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Technology appropriation and technology transfer in the Brazilian mining sector

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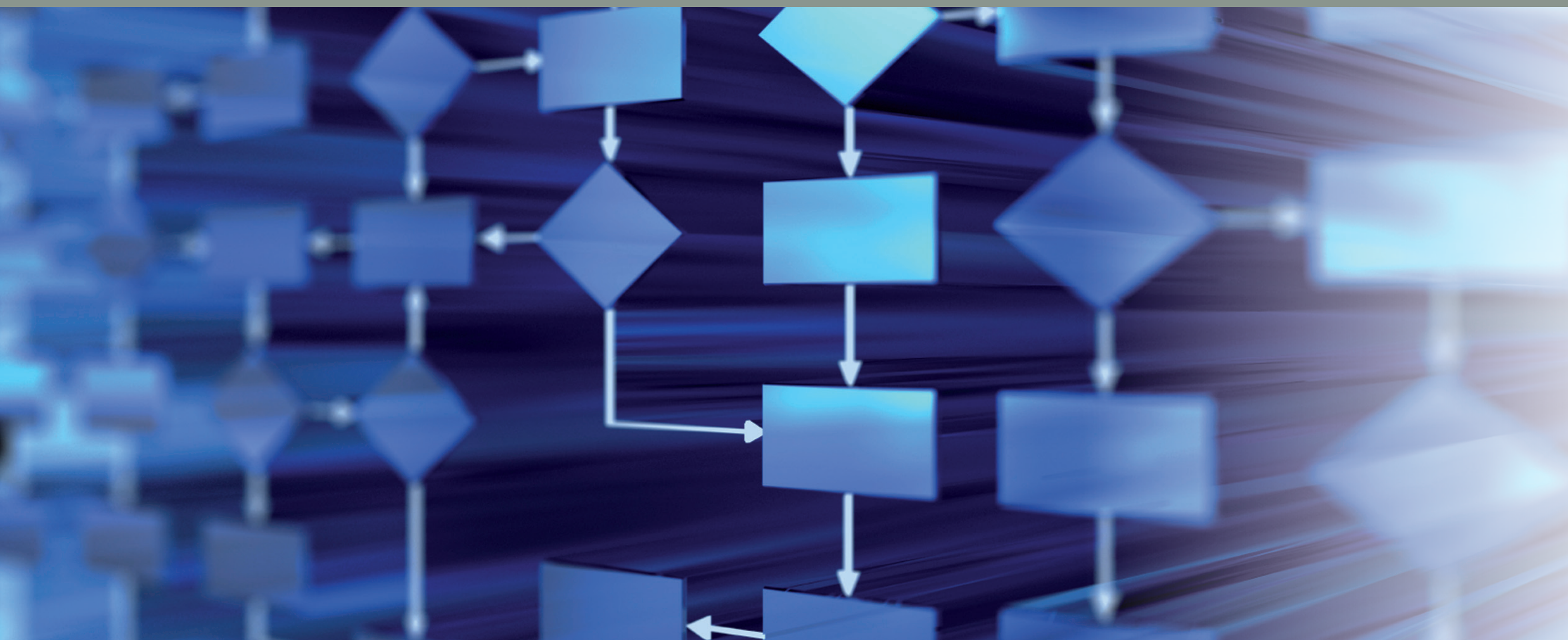

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Abstract

This paper focuses on the competitive dynamics, strategic challenges, technological needs and institutional innovation-promoting arrangements in Brazil's mining sector in order to identify the ways in which mining firms and mining equipment, technology and services suppliers (METS) handle innovation appropriation and technology transfer in the country. As the main sample consisted of resident and non-resident companies, the key technological areas of mining-related patenting in Brazil and the main patent stakeholders have been identified. The analysis of technology transfer among firms and to other mining industry stakeholders, mainly universities, drew on import contracts and highlighted the role played by foreign METS. A case study of Vale S.A., Brazil's largest mining enterprise, has been included, with emphasis on Vale's strategies to mitigate external challenges and to meet technological needs through innovation.

Keywords: Mining sector, Innovation, technology transfer, intellectual property

JEL codes: L72, L78, O31, Q55, L24, O14

Disclaimer

Introduction

Brazil is at the center of the policy debate on commodity-exporting, natural resource-intensive emerging economies and on whether natural resource-exploiting economies can generate innovation.

According to Furtado and Urias (2013), in answering these questions one must first consider the extent to which natural resources depend on deliberate human action, scientific knowledge and use of technologies to become actual “resources”. Arguably, for example, in order to become a good and have economic value, natural resources require a great deal of human intervention, involving a specific body of knowledge and techniques. Other resources are thus mobilized and used deliberately to tap those natural resources (Furtado and Urias, 2013).

It is counter-argued, however, that the tapping of natural resources is purely extractive and not linked to other resources and knowledge. Extraction therefore generates nothing – no new knowledge, technique or technological trajectory. Rather, existing techniques are used statically and non-transformatively. A natural resource economy is therefore not dynamic and related industries are not coordinated with other social and economic agents to generate innovation and, consequently, add value to the product (Furtado and Urias, 2013).

The debate has nonetheless gained momentum and has become less dichotomous since the 2000s, a period marked by the commodity boom and the growing contribution of natural resources to the gross domestic product (GDP) of countries whose economy is based on this type of activity. This suggests that economic development policies in natural resource-dependent countries should be strategically repositioned. It is now argued that dependence on natural resources is not the crux of the matter. Rather, the crux is whether the economy is sufficiently dynamic to promote intersectoral coordination and foster diversified output (Furtado and Urias, 2013; Figueiredo *et al*., 2017).

The importance of the role of the mineral sector in Brazil’s economy is beyond doubt. The mining sector accounted for 21 per cent of Brazil’s total exports in the first quarter of 2017 (Brazil Portal, 2017). In 2015, metallic minerals accounted for 76 per cent of total sales of Brazil’s mineral output (DNPM, 2016). The country’s balance of trade has been positive owing to the contribution of mineral exports over the past years, which attests to the positive role of the mining industry in national economic growth (Brazilian Mining Institute (IBRAM), 2015a).

While the mining sector is economically strategic to the country, mining output has an unbalancing effect on the economy, since it is concentrated both geographically and in the hands of few producers. This characteristic may be considered contradictory by those who attempt to describe and analyze Brazil’s mining activities, not only because of the country’s size, but also because of its geological diversity.

The “concentrated” pattern warrants the Vale S.A. case study. In 2015, the company and its subsidiaries ranked either first or second among the leading production companies in Brazil’s mining sector for various minerals (Table 1). Vale is outstandingly not only a producer, but also the operator of a large and sophisticated logistical system of railways and ports, which strongly distinguishes it from its competitors. Besides, it is Brazil’s leading iron ore producer and exporter and the country thus features in the global ranking of iron ore mining companies.

Table 1. Leading producing companies in Brazil (2015)

Top Producing Companies

Aluminium (Bauxite)		Copper	
Company	**Share (%) (*)**	**Company**	**Share (%) (*)**
MINERAÇÃO RIO DO NORTE	47,38	SALOBO METAIS	47,43
MINERAÇÃO PARAGOMINAS	33,19	VALE	26,32
ALCOA WORLD ALUMINA BRASIL	14,18	MINERAÇÃO MARACÁ INDPUSTRIA E COMÉRCIO	19,04
OTHER COMPANIES	5,25	OTHER COMPANIES	7,21
Tin		**Iron**	
Company	**Share (%) (*)**	Company	Share (%) (*)
MINERAÇÃO TABOCA	52,84	VALE	73,77
COOP MINERADORA DOS GARIMPEIROS DE ARIQUEMES	11,33	COMPANHIA SIDERÚRGICA NACIONAL	4,49
COOPERATIVA DE GARIMPEIROS DE SANTA CRUZ	19,04	SAMARCO MINERAÇÃO	3,98
OTHER COMPANIES	16,79	OTHER COMPANIES	17,76
Manganese		**Niobium**	
Company	**Share (%) (*)**	**Company**	**Share (%) (*)**
VALE MINA DO AZUL	53,75	ANGLO AMERICAN NIÓBIO BRASIL	51,17
MINERAÇÃO CORUMBAENSE REUNIDA	28,75	COMPANHIA MINERADORA DOPIRICLORO DE ARAXÁ	41,11
MINERAÇÃO BURITURAMA	14,08	MINERAÇÃO TABOCA	3,55
OTHER COMPANIES	3,42	OTHERS COMPANIES	4,17
Nickel		**Gold**	
Company	**Share (%) (*)**	**Company**	**Share (%) (*)**
ANGLO AMERICAN BRASIL	37,85	KINROSS BRASIL MINERAÇÃO	18,88
VALE	28,22	ANGLOAMERICAN ASHANTI CÓRREGO DO SÍTIO MINERAÇÃO	17,33
VOTORANTIM METAIS	20,47	SALOBO METAIS	8,43
OTHER COMPANIES	13,46	OTHER COMPANIES	55,36

(*) Share in the total value of the mineral production.

Source: *Brazil, National Department of Mineral Production (DNPM, 2015)*

Characteristics of Brazil's mining sector will be outlined in the sections below, with emphasis on its competitive dynamics, strategic challenges, technological needs and institutional innovation-promoting arrangements. The paper aims to describe patterns and distinctive features of Brazil's mining sector's technological agenda and proximity to or distance from global sector-specific innovative trends. To that end, answers will be provided to the following research questions:

- In which technological areas is the patent system being used by the mining sector in Brazil?
- How intensively do the mining equipment, technology and services suppliers (METS) use the patent system?
- How does Brazil's mining sector import technology? What role do the mining firms and METS play in this process?

Methodologically, two approaches were taken in reviewing innovation in Brazil's mining sector. Firstly, patents and technology import contracts for metallic minerals, involving mining companies and METS in Brazil, were analyzed. The analysis covered the 2000 to 2015 period and both resident and non-resident stakeholders. Secondly, a case study was conducted of Vale S.A., Brazil's largest mining company, with emphasis on its strategies to mitigate challenges and meet technological needs. This qualitative research exercise has sought to highlight and give examples of real-life experience.

1 Overview of Brazil's mining sector

From colonial times, the history of Brazil's development has always been linked to mining. As from the sixteenth century, the pioneers' search for precious metals and gems, especially gold, silver and diamonds, was a major means of opening up the country's territories to settlement, leading to the formation of villages and cities that bore witness to the discovery of new metallic mineral deposits, especially iron and manganese. The main regions thus explored were São Paulo, Minas Gerais, Goiás and Mato Grosso (in the south-eastern and central-western parts of the country).

