, All Commodities Index (PPI), is used as a deflator.

Figure 2 shows the historical evolution of the C1 cost (operating cost) and its relationship with the price of copper in the period 1985 - 2021.

Figure 2 - Relationship between C1 and the price of copper, 1985 - 2021



Data: Cochilco, GEM

Between the C1 cost series and the copper price, on an annual scale between 1985 and 2021, there is a positive correlation of 0.60 (if 1 year of lag in costs is considered, then the correlation rises to 0.73 and if 2 years are considered it rises to 0.82). However, the relationship between both series is not symmetrical, that is, the behavior of costs depends on whether the price series increases or decreases. According to a GEM study, the cost-price elasticity is 14% when the price of copper rises and 30% when it falls. In addition, the period in which costs are adjusted is longer in the case of a price increase, taking 4.8 years to adjust, while only 2.6 years in the case of a price decrease. Copper production also has a positive correlation of 0.57 with the price of the commodity, i.e., in general terms, the higher the price, the higher the production, given the incentive of the former.

After having introduced the behavior of the price and the relation that costs have with it, one might ask what are those practices that allow mines to continue operating without having to cut production? This is relevant since, on the one hand, there are mines that are forced to close and, on the other hand, once the price goes up again if there was a restriction in capacity then the benefits of the price increase would not be captured. In order to understand what allows mines to survive, we will analyze the conclusions obtained by Tilton (2001).

Tilton examines the crisis in the U.S. copper mining industry between 1975 and 1990 [2], and finds that while a significant number of mines closed or decreased production, others maintained or even increased production.

He concludes that the key to the survival of these mines lies in labor productivity. Those mines with high productivity at the beginning of the crisis, and more importantly, those that significantly increased their productivity during the crisis, were more likely to survive and even increase their production in the long term.

In this regard, the companies that survived made great efforts, and the technological changes, innovation and severe cost reduction led to a fivefold labor productivity increase in the U.S. copper mining industry, during the period 1980 - 2003[3] (Aydin, 2018).

Productivity affects the margin, since it has a direct impact on the variable cost. The higher the productivity, the lower the variable cost.

[2] Until the late 1970s, the price of copper was mainly referred to U.S. producers, who established copper prices according to annual contracts, which were adjusted on a quarterly basis. However, (1) the nationalization of deposits in South America and Africa, (2) the decentralization of the copper market due to the entry of oil companies seeking to diversify their commodity portfolio to hedge against oil price declines and (3) the end of the price mechanism as U.S. manufacturers began to prefer imports over domestic production, provoked a crisis in the U.S. copper industry. In 1974 the price was 462 [cUS$2022/lb], while in 1984 the price reached a low of 160 [cUS$2022/lb], the lowest value since 1935 (134 [cUS$2022/lb]) up to the present moment.

[3] In 1989 labor productivity (measured in tons per man hour) was more than 3 times the labor productivity in 1980.

THE ROLE OF PRODUCTIVITY

Productivity is an economic measure that accounts for the ratio of output between a good or service and some operational variable. Thus, labor productivity relates the amount of labor required for the production of a good.

