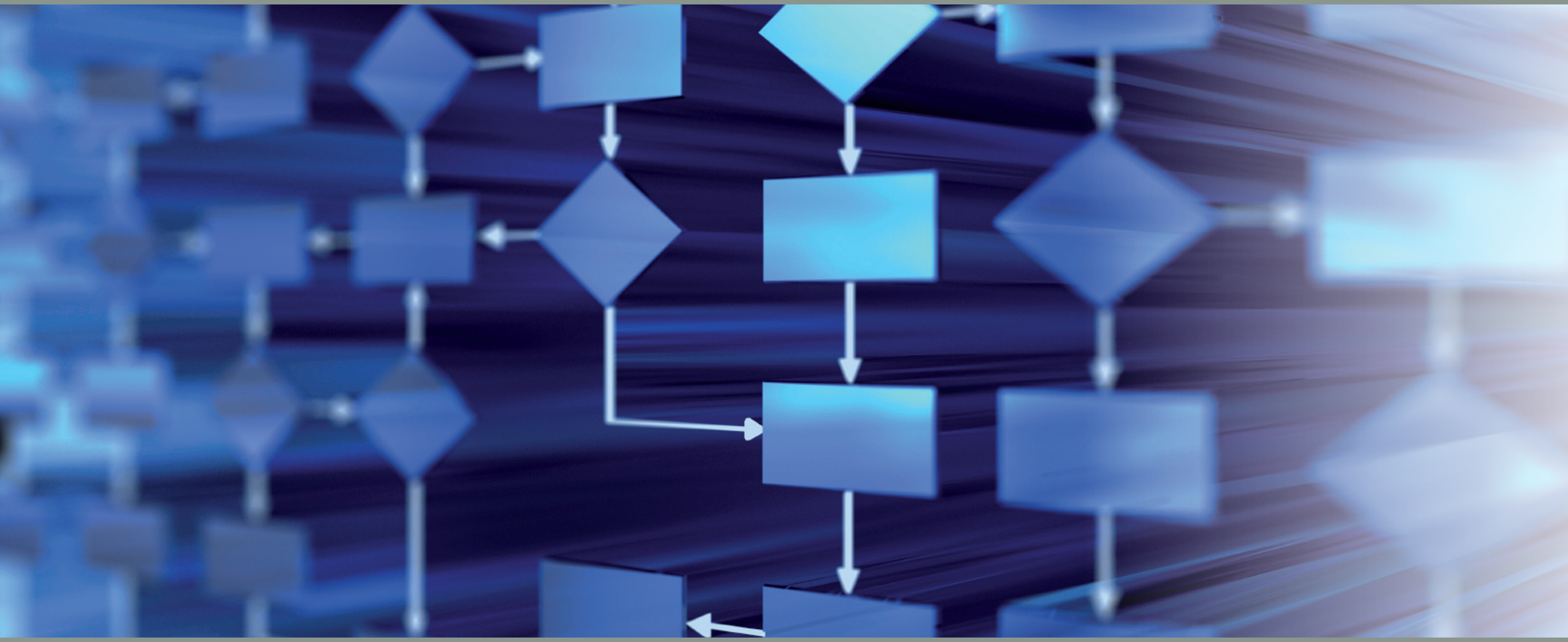
Economic Research Working Paper No. 56

Mining patent data: Measuring innovation in the mining industry with patents

Alica Daly
Giulia Valacchi
Julio Raffo



May 2019

WIPO
WORLD
INTELLECTUAL PROPERTY
ORGANIZATION

Mining patent data: Measuring innovation in the mining industry with patents

Alica Daly
Giulia Valacchi
Julio Raffo[1]

Abstract

Traditionally, the mining sector has been considered a slow innovator compared to other industries, like the manufacturing or pharmaceutical industries. However, we observe an upsurge in the innovation activity of the mining industry in the first half of the 2000s. During this period, mining innovation started to increase rapidly after periods of stagnation and downward trends. To conduct and in-depth investigation of the global trends and patterns behind this structural change in mining innovation, we formulated a general search strategy to identify patent activity in this sector. The strategy is repeatable over time and in multiple databases. It enabled us to produce a dataset of patents in mining and mining-related technologies. Using this newly-created database we identified at the basis of the structural change a switch away from refining technologies into exploration and environmental technologies probably explained by the took over of the so-called 4th Industrial Revolution. The types of actors active in the mining innovation also changed across time: there are now many more individuals, research centers and universities innovating in mining and relatively less companies. Finally, the country composition in the pool of mining innovation activity has radically changed with the appearance of China on the global scene starting from early 2000.