Only a small amount of iron was produced artisanally in Brazil until the nineteenth century in some steelworks (known as Catalan forges) established in Minas Gerais to reduce iron ore directly and to produce iron and steel. Mineral-extracting tools were rudimentary and non-resistant, usually made of cast iron. Veins were worked manually, with pointers and, when necessary, home-made blasting powders were used. The ore was transported in wheelbarrows and, over longer distances, by animal-drawn wagons (Center for Management and Strategic Studies (CGEE), 2002). The most sophisticated mines were the Minas Gerais gold mines, in which techniques brought by English (probably from Cornwall) and German miners, trained in their home countries, were used (CGEE, 2002).

The country's industrialization began early in the twentieth century and was driven by aluminum, copper, lead, iron, manganese and tungsten metallurgy. The major mining enterprises were managed by foreigners during that period, owing primarily to the war effort, with scheelite being mined in the north-east by United States Vachang engineers and manganese at Lafaiete, in Minas Gerais, by the United States Steel Company (CGEE, 2002).

As from the 1950s, mining featured in the country's industrial diversification and, as minerals featured among the main exported commodities, it continued to do so in succeeding decades. Interestingly, relations between Brazilian miners and foreign METS were maintained throughout the sector's development. In 1950, for instance, the *Companhia Vale do Rio Doce* – today's Vale S.A. – began to modernize *Itabira* mines (Minas Gerais), relying on Brazilian and United States technicians and introducing drilling technologies and off-road trucks. As the company had established partnerships with foreign METS, it could call on assistance from consultants who used available technologies to resolve situations and problems in its mines (CGEE, 2002).

As shown in Table 2, Brazil is now one of the world's largest mineral producers, playing a major competitive role internationally. Its mineral resources are considerable, both in abundance and diversity, and it produces 72 minerals, of which 23 are metallic, 45 are non-metallic and four are energy minerals (IBRAM, 2015). Most minerals in Brazil are produced in open-pit mines, as there are few underground mines. Few operations are conducted on a scale higher than 400 t/d (CGEE, 2002).

Table 2. Brazilian ore production (2015)

Mineral	Tons	World Rank	World Share
Niobium	84,189	1	92.29%
Iron	275,589,840	3	17.52%
Bauxite (raw ore)	37,057,000	3	12.77%
Manganese	1,226,458	5	6.74%
Tin	18,824	6	5.87%
Nickel	89,302	9	4.24%
Gold(*)	83,127	12	2.69%
Copper	359,463	14	1.86%

Source: World Mining Data (2017). Notes: Figures concern the main reserves and not the total national reserves for each mineral. (*) Gold output in kg

The country outstandingly produces and markets metallic minerals such as iron, manganese, chromium, nickel, copper, tin, zinc, cobalt, lead, gold, silver, platinum, osmium, iridium, palladium, mercury, radium, uranium, scandium and niobium. Currently, 37 active prospection and exploitation[1] and extraction permits are registered at the National Department of Mineral Production (DNPM, 2016a).

Since 2005, growing world demand for minerals, in particular iron, bauxite, manganese and niobium ores, has boosted the value of Brazilian Mineral Production (PMB)[2], which has risen sharply in less than a decade[3]. In 2000, PMB values amounted to less than 10 billion US dollars, but rose to 53 billion US dollars in 2011. That "commodities boom" period gave way, however, to a major international foreign-market ore price crisis, triggered by falling growth rates in large global economies, especially China. The fall in the PMB (from 44 billion US dollars in 2013 to 24 billion US dollars in 2016) was due to a downturn in the international prices of Brazil's primary mineral commodities, namely gold, copper, nickel, zinc, bauxite and, in particular, iron ore which is the "flagship" of Brazilian exports. That decline was not reflected in the volume of ore produced, which demonstrated the impact of external factors on the mining industry. These fluctuations were not trivial: prices rose by 392.46 per cent between 2002 (34.77 US dollars) and 2011(136.46 US dollars), according to World Bank data, but had fallen to 39.78 US dollars by the end of 2015.

Despite these foreign market fluctuations, the characteristics of Brazil's mining sector contributed to its competitiveness on the international mineral market. Generally, despite falling mineral commodity prices in relation to output (PMB), the mineral industry still added value to its product. The logistical structure is, moreover, integrated into the international market. Brazil's iron ore has remained competitive for these reasons (Ministry of Mines and Energy (MME), 2016).

There are sharp contrasts in mining in Brazil. High-technology mining companies operate in some regions alongside artisanal enterprises that use rudimentary and improvised mining techniques. In addition, the country's mineral capacity is under-explored: less than 30 per cent of the national territory has been mapped geologically on a scale appropriate for the

[1] Pre-concession (mining) authorization to search for minerals.
[2] The PMB methodology adopted by the Brazil's Mining Institute (IBRAM) is based on the arithmetic mean of the price of the mineral good x production and is used for all minerals produced in the country (except petroleum and gas) (IBRAM, 2015b and 2017b).
[3] <http://www.mdic.gov.br/noticias/9-assuntos/categ-comercio-exterior/486-metarlurgia-e-siderurgia-10>

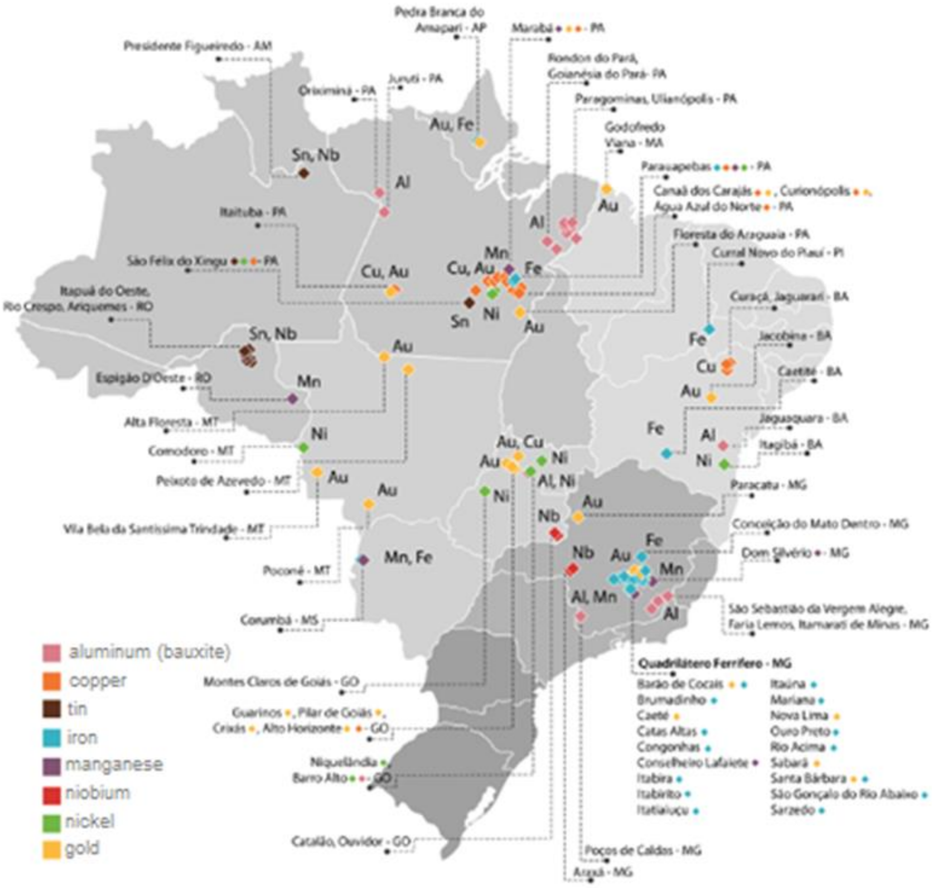
activity[4]. Brazil's mining sector therefore still holds great potential for investment in exploration and mineral production technologies.

The role of metallic minerals in Brazil

Metallic minerals accounted for 76 per cent of the total value of Brazil's marketed mineral output in 2015. Eight minerals – aluminum, copper, tin, iron, manganese, niobium, nickel and gold – accounted for 98.5 per cent of that value, at 17.3 billion US dollars.

Brazil has reserves of those eight metallic minerals in 17 of the country's 27 federal units (Figure 1). Iron ore, produced mainly in the states of Minas Gerais and Pará, was the main metallic ore marketed in 2015, accounting for 61.7 per cent of the total for that class of mineral (DNPM, 2016). Niobium, another strategic mineral considered rare worldwide, abounds in Brazil, and its known niobium reserves, totaling some 842 million tons, are found in the states of Minas Gerais (75%), Amazonas (21%) and Goiás (3%), constituting 98 per cent of world reserves. In 2015, Brazil ranked first in niobium production, with 92.29 per cent of the world total, followed by Canada and Australia (World Mining Data, 2017).

Figure 1. Main Mineral Reserves, 2015



Source: DNPM (2016a). Notes: Figures are given for the main reserves, and not for total national reserves, of each mineral.

Geographically, the main metallic substances marketed in 2015 were produced preponderantly in the states of Minas Gerais and Pará, in the south-east and north of the country respectively. The state of Goiás (west central region), which ranked third, accounted for only 7.10 per cent of the total of those eight marketed metallic minerals. The figures

[4] Idem.

show the extent to which Brazil's mineral sector is regionally concentrated in contributing to the country's marketed output of the primary metallic substances (DNPM, 2016).

Geographical concentration has contributed remarkably to fiscal imbalance, since funds must be transferred to the region in which the mining company operates. The federal units that received the most "mining royalties", the financial compensation for exploiting mineral resources (CFEM) in 2015 were Minas Gerais and Pará. The total amount accruing to these two states (265.9 million US dollars) was virtually equivalent to the total CFEM amount for that year (294.3 million US dollars), which is indicative of the high regionalization of Brazil's mining sector (DNPM, 2016a).

Mineral industries and foreign trade[5]

The mining sector achieved an 11.5 billion US dollar surplus in the first quarter of 2017, accounting for 21 per cent of all of Brazil's foreign market sales (Brazil Portal, 2017). This performance was owing to sales of iron ore, which accounted for 44 per cent of mineral-sector exports and 9.3 per cent of all Brazilian exports. Gold and niobium, too, performed well at 1.4 billion US dollars and 766.8 million US dollars respectively in that period. Imports grew concurrently by 53 per cent, totaling 3.9 billion US dollars, as imports of metallurgical coal and potassium had risen in volume and in value.