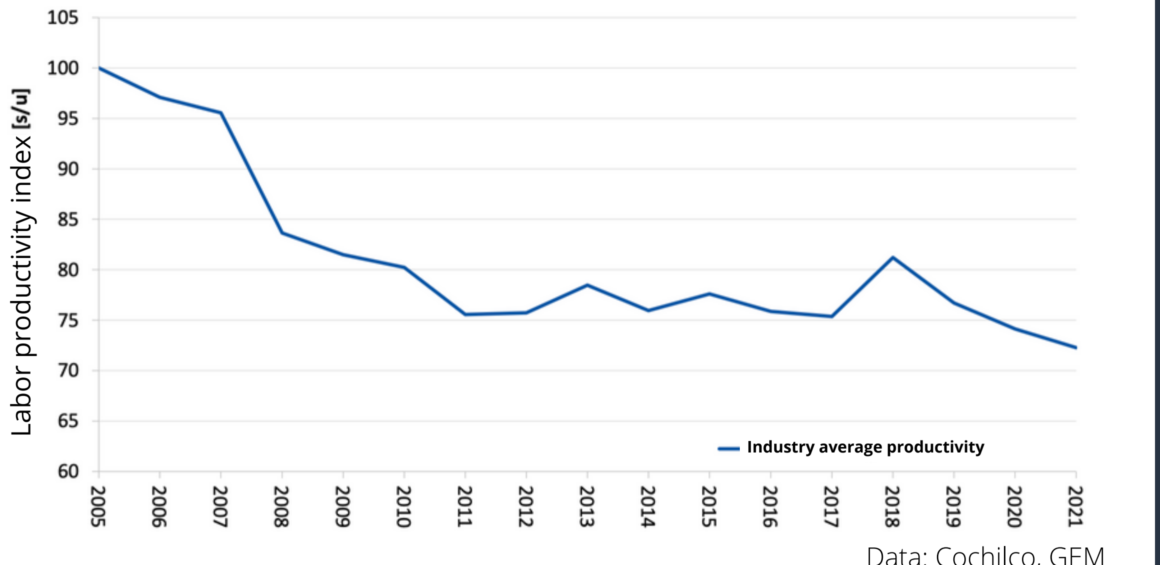
In terms of this report, labor productivity can be understood as the quotient between the production of fine copper and the amount of man-hours required for this production.

The emphasis in this Perspective is on labor productivity; however, other productivity indicators are mentioned, specifically total factor productivity (TFP).

The latter is related not only to labor, but to all the factors involved in production.

In the case of copper mining, both labor productivity and total factor productivity show similar behavior [4](Cochilco, 2016; Solminihac, 2018). In order to make this point explicit, **Figure 3** below shows the historical behavior of labor productivity in copper mining, particularly in the case of Chile[5].

Figure 3 - Evolution of labor productivity in copper mining in Chile, 2005 - 2021.



Data: Cochilco, GEM

4 In terms of historical evolution.

5 Calculated by Cochilco based on information from Codelco and the main private mining companies. It is calculated as the production of fine copper from the mine over the average mine's own workforce.

Figure 3 shows a downward trend, with 95% statistical confidence, for the period 2005 - 2021. In terms of the annual series, there is a slight negative correlation of -1% between the price of copper and productivity. This correlation increases to -4% when considering a lag of one year, and to -20% when considering two years of lag.

The latter suggests that a fall in price generates changes in labor productivity to a lesser extent one year later and these changes are more pronounced two years later.

Different authors have studied the behavior of productivity in the Chilean copper industry in terms of its historical evolution:

- Garcia *et al.* (2001): evaluate the labor productivity in Chile in the 1980s and 1990s and conclude that it increased in this period due to (1) discovery and development of new mines and (2) innovation and technological change. Regarding reserves, this study indicates that the discovery of deposits and their exploitation allows to increase reserves, but that it is technological change and innovation that allow maintaining these reserves over time. As an example, Andina, El Teniente, Salvador and Chuquicamata are mines that increased their labor productivity in the two decades of the study.

- Jara *et al.* (2010): analyze the period 1992 - 2009, and conclude that labor productivity has played a fundamental role in the growth of copper production in the country. This study also shows that improvements in productivity are not only explained by better quality deposits and/or operational factors, but also by specific efforts at company and industry level in innovation (management and technology).

- Cochilco (2016): measures the total factor productivity in the period 2000 - 2014 and concludes that it shows a negative trend, both in Chile and in the world. It attributes one of the factors responsible for this fall to the "super cycle" of prices, fundamentally a consequence of the demand shock from China. It is concluded that the end of high prices would require mining to refocus on cost control and productivity improvement. To this end, it is necessary to adopt both public and private measures to boost productivity.

- Urrutia *et al*. (2017): account for a 1% annual decrease in total factor productivity from 2000 to 2014, accumulating a 14% decrease in that period for copper mining (because of endogenous and exogenous factors to the operation). They also report a generalized decrease in labor productivity in the period, placing domestic operations below foreign operations in terms of labor productivity. Additionally, the authors report the existing gap between medium-sized and large mining in terms of productivity, stating that this gap has been widening over time, with medium-sized mining lagging behind, whose productivity is falling faster than that of large mining.

- Solminihac *et al.* (2018): conclude that between 1999 - 2010 labor productivity has shown a downward trend, falling by an average of 42%. They explain this fall in labor productivity and total factor productivity, due to four determining factors: real wages, electricity price, copper price and ore grade.

- Villena and Greve (2018): show that the industry total factor productivity fell in the period 1985 - 2015. They attribute 15% of this fall to the decrease in grades, which is an exogenous variable opposed to technological change.

The relationship between price and productivity depends on (1) the time horizon to be evaluated and (2) the price cycle. According to Tilton (2014): (1) in the short term, in a price boom scenario, productivity is under downward pressure, because the focus of the miners will be on producing as much as possible, neglecting the efficiency of the operation; (2) on the contrary, in the short term, in a weak price scenario, productivity increases, which in the medium term can further accentuate the fall in prices by reducing operating cost; (3) in the long term, the relationship continues to be negative, *i.e.*, increases in price would imply falls in productivity and, on the contrary, falls in price would imply increases in productivity.

It should be noted that in the long run the relationship is bidirectional, since productivity would also affect price.

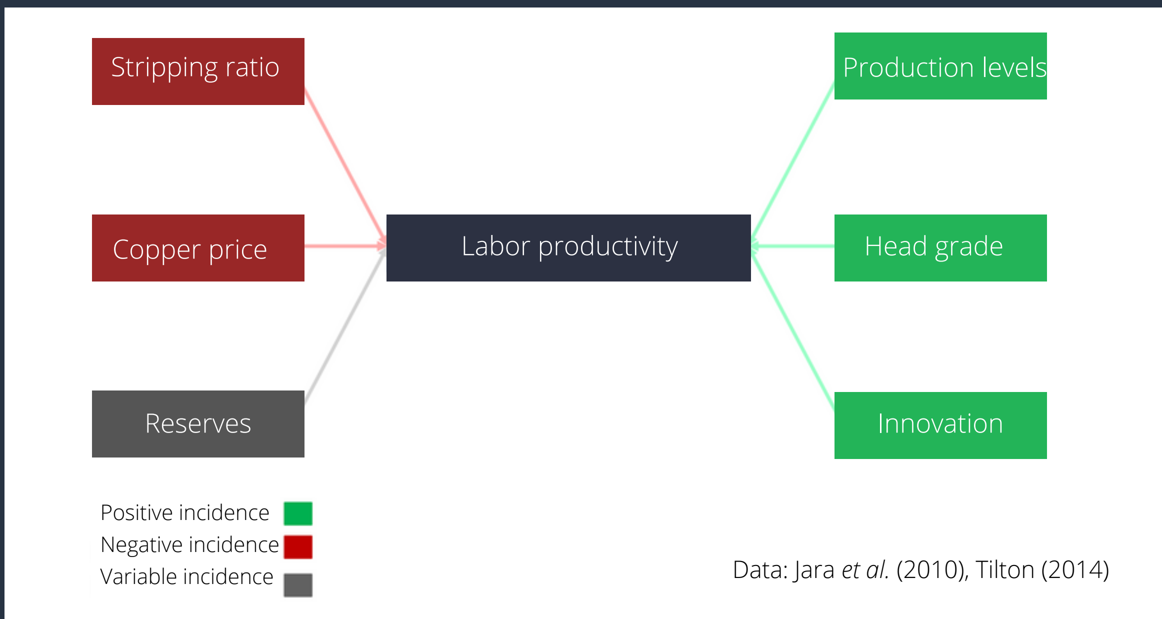
Higher productivity due, for example, to some significant technological breakthrough at the industry level, would reduce operating cost, putting downward pressure on price. Otherwise, if technical advances do not prevent resource depletion and productivity falls, the price will be on upward pressure in the long term.

As noted above, price is one of the variables with the greatest impact on productivity[6].

Mining companies in the copper industry are price takers; therefore, they cannot adjust their productivity by adjusting the price. Given the above, the question arises as to what other variables affect productivity and which ones offer opportunities for the future.