The mining sector has contributed greatly to Brazilian exports in recent decades. Metallic minerals rank among the first four exported goods. Apart from its share of exports, mining, which tends to generate a surplus, has contributed positively over the years to the country's balance of trade. The mining industry has therefore been closely correlated with national economic growth (IBRAM, 2015a).

The main countries that purchased ores from Brazil in 2015 were China, Japan, Netherlands, the United States of America and Canada, in that order. China is the largest customer for Brazil's minerals, in particular iron. In 2015, 31.93 per cent of the main metallic substances exported by Brazil were bound for the Chinese market (DNPM, 2016a).

Brazil has imported metal commodities from Chile, Peru, Argentina, the Russian Federation and China. In 2015, 43.58 per cent of metallic substances imported into Brazil, in particular copper, originated in Chile (DNPM, 2016a).

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[4] *Idem.*

[5] The aggregate mineral sector data proved here include metallic and non-metallic ore extraction and mineral processing.

Trends and new policies for Brazil's mining sector

Innovation is important to effective exploitation of natural resources, but issues concerning the actual impact of innovation on the sector and the factors that stimulate innovation in individual countries remain controversial (Figueiredo *et al.*, 2016).

The mineral commodity super cycle during the 2000s has revived discussion on the capacity of natural resource-intensive economies to innovate and, more specifically, on the advantages of mineral resource exploitation as a driver of these countries' development.

As part of the debate, Figueiredo (2016 and 2017) has analyzed the accumulation of technological capabilities by mining firms in Brazil's mining industry between 2003 and 2014. "Technological capability" is the set or stock of knowledge resources that allows companies to perform both production or operation and innovation activities, while production capabilities relate to the use/operation of existing production technologies and systems; innovation capability permits changes to existing technologies or even generates new technologies.

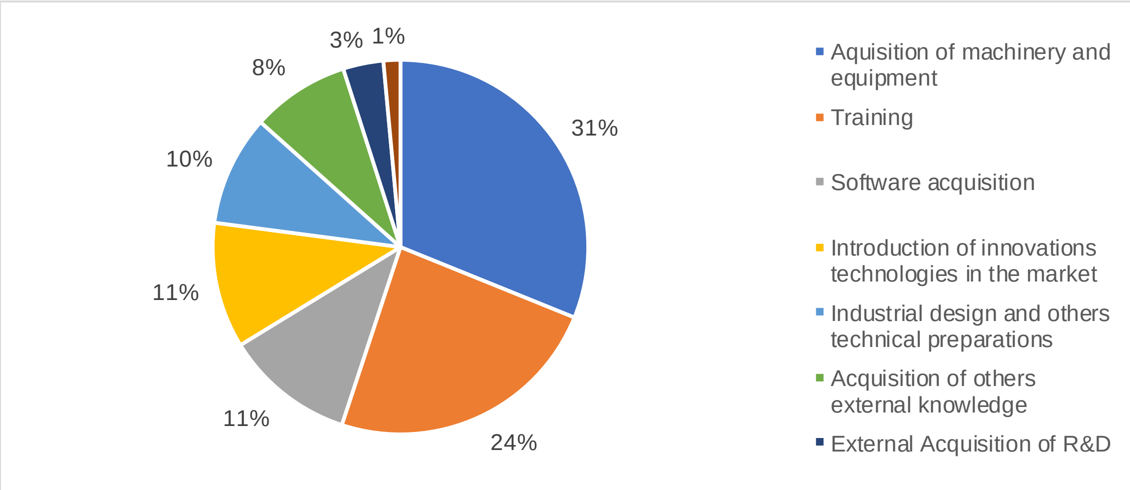
The findings show that the interviewed companies achieved new levels of technological capability acquisition during the period under review. In particular, 60 per cent of the companies enhanced mineral processing from a basic innovation capability to an intermediate level and began to make improvements to equipment, water reutilization systems and to grinding, crushing and ore separation engineering. Moreover, owing to mineral-processing technological capability accumulation, production companies' work productivity increased and export revenue figures rose. As the surveyed companies accounted for 63 per cent of the country's mineral output in 2014, Brazil's mineral sector has inferably been more actively innovative in the last decade. Analysis has shown, however, that that these dynamics are still not very linear, since those companies were not only disparate, but also displayed differing innovation levels internally (Figueiredo *et al.*, 2016).

The Innovation Survey (PINTEC) conducted by the Brazilian Institute of Geography and Statistics (IBGE) on the sector's primary ways and means of acquiring technology, shows that Brazil's extractive industry has innovated primarily by acquiring machinery and equipment and secondarily by training personnel, which may be deemed complementary[6]. The survey sample consisted of 47,693 innovation-implementing companies, 1,138 of which were in the extractive sector.

Figure 2 shows part of PINTEC's findings, highlighting the scale of innovative activities conducted by extractive companies from 2012 to 2014. Machinery and equipment acquisition and training accounted for 55 per cent of the extractive companies' innovative activities. These findings spotlighted the importance of reviewing the technology transfer role of METS in Brazil's mining sector. The mineral sector innovation rate (42%) had doubled in comparison with the average for the previous five innovation surveys (21%). This increase was mirrored by activities such as machinery and equipment acquisition and research and development (R&D), both of which had doubled in value since earlier research (Lins, 2017 in Oliveira, 2018).

[6] These findings apply to petroleum and gas extraction.

Figure 2. Innovative activities conducted by extractive companies and order of magnitude



Source: IBGE (2016)

With regard to the sector's commitment to the promotion of innovation, companies, government representatives and trade associations have discussed the challenges faced by Brazil's mining sector. During the 17th Brazilian Mining Congress (Belo Horizonte, Minas Gerais, September 2017), those groups highlighted two major drivers of innovation, namely higher productivity and operational efficiency and the social license to operate, with emphasis on environmental sustainability and relations with local communities (Table 3).

Table 3. Mining sector challenges and technological demands

Unlocking productivity and operational efficiency	Social license to operate
Digitalization and the Internet of Things in mining	Mining tailings dams
The fully connected mine	Mining waste management
Autonomous vehicles for the mining industry	Water resources
Blasting strategies for increased mill productivity	Climate change
Safety and health in mining	Mining and communities

Source: adapted from the 17th Brazilian Mining Congress – Exposibram 2017. Belo Horizonte, September 18 to 21.

In raising productivity and operational efficiency, the sector has tended to focus on technologies conducive to greater automation of activities, in particular those that are occupational safety hazards, and to lower operating costs. Digital and satellite connectivity technologies are other factors of investment in innovation through which companies seek process-efficiency gains.

Brazil's mineral industry has increasingly integrated the social license to operate agenda into its investments, with emphasis on improvements that can enhance sustainable behavior, not only environmentally, but also in relation to communities in the vicinity of operations.

Priority has been given to dam management in particular, by including it not only in the sector's agenda, but also in the agendas of local governments and the legislature. This resulted from the Bento Rodrigues accident, which occurred when Samarco Fundão Dam burst in Minas Gerais in November 2015. It shows the extent to which the mining sector reacts to events rather than adopts a more proactive stance conducive to a structuring and long-term approach by anticipating innovative solutions for potential future problems.

Furthermore, Brazil's mineral sector faces challenges inherent in the national scenario. It was not by coincidence that the Ministry of Mines and Energy (MME) published the 2030 National Mining Plan – Geology, Mining and Mineral Transformation (MME, 2010), in May 2011 as guidance for medium and long-term policies for progress in mining activities. The challenges mapped cover matters such as infrastructure and logistics, sustainability, occupational safety and health, and micro and small local businesses.

Moreover, the Brazilian Government made changes to the mineral sector's rules in Provisional Presidential Decree No. 790 on June 25, 2017 (MP 790). Brazil's current Mining Code was established in 1960 and updated in 1996, but has been superseded by current market demands. The federal government wishes to implement new rules to make the sector more competitive and to attract more investors by increasing transparency and legal security.

Highlights of the new rules include: (a) an increase in the sector's royalty rates (CFEM); (b) establishment of the National Mining Agency (ANM) to replace the current DNPM in regulating and overseeing the sector; (c) a higher ceiling for fines; (d) inclusion of rehabilitation of degraded environmental areas and mine decommissioning plans in miners' responsibilities; and (e) extension of the mineral prospection and exploration period. Conceptually, MP 790 broadens the scope of the federal government's competences and of regulated activities. The regulation now covers the entire life cycle of the mining activity, from prospection and extraction to ore marketing and mine decommissioning. The new rules seek to boost the sector's dynamics and, consequently, its modernization and to intensify the country's mineral production through new investments and thus new technology[7].

The propensity to incorporate innovative activities has been rising gradually in Brazil's mineral sector and its representatives have displayed higher levels of commitment. The sector's revamping has included a legislative overhaul, highlighting the diversity of forces that have driven Brazil's mining companies to rethink their forms of action.

Institutional collaboration for innovation

Some of the behavioral characteristics of Brazil's mining companies when acquiring technological capabilities and technologies will be considered in this section. These dynamics are very important if it is borne in mind that the innovation environment can be improved by institutional collaboration and linkages rather than isolationist behavior and aversion to sharing content and experience.

Figueiredo (2017) has stressed the importance of collaboration among companies in building their technological capabilities. Research has confirmed that, between 2003 and 2014, much of Brazilian miners' innovative technological capabilities was accumulated in partnerships with universities and local research institutes, consultants and agents along the production chain (suppliers and clients).

Institutional collaboration in the mineral sector has sound historical foundations in Brazil. The sectoral innovation system was formed through a long process of technological and scientific skills building and accumulation, involving feedback and interaction among companies, research institutions and universities. It is not by chance that undergraduate and postgraduate courses in Mining Engineering, Materials Engineering and Metallurgy have

[7] http://revistamineracao.com.br/2017/10/09/mineracao-brasileira-precisa-se-renovar-afirmam-especialistas.

flourished and are well established at the Federal University of Minas Gerais (UFMG) (Suzigan *et al.*, 2008).

Brazil's mining companies and academic community (universities and research centers) collaborate considerably under cooperation agreements and formal partnerships. This has been achieved incrementally, as some confidentiality and intellectual property issues are yet to be resolved in order to smooth out such relations. Vale S.A. exemplifies the way in which such obstacles can be overcome. It has broadened its portfolio of academic partners since 2010, by issuing calls for proposals for partnership with governmental science promotion agencies, and has thus gained access to a broad spectrum of research groups that were previously unknown to the company (Mello and Sepulveda, 2017).

METS are equally crucial innovation stakeholders in the mining sector, as noted in studies abroad (Francis, 2015). Mining is a catalyst of technical progress and the capital goods industry has emerged to provide solutions that meet the mining companies' technological demands (Furtado and Urias, 2013).