Based on the literature review and essentially on Jara *et al*. (2010) and Tilton (2014), **Figure 4** shows the main variables affecting labor productivity.

Figure 4 - Main variables affecting labor productivity



Data: Jara *et al.* (2010), Tilton (2014)

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[6] Tilton (2014), blames the demand shock from emerging countries such as China (and therefore the increase in the copper price) and not the depletion of resources (drop in grades), as responsible for the drop in productivity in the industry. On the other hand, he argues that mining companies have traditionally avoided resource depletion thanks to technological improvements, which has historically controlled the price of copper.

In addition to the factors shown in **Figure 4,** other factors at the operational level have been pointed out, such as metallurgical recovery with a positive impact on productivity (Cochilco, 2016), and others at the market level such as real wages (correlated with the price of copper) and the price of electricity, with a negative impact on productivity (Solminihac, 2018).

It should be noted that the role of reserves is not entirely clear, as it would not necessarily apply in the same way for all mining companies.

Because, typically, when there is a price shock, mining companies readjust their reserves according to the new price outlook, which makes historical analysis difficult (Jara *et al*., 2010).

However, mines with larger reserves and a higher LOM (Life of Mine) tend to face greater incentives to innovate and invest in technology. Thus, reserves would be expected to have more of a positive effect on productivity.

Once these variables have been analyzed, it is necessary to ask what the industry can do to increase its productivity. Garcia *et al*. (2001), Jara *et al.* (2010) and Tilton (2014) point to innovation as key in this regard. Since it is not possible to choose the price or change the qualities of the deposit (on which operational factors depend), innovation is precisely the variable on which efforts should be focused.

In the above example of the U.S. industry crisis, innovation was a key factor in the industry's survival. The incorporation of larger trucks, SX - EW processing, among others, stand out among the main innovations in this period.

These innovations allowed the industry to increase its productivity. To better understand what are the recent trends in mining innovation, the following section develops this idea, identifying those opportunities for the industry to increase its productivity[7].

[7] It should be noted that much of the innovation effort is focused on productivity: innovation in mining aimed at increasing productivity concentrates the largest number of scientific articles published in terms of innovation, only behind innovation to increase safety and ahead of innovation to increase sustainability, efficiency, human capital, cost reduction, among others (Gruenhagen and Parker, 2020).

INNOVATION, A KEY TO THE FUTURE OF MINING

In recent years, academia and industry have begun to coin the term "Industrial Revolution 4.0" to refer to the innovation process happening in the industry in terms of: (1) expansion of communication and wireless networks, (2) deployment of robots and intelligent machines, (3) increased computing power at lower cost, and (4) development of big data analytics techniques.

Such changes are transforming the way goods are produced by increasing the level of productivity (Davies, 2015).

The mining industry is no stranger to this process and a significant part of the industry's innovation trends are aligned with this source of development (Daly *et al.*, 2020).

The question is the magnitude of the impact that this revolution would have on mining. Humphreys (2020) points out that unlike the evident impact on productivity that this revolution is having for other industries, or the impact that the second industrial revolution[8] had on mining productivity, the impact of the fourth revolution is not yet clear. The challenge for mining companies is therefore to capture the greatest potential that this revolution offers.

[8] The second industrial revolution refers to the process of technical and scientific progress that took place in the second half of the 19th century (mainly in the last quarter) and up to the beginning of World War I. The main advances in this period include electricity, internal combustion engines, oil refinement and the use of steel (Mohajan, 2020).

The fact that the magnitude of the impact of this revolution is not clear is essentially due to the capital-intensive nature of mining (in addition to the physical characteristics of the activity), which makes it an inertial industry, with a certain resistance to change (Humphreys, 2020).

Greater complexity in terms of the activity regulation and technological adoption only increase the inertial character of the activity by increasing the capital expenditure of projects (Radetzki, 2006).

The implications of the increase in these environmental, political and social restrictions not only affect investments, but also the costs of the operation [9] itself (Tilton, 2001). This, together with the fall in grades[10] (Olvera, 2021), the hardening of the rock as mines age, and the increase in their depth (Cochilco, 2020), make innovation imperative for mining.