This has held true for Brazil, too. Throughout its history, as noted at the beginning of this paper, the technological development of Brazil's mining corporations has drawn both on the direct participation of foreign producers and on various engineering services. New mining technologies had frequently been brought into Brazil by outside companies and the foreign technicians who came to work in the mines brought what was best known in their home countries (CGEE, 2002).

Furthermore, it was common practice to send Brazilian professionals abroad to complement their studies and machine and equipment manufacturers sometimes promoted visits to open mines worldwide as a means of observing products and more efficient production processes (Bertasso and Cunha, 2013). In addition, returning Brazilian technicians, who had worked in foreign companies and had absorbed their practices, actually disseminated new technologies.

Even though a significant part of Brazil's technological base is imported, domestic machinery, equipment and engineering services were used to modernize much of its mining industry. It is noteworthy that, since the 2000s, the machine and equipment sector has mirrored the concentration and internationalization of the mining sector. This shows that the companies are interdependent. As mining companies became stronger and more complex, thus demanding more comprehensive technological solutions from suppliers, the latter began to build alliances with the mining companies in order to develop new products jointly. This association took the form of knowledge and competency transfers. Machine and equipment suppliers provided training for mineral sector workers and monitored and maintained (preventively and remedially) the machines and equipment supplied (Bertasso and Cunha, 2013). However, in comparison with other countries such as Australia, South Africa, Chile and the United States of America, the trend in Brazil is still nascent, owing to the dearth of examples, which are confined to the major mining companies (Figueiredo, 2017).

Brazilian miners seem to be more willing to interact with external players. Brazil's mining companies have been driven to search for solutions "outside their own gates" in order to acquire different experience and skill sets.

2 Use of the patent system and technology transfer in Brazil's mining sector

This section will consider the main two mechanisms used by mining companies and METS in Brazil to build their technological capabilities, namely technology development and technology acquisition from abroad. It will identify the main technological innovation areas and stakeholders in Brazil's mining sector and the ways in which companies have been importing new technologies. Both analyses have drawn on a sample of patent and technology import contracts involving resident and non-resident mining companies and METS[8].

Technology innovation

A sample of 130 resident and non-resident mining companies and METS that filed patents at INPI from 2000 to 2015 was analyzed. As Table 4 shows, these companies filed 7,933 patents and utility models, including 4,273 for mining technologies filed by 21 mining firms and 83 METS.

Table 4. Research sample (patents applications) (2000–2015)[9]

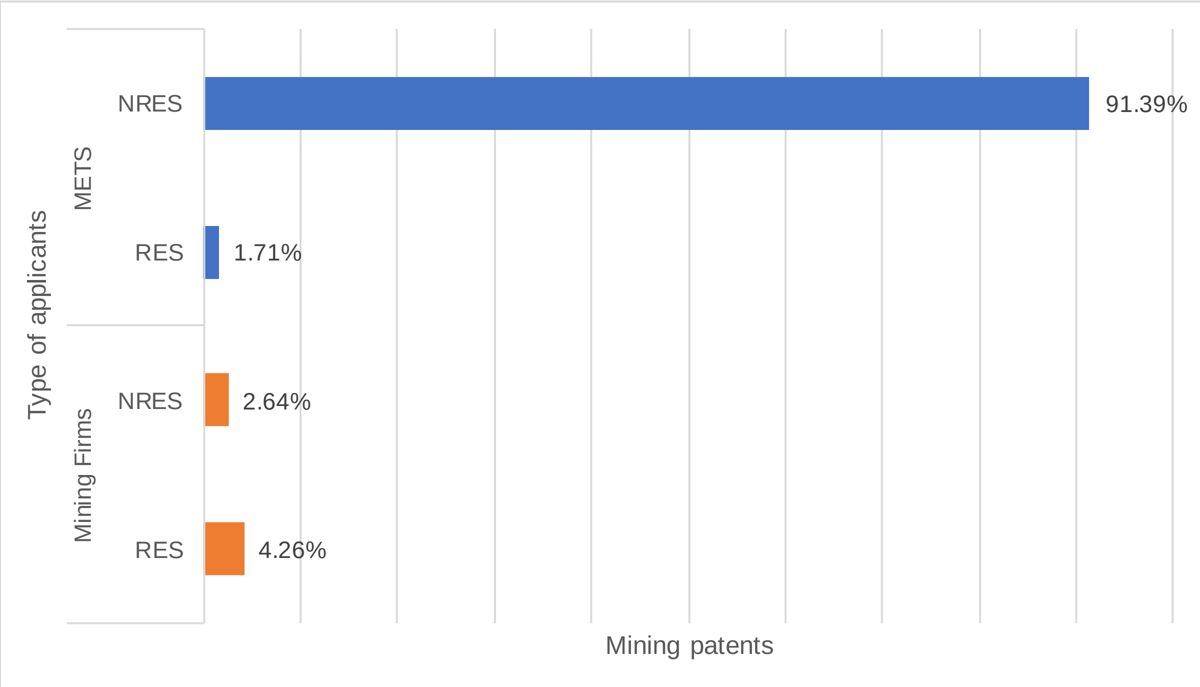
	Mining firms			METS			TOTAL
	RES	NRES	Total	RES	NRES	Total	
Number of applicants	15	10	25	35	70	105	130
Total patents filed	234	131	365	106	7,462	7,568	7,933
No. of applicants (only mining patents)	11	10	21	22	61	83	104
No. of patents (only mining patents)	182	113	295	73	3,905	3,978	4,273

Source: BADEPI (2018). Notes: RES = Resident; NRES = Non-resident

As shown in Figure 3, non-resident METS predominate in applications for patents in Brazil's mining sector. They account for nearly all of the mining patents filed from 2000 to 2015.

[8] The Appendix contains details on the methodology used.
[9] With regard to the type of application filed from 2000 to 2015, the number of utility models is so very much lower than the number of patents that "patent" is used in this paper to refer to all applications filed to protect technology.

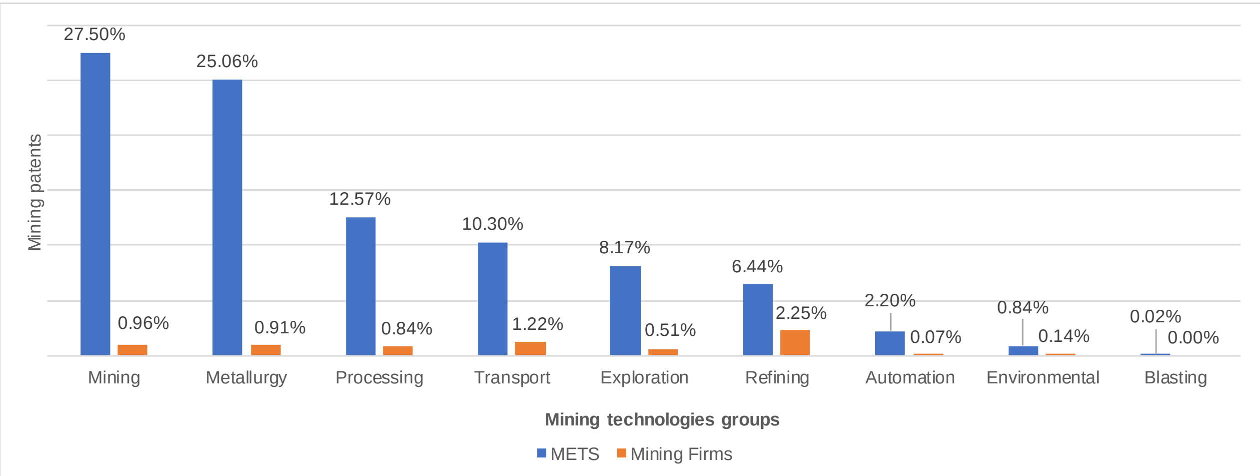
Figure 3. Mining patents, by type of applicant (2000–2015)



Source: BADEPI (2018). NOTES: RES = Resident; NRES = Non-resident.

METS are more likely to file patents for mining and metallurgy technologies, while mining firms focus on refining and transport technologies, as can be seen from Figure 4.

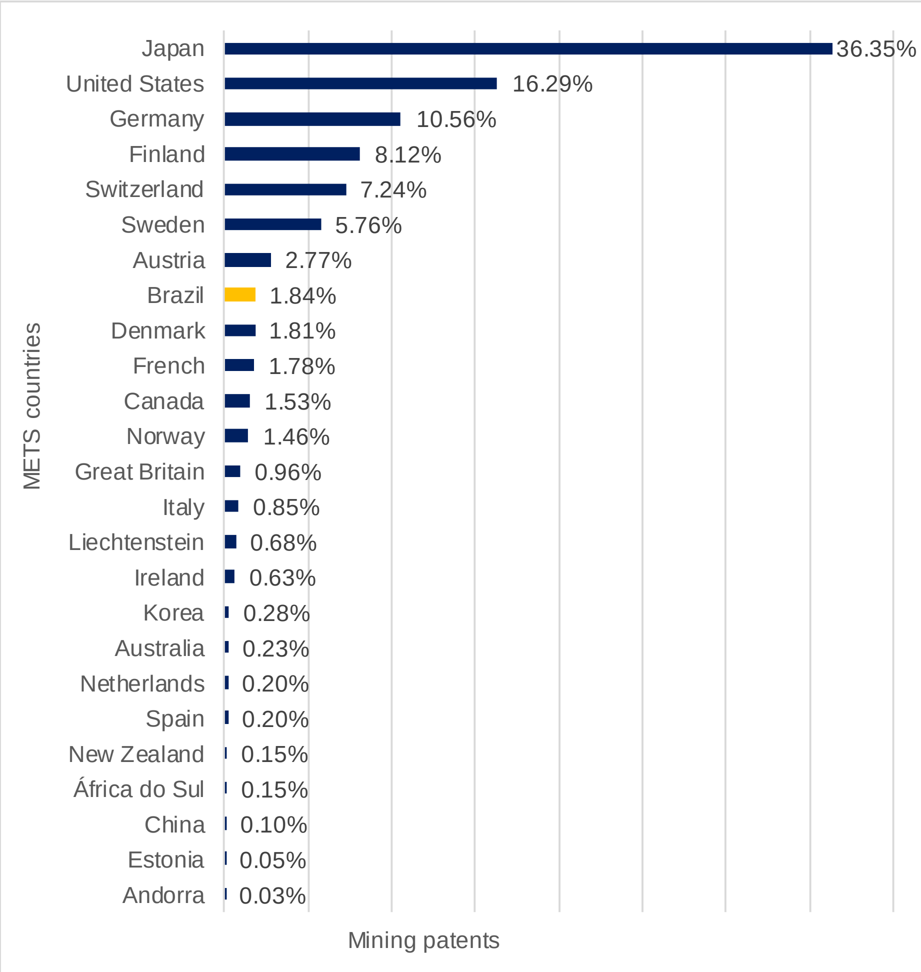
Figure 4. Mining patent applicants, by mining technology group



Source: BADEPI (2018)

It can be seen that most of the METS applicants were from Japan, as they accounted for 36 per cent of the 3,978 patents filed in the period under review, followed by North American and German METS. Although Brazilian METS hardly feature in these results, they seemed more concerned to protect technology in Brazil than Canadian or Australian METS, for instance (Figure 5).