In order to accelerate innovation, literature recognizes and recommends the following basic principles and practices that enable the development of an innovative ecosystem:

- Culture: Bryant (2015) recommends collaborating with world-class innovation leaders outside the mining ecosystem in order to accelerate changes towards an innovative culture. Based on the Australian mining industry's experience in innovation, the main values that companies should possess in terms of organizational culture are (1) risk tolerance, (2) creativity and (3) trust among stakeholders.

- Diversity: Boston Consulting Group [11] (2018) concludes that increased diversity in leadership teams at a multidimensional level (that is people with different backgrounds, gender, age, country of origin and experience in the industry or another industry) brings more and better innovation which is subsequently reflected in higher margins (on average more diverse companies have 9% higher EBIT margins than less diverse ones).

[9] According to Tilton (2001), the higher costs derived from greater restrictions are partly responsible for the crisis in the U.S. copper mining industry in the 1970s and 1980s, as U.S. mines became less competitive.

[10] It is productivity and exploration that precisely counteract resource depletion (Humphreys, 2020).

[11] More than 1,700 companies in various industries in both developed and developing countries were evaluated for this study.

- Collaboration: Sánchez and Hartlieb (2020) note the relevance of strengthening alliances between research centers and mining companies, in order to join efforts and capabilities. Regarding this point, Fundación Chile, a public-private organization whose purpose is to promote and create innovation in Chile's industries for the sake of sustainable development, suggests the promotion of open innovation initiatives that occur through the collaboration of key players in the mining ecosystem: suppliers, entrepreneurs, researchers, venture capitalists and other entities (Expande, 2019).

In addition to the above, it is of vital importance to recognize the main innovation trends in the worldwide mining industry. Among these, the following currently stand out (Sánchez and Hartlieb, 2020):

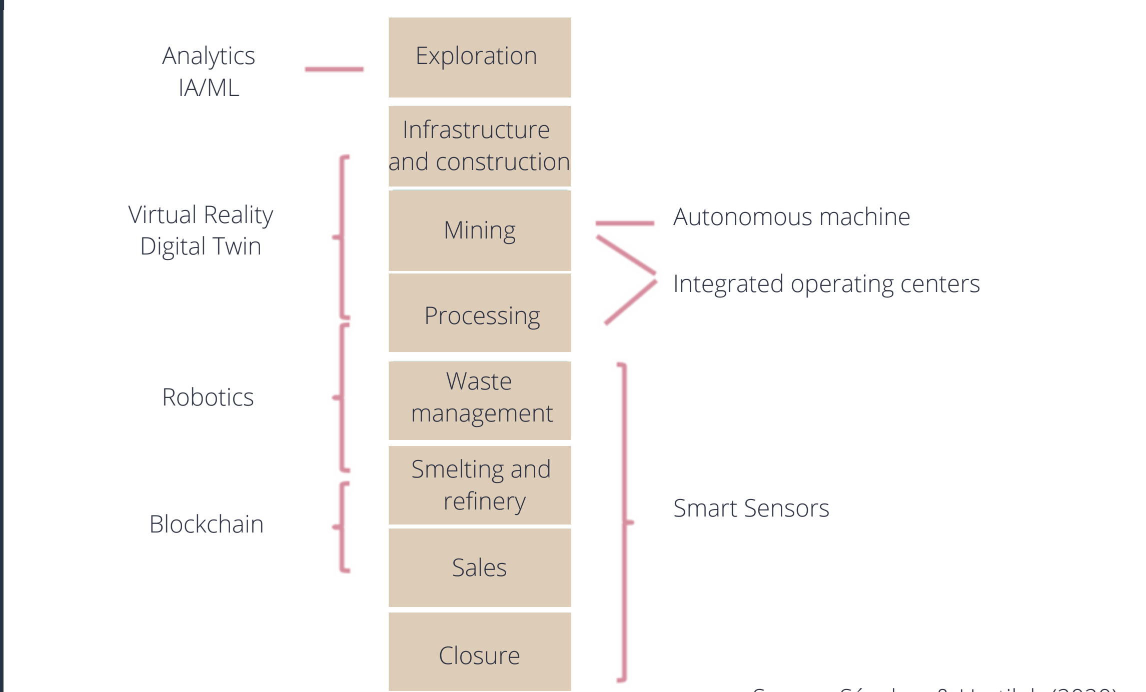
- Digital transformation: through the incorporation in the mining value chain of the "Industrial Revolution 4.0" tools, such as automation, robotics, internet of things, remote work operation, analytics, digital twins, smart sensors, blockchain, among others **(Figure 5)**. With a potential benefit estimated in 2017 by the World Economic Forum and Accenture of US$ 190 billion for the period 2016-2025, equivalent to approximately 9% of the industry's economic benefit, digital transformation stands out as one of the areas of greatest potential and value contribution for the mining business. However, its effective adoption and value creation requires changes in the structures of organizations to facilitate coordination and convergence between the different business units and thus guide the operation to a culture of continuous improvement.

- Electromobility: through the replacement of light vehicles and heavy machinery based on fossil fuels by electric-powered equipment such as trolleys, batteries, cables, hybrids or hydrogen, it offers more economical and environmentally friendly transportation alternatives.

- Continuous mining (CM): originating in coal mining, continuous mining and ore handling systems allow higher productivity levels, cost reductions and safer operating conditions. Due to the greater hardness of the rock, most metallic deposits require the use of drilling and blasting processes that prevent continuous operation. However, given its advantages, the innovation and development of continuous mining systems that go beyond coal mining (as is the case of some initiatives in iron ore or underground mining) is undoubtedly a focus of development that will probably gain relevance in the future.

- Heap leach (HL): associated with leaching and recovery of solutions directly at the ore site. This methodology aims to minimize the impact on the surroundings and avoid waste generation. Given its characteristics, it involves a lower operating cost and the recovery of lower grade leachable minerals that are not economically convenient to process by conventional leaching. Challenges in this line refer to improving the permeability of the rock and hydrogeological control in order to avoid groundwater contamination by seepage.

Figure 5 - Digital transformation technologies in the mining value chain



Source: Sánchez & Hartileb (2020)

Additionally, in recent years there have been advances in the study of primary sulfide leaching, in order to replace the pyrometallurgical process generally used for this type of sulfide with a hydrometallurgical process.

Different reagents have been studied that can be added to the heap leaching process to obtain higher recoveries, such as sodium chloride, organic compounds with thiocarbonyl groups (such as thiourea) and iodine compounds.

If this process is possible, it would increase productivity and reduce water consumption and the emission of atmospheric pollutants released compared to its metallurgical counterpart.

Among the technological development and innovation alternatives available to the industry, GEM stands out for the development of solutions based on the application of Machine Learning techniques for the identification of prospective areas and delineation of resources and geological anomalies, the use of predictive models based on real-time data capture, the evaluation of the implementation of autonomous truck technologies (which currently represent less than 1% of the world fleet and a technological adoption growth rate above 30%), electromobility alternatives, continuous mining and heap leach, including risk analysis and options, among others.

This is fundamental for the industry because as it has been extensively mentioned in this report, in terms of productivity, more and better deposits would counteract the depletion of resources and the eventual increase in costs associated with the aging of deposits.

CONCLUSION

The price of copper, like other mineral commodities, has historically experienced different trends and high volatility, trends associated with market variations and structural breaks. Copper price is down 19% from last year's average, and this decline is likely to be accentuated as a result of an eventual global recession.

In the face of a significant and sustained copper price decline, not all mines are able to sustain their production.

The purpose of this report was to evaluate what are the characteristics of the mines able to survive during a low price cycle, in terms of production, and what can be done to adopt these characteristics.

After a review of the literature based on downward price cycles and their impact on mining activity, it is concluded that labor productivity is a key variable in the survival of copper mines. Moreover, it follows that mines with high productivity at the onset of a price crisis, and more importantly mines with the ability to increase their productivity during the crisis, are more likely to maintain or increase their production levels.