Figure 5. Mining patents filed by METS, by country of origin (2000–2015)



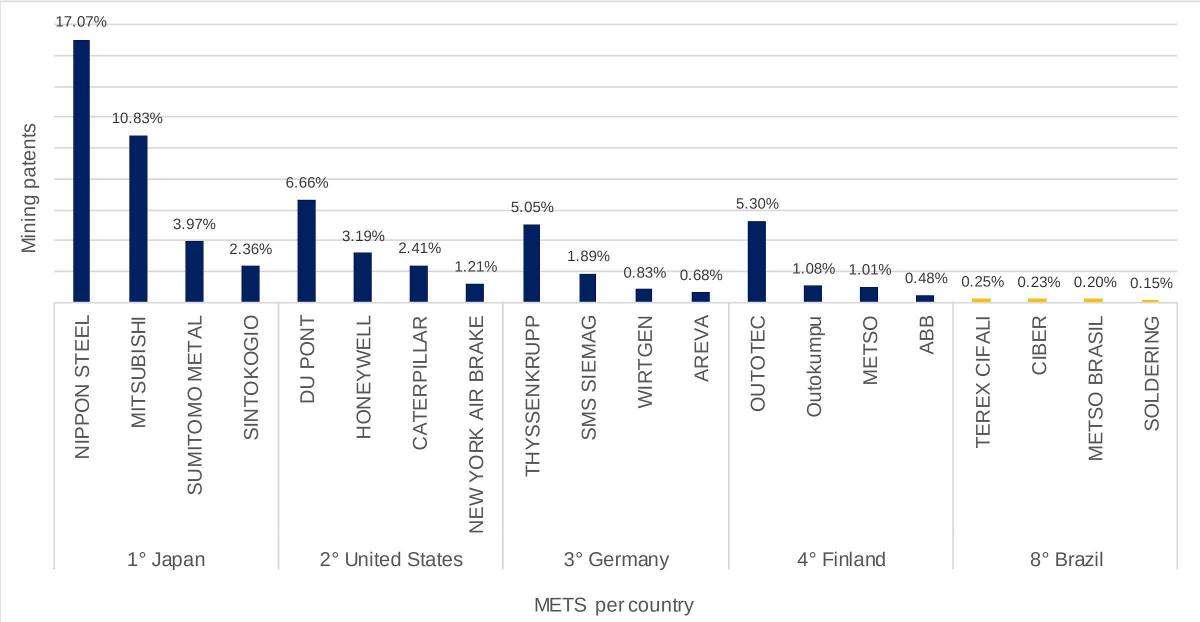
Source: BADEPI (2018)

The major two METS applicants were Nippon Steel and Mitsubishi, from Japan. They focused on metallurgy and mining technologies. The leading applicants among resident METS were Terex Cifali and Ciber, both of which deal with transport and processing technologies (Figure 6).

Figure 7 shows applicant mining firms. There is a wide gap between Vale S.A. and the other mining firms. While Vale filed 46.8 per cent of patents from 2000 to 2015, the remaining firms filed 53.2 per cent of patents altogether. This confirms the above-mentioned concentrated nature of Brazil's mining sector.

Vale has filed for patents mainly in transport and refining technologies. Transport is assumably crucial to Vale's patenting strategy because of its logistics business and demand for railway technologies. In addition, Vale has protected technologies in seven of the eight mining technology areas present in WIPO Mining Database, and has not applied for patents in blasting technology only. Here, too, Vale's representativeness warrants a more detailed analysis, which will be provided in the third section of this paper.

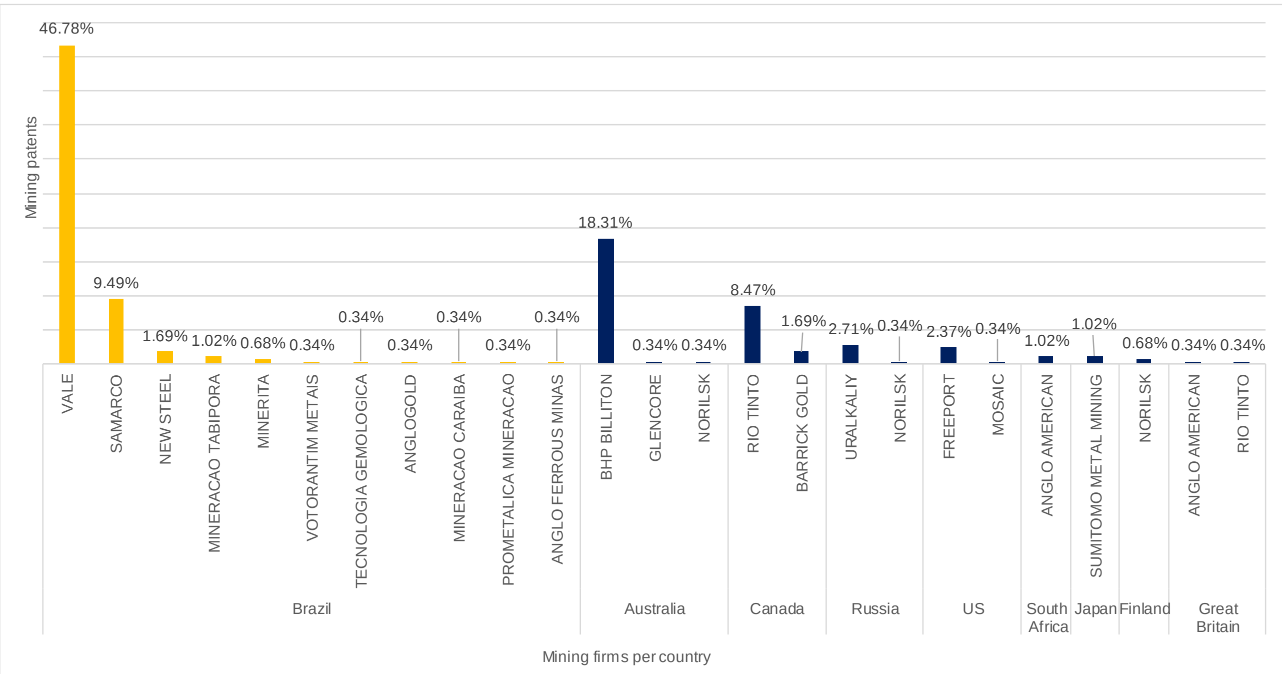
Figure 6. Leading METS applicants (2000–2015)



Source: BADEPI 2018

The Anglo-Australian Broken Hill Proprietary Company Limited (BHP Billiton) was the leading applicant among non-resident mining firms, followed by a Rio Tinto Canadian subsidiary. BHP Billiton applied for patent protection mainly in refining technologies. The company did not seek to patent transport, environment, automation and blasting technologies in Brazil. Here, too, this mining firm's patenting strategy focused on refining technologies in Brazil's mining sector, in the same way as its Brazilian competitor, Vale S.A.

Figure 7. Leading applicants among mining firms (2000–2015)



Source: BADEPI (2018)

According to Figueiredo (2017), Brazil's mining sector's technological capabilities are greatest in mineral processing (refining), which is warranted by the need to maximize productivity and minimize costs. Companies are consequently more concerned about being competitive in those areas and, therefore, protecting such technology.

Technology transfer

Some non-resident METS that used the patent system in Brazil had been contracted by resident mining firms to provide technological service or technological know-how. The sample of 18,252 import contracts registered in INPI's database showed that 707 concerned mining companies and METS. As Table 5 shows, 26 mining firms and 14 resident METS were recorded as technology contractors. Only two METS contracts did not involve a parent company and its resident subsidiary. Resident METS (the subsidiaries) assumably acted as intermediaries between non-resident METS and resident mining firms in order to operationalize technology transfers.

Table 5. Research sample (technology import contracts) (2000–2015)

	Mining firms			**METS**			**TOTAL**
	RES	**NRES**	**Total**	**RES**	**NRES**	**Total**	
Import contracts (No. of contracts)	N/A	N/A	**N/A**	N/A	18,252	**18,252**	**18,252**
Import contracts (No. of contracts in Brazil's mining sector)	N/A	N/A	**N/A**	N/A	707	**707**	**707**
Import contracts (No. of contractors)	26	N/A	**26**	14	N/A	**40**	**40**
Import contracts (No. of providers)	N/A	N/A	**N/A**	N/A	295	**295**	**295**

Source: BADEPI (2018). NOTES: N/A = Not applicable.

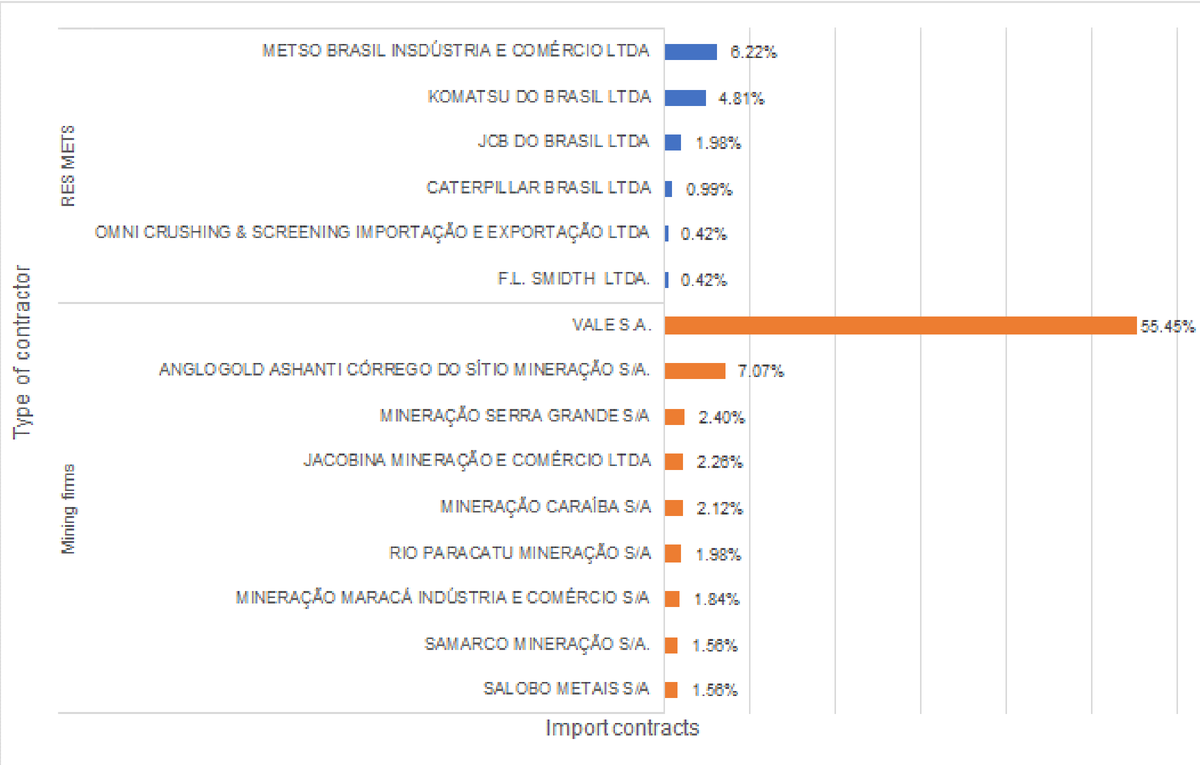
Table 6 shows technology import contracts, by type, by contractor and provider by supplier. Technical assistance services contracts were the type of contract most used, mainly by resident mining firms. This finding assumably flows naturally from the above-mentioned point on non-resident METS' key role in providing technical services to Brazil's mining enterprises (CGEE, 2002; Bertasso and Cunha, 2013).

Table 6. Technology import contracts, by type, by contractor and by supplier (2000–2015)

Type of contract	Contractor		Supplier
	RES Mining Firms	RES METS	NRES METS
Technical assistance services	82.0%	10.3%	92.4%
Know-how agreement	1.6%	5.4%	6.9%
Patent licensing	0.0%	0.7%	0.7%
Total	**83.6%**	**16.4%**	**100.0%**

Source: BADEPI (2018)

Figure 8. Leading contractors (2000–2015)



Source: BADEPI (2018)

Figure 8 shows that Vale S.A is the leading contractor, accounting for more than half of the INPI-registered technology import contracts. If the parent companies are taken into consideration, then it can be said that four mining groups, namely Vale S.A., Anglo Gold Ashanti, Kinross and Yamana Gold, are represented by their Brazilian subsidiaries in technology-transfer contracts negotiated with non-resident METS, as observed in Table 7.

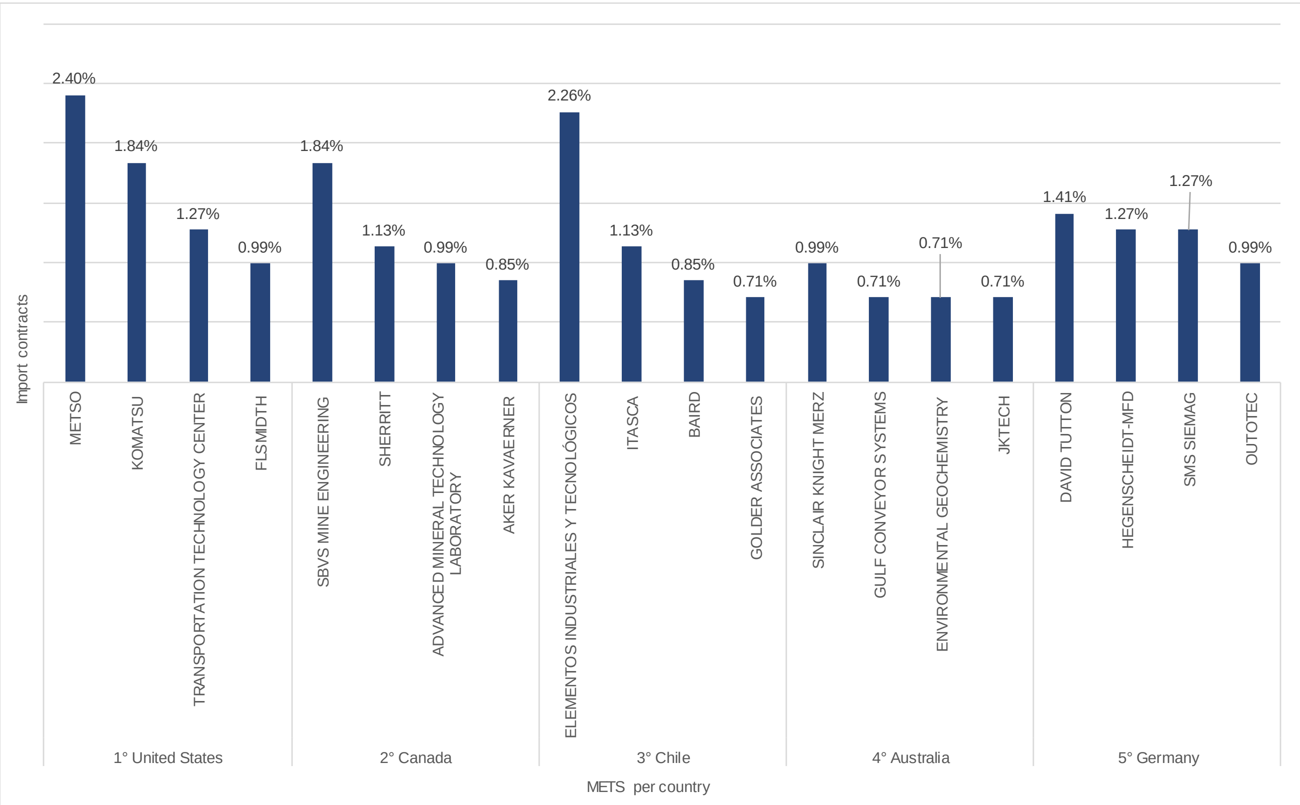
Table 7. Mining firm contractors (subsidiaries and parent companies)

Contractor (Mining firms)	Parent company
SALOBO METAIS S/A	Vale S/A
SAMARCO MINERAÇÃO S/A.	
ANGLOGOLD ASHANTI CÓRREGO DO SÍTIO MINERAÇÃO S/A	Anglo Gold Ashanti
MINERAÇÃO SERRA GRANDE S/A	Anglo Gold Ashanti and Kinross
RIO PARACATU MINERAÇÃO S/A	Kinross
JACOBINA MINERAÇÃO E COMÉRCIO LTDA	Yamana Gold
MINERAÇÃO MARACÁ INDÚSTRIA E COMÉRCIO S/A	
MINERAÇÃO CARAÍBA S/A	N/A

Source: based on mining firms' websites (2018).

Figure 9 shows that the suppliers of most technology import contracts are from North America. Metso's and Komatsu's subsidiaries are the major suppliers from the United States of America and, as can be seen from Figure 8, they have been contracted by their own subsidiaries, Metso Brasil and Komatsu do Brasil, both acting as technology transfer intermediaries. Another two major suppliers are Chile's Elementos Industriales y Tecnologicos and Canada's SBVS Mine Engineering.

Figure 9. Leading suppliers, by country of provision of the contract (2000–2015)



Source: BADEPI (2018)

Collaboration with academia or international partners is another potential knowledge transfer channel to Brazil's mining sector. However, very few Brazilian applicants in the mining sector engage in co-patenting with academic institutions or international co-inventorship (Table 8). Of the 255 Brazilian patent applications relating to mining technologies, including both resident mining firms and METS, only 11 patents were filed jointly with academic institutions and 12 were co-invented with foreign inventors.

Table 8. Co-applications and foreign inventors, by mining technology

Resident firms		Co-applications with universities		Foreign inventors	
NIPPON STEEL	METS	N/A	0	METALLURGY	1
SAMARCO MINERACAO	Mining firm	EXPLORATION	1	PROCESSING	1
VALE S.A.	Mining firm	ENVIRONMENTAL	2	ENVIRONMENTAL	1
		EXPLORATION	3	EXPLORATION	3
		MINING	1	MINING	3
		PROCESSING	2	REFINING	3
ANGLOGOLD ASHANTI BRASIL	Mining firm	ENVIRONMENTAL	1	N/A	0
MINERAÇÃO CARAIBA	Mining firm	METALLURGY	1	N/A	0
TOTAL			**11**	**TOTAL**	**12**

Source: BADEPI (2018). NOTES: N/A = Not applicable.

In view of the major role of Vale S.A. in Brazil's mining sector, this company's technological strategies will be the subject of a case study in the next section.

3 Vale S.A. Case Study

Vale's history dates back to the late nineteenth century. After the largest iron ore deposit in the world was mapped at Itabira, in Minas Gerais, foreign miners flocked to the city in order to explore the region, following the establishment of the London-based Itabira Iron Ore Company, the first company authorized to prospect for iron in the region.

In the early twentieth century, the company was targeted by nationalist campaigns calling into question its right to exploit ore in Brazil and the company's management by a United States businessman, Percival Farquhar. Under his stewardship, the company expanded logistically, building ports and railroads to transport the exploited ore (Vale, 2012).

In 1942, the Governments of Brazil, the United Kingdom and the United States of America signed the Washington Accords, which laid the foundations for the establishment in Brazil of an iron ore-exporting company. Under the Accords, the British Government undertook to transfer, free of any encumbrance, the iron ore deposits owned by Itabira Iron Ore Company to the Brazilian Government, which ultimately took over the entire production complex and established a company tasked with extracting, transporting and shipping Itabira ore. Companhia Vale do Rio Doce (CVRD) was established in 1942 as a State-owned company (Vale, 2012)[10].

In 1966, CVRD began to grow more quickly and a new iron ore production era dawned for the company. In 1974, it took the lead in iron ore exports, which it has not relinquished since. Two decades later, in 1997, CVRD was privatized and, in 2006, it made other giant step by acquiring INCO, a Canadian firm, and thus became the world's second largest mining company after the Anglo-Australian BHP Billiton. The purchase of INCO, founded more than a century ago, was a major step that brought Vale into the nickel market.

[10] Vale S.A. became the brand and the company name in 2007. It had always been known by that name on the stock exchanges, but had continued to use the original corporate name. In 2008, Companhia Vale do Rio Doce stopped using the acronym "CVRD" and began to use the name "Vale".