In Chile, labor productivity has historically shown an increasing behavior until the end of the last century. However, since the 2000's and as a result of the commodity price super cycle triggered by the demand shock from emerging economies, productivity has adopted a negative trend.

In the context of low prices and with the aim of understanding how to reverse lower productivity, the variables that have the greatest impact on productivity are analyzed.

The main variables with a negative impact are: (1) the price of copper and (2) the stripping ratio. The main variables with a positive impact are: (1) production levels, (2) head grade and (3) innovation.

Innovation is the variable on which efforts should be focused. The reason being, in addition to the discovery of new resources, it is innovation that has historically been able to compensate for resource depletion.

In recent years, innovation in mining has been mainly oriented towards: (1) tools derived from the "Industrial Revolution 4.0" (2) electromobility (3) continuous mining, (4) heap leach and (5) leaching of primary sulfides.

The remaining challenge is to develop, generate and apply innovation, beyond the inertial industry paradigms.

In this way, the effect of resource depletion will be counteracted and mines will be prepared for low price cycles and thus be able to survive them.

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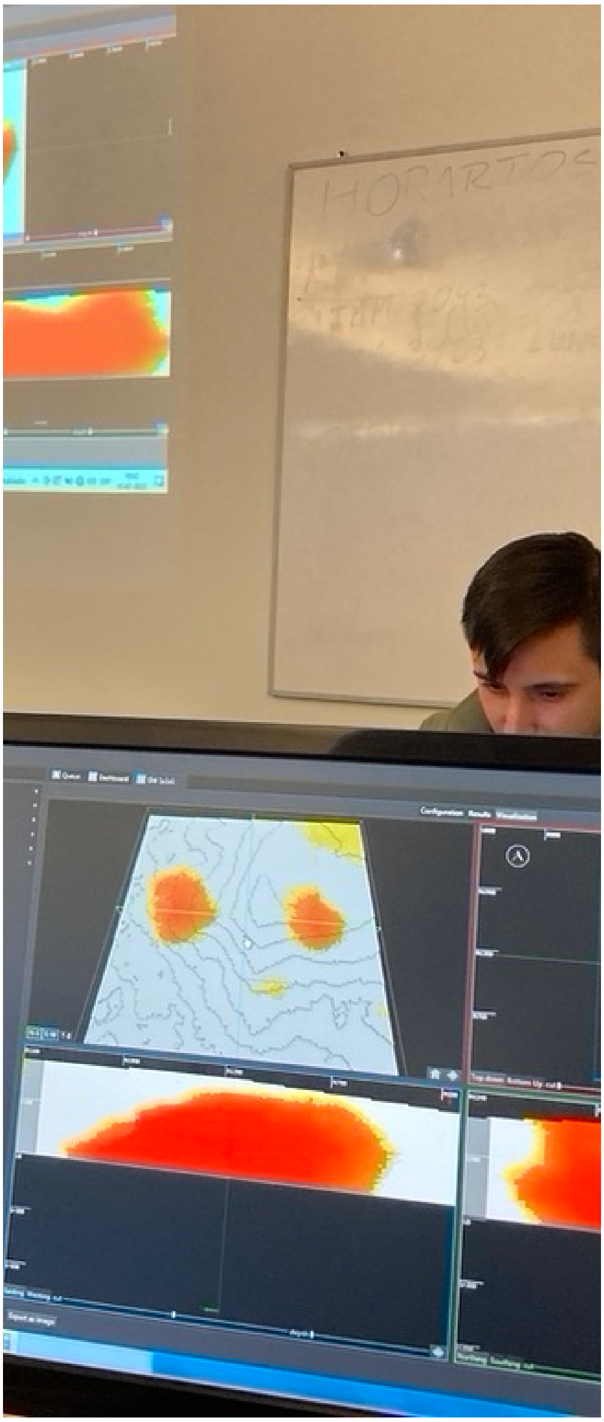
By constantly publishing new research papers, developing new software and artificial intelligence tools, GEM is the industry benchmark to provide you with a cutting-edge solution for each of the above mentioned innovations, "paving the way for the future of mining".



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