Vale S.A. is a now a multinational company; it is active on six continents and is one the largest iron ore producing companies in the world, as the world leader in the production of pellets. Vale produces coal, copper, fertilizers, manganese and ferroalloys. Its iron ore production flagship, Carajás deposits, in the state of Pará, is the world's largest open-pit iron mine. On average, the Carajás rocks have a 67 per cent iron ore content, which is considered a very high grade.

In Vale's operations in Brazil, ores are exploited through four fully integrated systems consisting of mines, railroads, pellet plants and seaport terminals (North, South and South-East Systems). Moreover, Vale has logistical infrastructure in Indonesia, Mozambique, Oman, Philippines and Argentina. As an intensive power user, consuming about five per cent of all energy produced in Brazil, the company operates hydroelectric plants in Brazil, Canada and Indonesia in support of its operations. Furthermore, Vale conducts steelmaking operations through joint ventures.

In 2017, Vale was ranked, by company market value, among the five largest companies in the mining sector (Mining, 2017).

Science, technology and innovation at Vale

Like any big mining company, Vale faces major technology and innovation challenges. Producing hundreds of millions of tons of ore yearly, Vale's operations involve complex and sophisticated logistics and increasingly advanced energy-intensive prospection, exploration and mineral-processing technologies, while minimizing environmental, health and safety impacts.

In taking up these technological challenges, Vale has established several internal R&D facilities. The first facility, the Mineral Development Center (CDM), was founded in 1965 in order to develop technological improvements to the extraction and processing of *itabirito,* a low iron-content ore extracted from Minas Gerais deposits. CDM was instrumental in making the technological change through which Vale became the world's largest iron ore exporter (Mello and Sepulveda, 2017). At the time, in a technological leap forward, Vale pioneered the use of magnetic separators that raised the productivity of *itabirito* (Vale, 2012). Present-day CDM's specialists use state-of-the-art equipment to investigate production and processing methods for different types of ores and to ensure mineral project viability. The second facility, the Ferrous Metals Technology Center (CTF) was established in 2008 to focus research on the use of iron ore and coal in steelmaking. Both CDM and CTF are located in the south-eastern state of Minas Gerais.

The third facility, the Logistic Engineering Center (CEL), was established in 1997 with three units based in Espirito Santo (south-east), Maranhão (north) and Minas Gerais (south-east), respectively. Its main characteristic is its combination of lectures and practical lessons in providing port and railway technical training to employees and market professionals.

Sudbury Neutrino Observatory Laboratory (SNOLAB), an underground laboratory in Sudbury, in the province of Ontario, Canada, was established concurrently[11], its objective being to enhance scientific research output and to generate new knowledge on rock

[11] The construction of SNOLAB's surface facilities and underground laboratories were funded by the International Joint Venture Program of the Canada Foundation for Innovation (CFI), Ontario Innovation Trust, Northern Ontario Heritage Fund Corporation and FEDNOR. Operating costs have been supported by Ontario Research Fund's Research Excellence Program, the Natural Sciences and Engineering Research Council (NSERC), CFI and member institutions. The city of Sudbury is providing a five-year grant for public education on new developments at SNOLAB.

excavation and drilling for dissemination to the mining chain[12]. The construction of the major laboratory was completed in 2009 and the entire laboratory began “clean space” operation in March, 2011.

In 2009, Vale Institute of Technology (ITV) was founded under a broader science, technology and innovation (ST&I) strategy designed to take up technological challenges over the long term[13]. ITV is a major link between Vale and the scientific and technological community (Mello and Sepulveda, 2017). It is a non-profit research and postgraduate teaching institution with two units, one in Pará and the other in Minas Gerais. This new R&D department has complemented existing departments, by giving the company a longer-term view of its innovation strategy. Since 2009, Vale has been in closer contact with external partners, such as universities and funding agencies, and has thus found new, open-innovation approaches to ST&I involving “the use of purposive inflows and outflows of knowledge to accelerate internal innovation and expand the markets for external use of innovation” (Chesbrough, 2006).

The two models – closed and open innovation – are complementary and coexistent. Historically, internal R&D facilities have been tasked with incremental solutions, dealing with short-term results linked to operational demands and focusing on greater efficiency and lower costs. When Vale decided to found ITV and concurrently broaden its R&D portfolio through partnerships with the ST&I community, it took yet another approach to technology by including challenges that demanded disruptive solutions and a long-term vision.

The company has been marked by moves towards centralization and decentralization throughout its technology and innovation governance history. From 1965 to 2018, the company moved intermittently from centralized technology governance in a corporate department to decentralized governance through its Business Units (BUs), with no single corporate structure in charge of technology strategy decisions. Vale’s governance currently comprises a Strategy, Exploration, New Business and Technology Board that is directly linked to Vale’s CEO, illustrating the extent to which innovation is integral to the company's strategy.

Vale’s institutional collaboration to foster R&D[14]

As mentioned above, ITV began to coordinate the company and ST&I community more broadly and methodically in 2009. Since 2010, Vale has entered into major partnerships with Brazilian funding agencies in order to launch Calls for Proposals to promote R&D projects in states in which Vale operates. State Research Foundations (FAPs) are National Science and Technology System entities attached to state governments.

Through these partnerships, Vale has expanded its portfolio of R&D partners and related research themes. From 2010 to 2018, these partnerships have involved the ST&I community in six Brazilian states, namely Minas Gerais, Pará and São Paulo (in 2010), Espírito Santo and Rio de Janeiro (in 2016) and Maranhão (in 2017).

In addition to State funding agencies, Vale has acted in coordination with federal government agencies, such as the National Council for Scientific and Technological Development (CNPq), which plays a significant role in national science and technology policy formulation (in 2009 and 2011), and the Brazilian Development Bank (BNDES) in

[12] http://www.vale.com/canada/EN/initiatives/innovation/snolab/Pages/default.aspx (06/10/2018).
[13] The Department of Vale Institute of Technology was renamed Department of Technology and Innovation in 2013 and Executive Management of Technology and Innovation in 2015. In 2018, the Department was divided up and technology portfolio management was decentralized to some of the company’s other departments.
[14] See www.vale.com/MAIS.

2012. In each agency, Vale shares financial resources with the government, thus improving the purpose and strength of the collaborative model. This was, moreover, a means by which both sides – the company and the public authority – leveraged resources from each other.

Vale's BUs are in contact with a variety of R&D institutions in order to exchange information and practices that will enable both sides to learn from each other and, consequently, devise more innovative solutions to meet technological demands. It is a virtuous circle, from which the company and the ST&I community benefit.

Highlights of partnership outcomes include the project on the use of biotechnology to accelerate environmental solutions in the field and the project implemented to automate routine mining activities in order to optimize operational processes (Vale, 2017). In addition to new technologies, other important findings comprise the number of new researchers recruited under research grants. For example, under the partnership with FAPs in Minas Gerais, Pará and São Paulo, 621 research scholarships are active in 30 universities and research institutes (Vale, 2017).

Vale's Intellectual property strategy

Vale's IP strategy is a recent development. Before 2009, Vale did not have a structured and coordinated IP process. IP was not treated globally but piecemeal, under a restricted strategy. In fact, IP was a small, almost isolated, area involving administrative and bureaucratic activities rather than those evocative of a consistent IP strategy. During that period, Vale's patent application practice focused on what might be termed "tooling", encompassing small incremental technologies involving equipment and tools used in day-to-day activities. The company did not focus on technology *per se*, but on minor operational improvements. It can be said that documentary and administrative management was geared to protecting developments, but no strategy was in place to evaluate whether inventions were actually being used in operations or whether they could be licensed or made available to third parties. However, even though it lacked a coordinated IP strategy, Vale *did* acquire new knowledge and technologies from some inventions during that period, as some had been applied in operations and had generated value for the company (Oliveira, 2018).

In acquiring INCO and its highly renowned R&D center in 2006, Vale also acquired a substantial technological hardcore, owing to INCO's mining patents, and Vale's portfolio increased by approximately 1,500 active processes, brands and patents. In 2010, as Vale INCO, the company began to manage the entire portfolio of Canadian patents, all of which concerned nickel operations. As a result, the IP department was obliged to implement more robust procedures (Oliveira, 2018).

In 2009, IP activities began to be more structured and to focus on technology rather than minor improvements[15]. This change was consistent with the new company's ST&I position. ITV hired a specialized team, with employees who could effectively address IP issues and formulate an integrated IP strategy for the company. The establishment of the Intellectual Property and Technological Intelligence Management department and the search for trained IP professionals were fundamental to leveraging and consolidating Vale's IP. In 2009, the new Management department published a global standard-setting instruction in order to establish rules and guidelines on IP activities within company. IP at Vale was crucially boosted when the department began to promote in-house training in order to build an IP culture in the BUs. IP Management was designed to support the entire company by

[15] The new approach was taken in Brazil rather than Canada, as INCO already had extensive patent portfolio experience.

disseminating the inventions developed and by monitoring patents, technological trends and competitors (Oliveira, 2018).

In 2014, the Management department began to discuss IP "best practices" in an endeavor to define a more structured approach for the BUs, owing to the importance of the technology to be protected and the choice of country in which patents might be filed. Vale therefore decided to recommend IP strategy implementation practices[16]. One major action consisted in formulating, implementing and often amending the Global Intellectual Property Policy that regulated IP-related issues and guided all Vale employees. In formulating the IP strategy in 2014, Vale reviewed its patent portfolio, which was thus optimized, as some patents had become obsolete or were not strategic to the company. Nine hundred patents were excluded from the portfolio, which led to lower costs and more focused patent management (Oliveira, 2018). In 2016, the Intellectual Property and Technological Intelligence Management department, furthermore, formulated Global Intellectual Property Management procedures[17]. The training programs have expanded to cover as many BUs as possible, while dissemination of IP procedures through internal media, lectures and similar events has been increased.

Strategically, Vale files patent applications primarily in Brazil. The company uses the Patent Cooperation Treaty (PCT) system, which gives access to the results of international search reports, in order to decide whether to file patent applications in other countries. Operationally, the IP Management department has structured and centralized the entire technology protection process into technology evaluation, patent search, protection and maintenance and has adopted specific forms and tools in order to coordinate the BUs' IP activities. Vale considers that it is vital to protect technologies that are integrated into its core business. The strategy under the current model is to protect inventions that are aligned with the company's business in Brazil and in the world, rather than simply expanding its IP portfolio without any specific focus (Oliveira, 2018).

Technology import contracts and technology transfer at Vale

In the 1950s, the major problem faced by CVRD was competition. The end of Second World War had contributed to the recovery of the mining sector, with post-war Europe as the main market. Iron ore producers such as Canada, Sweden and several African countries were physically closer to the consumer markets (United States of America and Europe) than Brazil, leading to lower freight costs and, consequently, ore prices (Vale, 2012).

As it already exported more than 80 per cent of Brazil's iron ore to the United States of America and was concerned about the new market configuration, CVRD began to modernize the operations of the mine-rail-port complex and the maritime transport system in a drive to diversify iron ore markets and boost exports. Integrated mine-rail-port logistics was the keystone of the project. CVRD began concomitantly to invest in technology acquisition, by purchasing technologically advanced extraction (mining) equipment, such as electric drills, electric air compressors and electric excavators for dismantling and loading hematite blocks. In the early 1960s, the company also began to invest in process technologies primarily to address the issue of *itabirito* ore, which is a more brittle mineral that lowered the quality of the ore produced by the company. In 1956, CVRD joined forces with Armor Research Foundation of the Illinois Institute of Technology (Chicago, United States of America) in order to promote studies and research on the use of *itabirito* from Minas Gerais.

[16] Internal Vale documents such as "Análise das Commodities Vale por abrangência territorial e cadeia de produção", Department of Technology and Innovation, December, 2014.
[17] Internal Vale documents.

The initiative was supported by the federal government, which decided to defray 50 per cent of the costs of the studies (Vale, 2012).

Encouraged by technological changes to the global steel industry, in particular the introduction of furnaces that required the use of higher-grade iron ore and buyers' demand for more stringent chemical and grain sizes, CVRD acquired technologies to optimize the use of ores. In 1961, in an endeavor to provide an industrial technical service to improve ore profitability through concentration and agglomeration processing, CVRD established Beneficiamento de Itabirito *S.A.* (BENITA), with the support of investment by United States and European companies (Vale, 2012).

Another major technological development during that period was the advent of sintering and pelletizing processes, through which mineral fines were transformed into small iron pellets for steel manufacturing (pellets). Fines had been regarded as tailings because they could not be used directly in steel-mill blast furnaces on account of their granulometric properties. As newly developed goods, pellets were, moreover, a means of raising mining output. In 1962, CVRD joined technical and scientific organizations from the United States of America, Europe and Japan in launching studies for the construction of a pellet plant. Overall responsibility for the mill project lay with the United States company Arthur G. McKee (Cleveland, United States of America) (Vale, 2012). Owing to this technology, CVRD minimized environmental impacts, as the mineral fines had previously been stacked near the mines and had damaged the environment by emitting particulates, which were very fine, potentially airborne, particles of solid material. Vale's second largest business is currently the sales of pellets (Oliveira, 2018).

The examples show that technological investment, either for process improvement or for the improvement or acquisition of equipment with embodied technology, has been a longstanding Vale practice, dating back to the early decades of its existence. At that time, the aim of technological innovation was market diversification in order to keep ahead of competitors by enhancing multi-mineral mining viability. The examples also show that, owing to contact with non-resident players, Brazil's mining sector had acquired knowledge and skill sets to take up national challenges.

Despite its inclusion in Vale's activities from the outset, technology transfer is not structurally the purview of a specific department. Technology acquisition through the purchase of machinery and equipment falls within the remit of the Procurement Department. The IP Management department becomes involved in technology transfer as soon as Vale needs to know how to operate the machines or equipment, by drafting import contracts or securing technical assistance services (Oliveira, 2018). As can be seen from Figure 8, Vale registered the highest number of import contracts with INPI between 2000 and 2015. This is consistent with innovation survey results, which have shown that innovation in Brazil's extractive industry had consisted mostly in acquiring machinery and equipment and, to a smaller extent, in conducting training activities (Figure 2).

As to the other side of the technology transfer coin, Vale does not have a structured process in place to license technology developed in-house or through R&D project partnership with external institutions. In view of the importance of a culture of technology transfer and in-house or external R&D project outcomes as means of adding value to the business, Vale's IP Management department is planning to implement such procedures in the company (Oliveira, 2018).

As Vale is the major stakeholder in Brazil's mining sector, that trend may augur a paradigm shift in other Brazilians mining companies, by pushing the entire sector in the same direction or even opening up new development pathways for Brazil's mining sector.

4 Innovation patterns in Brazil’s mining sector: final considerations

The questions raised at the beginning of the paper were whether natural resource economies could generate innovation and whether mining innovation could give a competitive edge to a country’s economy.

On the basis of the above considerations, it can be agreed that the production of mineral resources *does* generate new knowledge, techniques and technology trajectories. Dependence on natural resources is not the crux of the matter if the economy in question is sufficiently dynamic and can promote intersectoral collaboration and foster output diversification. Brazil’s mining sector seems to be unique in terms of diversity and dynamism. Despite the size and geological diversity of Brazil, mining activities are concentrated geographically and in the hands of a single company. Minas Gerais and Pará account for more than half of Brazil’s mining output, and Vale S.A. is the predominant producing company. These factors are critically important to any analysis of innovation and technology transfer in the sector, as the same pattern of concentration is mirrored in decisions on the technology agenda of Brazil’s mining sector.

The sector seems to focus more on protecting technologies that raise productivity and lower costs, such as mining (extraction), metallurgy, processing, refining and transport technologies, rather than on a technological agenda with emphasis on long-term solutions that will actually change the way of doing things, such as automation and environmental protection. The perceptible underlying rationale gives pride of place to innovation that focuses on short-term matters, such as operational improvements and cost reduction, in setting a technological trajectory (Dosi, 1982).

Brazil’s mining sector should invest in prospection for new deposits (Greenfield projects) and in mineral extraction technologies in order to take advantage of the country’s geology, size and diversity. In view of the role played by mining firms and METS in the technology protection agenda, it must be stressed that mining firms have not heretofore focused on the protection of exploration and mining technologies. That role has been played by non-resident METS, which have mainly protected mining technologies (extraction), while mining firms have mainly protected refining and transport technologies.

The patent data analysis has shown the patterns of concentration of the few companies that are active in the mining sector in Brazil. Non-resident METS, from Japan and North America in particular, accounted for practically all applications filed for mining technology patents. The concentration pattern for mining firms shows that only one resident mining firm, Vale S.A, has patents in seven of the eight mining technology areas considered in this paper.

Data analysis of the use of technology import contracts in Brazil’s mining sector as a means of technology transfer has shown that non-resident METS are still the main suppliers of technology and technical assistance services to resident mining firms. Their role has been fundamental to mining technology development in Brazil. This characteristic has been corroborated by some global mining strategy studies, according to which companies, in times of crisis, choose to keep their main operations at the lowest possible cost and to focus on the operating cash flow ratio to ensure long-term profitability. As a result, the sector’s innovative capability tends to be confined to short-term solutions, which in turn contributes to companies being “followers” of existing technologies (EY, 2016). Mining companies thus become clients of existing technologies rather than investors in long-term, more disruptive R&D to meet future challenges.

However, mining industries are observably willing to aggregate value, which makes them innovate in higher-value goods such as iron ore pellets or, more recently, invest in automation technologies, such as drones, in order to optimize exploration activities.

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Appendix

Methodology

This section contains details on the origin of the mining firms and METS companies that were included in the sample for data analysis. The investigation was restricted to the 2000-2015 period.

Research sample

Data analysis was conducted under two heads, determined by those companies' registered offices, as shown below.

Resident companies

Resident companies were listed by Brazil's Federal Revenue Office. The list showed companies' main economic activity, and their corporate National Register of Legal Entities (CNPJ)[18] data were used in searches. The resident companies sampled fell into the National Classification of Economic Activities (CNAE) below.

Table 7. Resident firms, by type

Resident mining firms	Resident METS
CNAE - Group 071 Extraction of iron ore - **Group 072 Extraction of non-ferrous metal ores**	CNAE - Group 285 Manufacture of machinery and equipment for mineral extraction and for construction - Subclass 3314-7/15 Maintenance and repair of machinery and equipment for use in mineral extraction, except for the extraction of petroleum

Source: IBGE 2018

Non-resident companies

A ranking of the first 50 non-resident mining companies, by capitalization, was used. INPI's Intellectual Property Statistical Database (BADEPI) was searched in order to identify non-resident mining firms so ranked that had filed patent applications from 2000 to 2015.

The search in respect of non-resident METS was based on technology import contracts registered in BADEPI as a means of identifying non-resident METS that had applied for mining patents from 2000 to 2015. The main name of non-residents METS was used as the standard.

Moreover, import contracts were used as a proxy for technology transfer and fell into the following categories: patent and industrial design licensing; know-how agreements; franchising; technical assistance services; and trademark licensing. All suppliers were non-resident METS and the contractors were resident mining firms and METS.

[18] Companies are registered in the National Register of Legal Entities (CNPJ), held by Brazil's Federal Revenue Office; it contains data such as the company's name, founding date and other information.

Table 8. Non-resident firms, by type

Non-resident mining firms	Non-resident METS
- The leading 50 mining firms **BADEPI** **Applications for mining patents**	BADEPI Technology import contracts Applications for mining patents

Table 9 summarizes the research sample configuration; it reflects the two types of company (mining firms and METS) and their origin (resident and non-resident).

Table 9. The research sample (in full) (2000–2015)

	Mining firms			METS			Total		Total
2000-2015	**RES**	**NRES**	**Total**	**RES**	**NRES**	**Total**	**RES**	**NRES**	
Research sample (No. of companies)	8,252	50	**8,302**	1,252	303	**1,555**	**9,504**	**353**	**9,857**
Patent applicants (No. of companies)	15	10	**25**	35	70	**105**	**50**	**80**	**130**
Patents filed (No. of patents)	234	131	**365**	106	7,462	**7,568**	**340**	**7,593**	**7,933**
Mining patent applicants (No. of companies)	11	10	**21**	22	61	**83**	**33**	**71**	**104**
Mining patents filed (No. of patents)	182	113	**295**	73	3,905	**3,978**	**255**	**4,018**	**4,273**
Import contracts (No. of contracts)	N/A	N/A	**N/A**	N/A	18,252	**18,252**	**N/A**	**18,252**	**18,252**
Import contracts (No. of contracts within Brazil's mining sector)	N/A	N/A	**N/A**	N/A	707	**707**	**N/A**	**707**	**707**
Import contracts (No. of contractors)	26	N/A	**26**	14	N/A	**14**	**40**	**N/A**	**40**
Import contracts (No. of providers)	N/A	N/A	**N/A**	N/A	295	**295**	**N/A**	**295**	**295**

Source: BADEPI, 2018