Keywords: intellectual property, patents, patent data, mining, innovation, mining services, METS
JEL code: O34; Q55; L71; L72; L64

Disclaimer

---

[1] Corresponding author: alica.daly@wipo.int. Part of this work was conducted when Giulia Valacchi was writing her PhD thesis at the Centre for International Environmental Studies, Graduate Institute of Geneva.

Acknowledgments

This paper is the result of a research project conducted in the context of the Project on Intellectual Property (IP) and Socio-Economic Development – Phase II (CDIP/14/7). The authors are grateful to the participants to the WIPO Experts Meeting on *Global Innovation Patterns in the Mining Industries* (May 2017, Geneva), at which the initial approach to the search was first presented for their valuable feedback and suggestions. In particular, the authors wish to thank Asrat Tesfayesus and Steve Melnick from the United States Patent and Trademark Office (USPTO) for carefully reviewing the search strategy and Alvaro Gonzalez Lopez from the National Institute of Industrial Property of Chile (INAPI) for testing the search strategy and David Humphreys for his mining expertise. We would also like to thank the USPTO, INAPI, the National Institute of Industrial Property of Brazil (INPI), the Canadian Intellectual Property Office (CIPO) and IP Australia for the provision of data, as well as Asrat Tesfayesus and Andrew Toole (USPTO) for their assistance with the Search Engine tool.

NOTE: All the (publicly available) data, data catalogue and data schema, as well as SQL and STATA scripts used and described in this paper can be obtained upon request.

1. Introduction

Products of the mining industry are an essential part of our lives. We need them to satisfy our everyday needs. The growing worldwide population, together with the rising living standards, increases the demand for minerals. The mining industry faces continuous challenges to meet such demand and to fulfill the sustainability requirements imposed by policy makers. Innovation is a key instrument to address these challenges.

Traditionally, innovation economists have not considered the mining sector to be very innovative (Scherer, 1984; Bartos, 2007). According to this view, mining firms are more likely to be large and capital intensive in order to benefit from the economies of scale when facing a demand that relies mostly, if not only, on the price of mining commodities. Mining firms have few incentives to differentiate through product innovation or branding. Most innovations are related to cost-cutting processes, aiming to improve their narrow margins. As a result, mining firms source new technologies from their own production engineering departments or embedded in products and services obtained from specialized suppliers (Pavitt, 1984).

Nevertheless, there is compounding evidence to suggest not only that the mining sector is innovative, but also that, recently, it is increasingly so. In most mining countries, this sector often contains a disproportionate number of innovative firms compared to other sectors (Arundel & Kabla, 1998). In addition, the sector has observed a dramatic increase in all innovation indicators since the early 2000s.

In Europe alone, around USD 657 million was spent on research and development (R&D) in mining in 2015. Although it is still much lower than so-called high-tech sectors, such as pharmaceuticals (USD 10,868 million) or chemical manufacturing (USD 7,416 million) in the same year, it is still higher than agriculture (USD 654 million) and consumer electronics manufacturing (USD 347 million)[2].

We also observe that intellectual property (IP), particularly patents, have an increasing importance for the mining industry. There were more mining related inventions looking for patent protection in the last five years than all those accumulated from 1970 to 2000. Large mining enterprises and firms specialized in mining equipment, technology and services (METS) increasingly make use of IP in pursuing their internationalization strategy. Both mining and METS companies operate in different countries and patents may help them secure their IP across jurisdictions and appropriate the knowledge embedded in new products and processes.

A patent is a legal right that is granted for any device, substance, method or process that is new, inventive, and useful. Patents give the owner exclusive rights to exclude others from commercially exploiting the invention for a limited period of time. In return for exclusive rights, patent applications must be published and must fully disclose the claimed invention. As a result of this requirement, the body of patent literature reflects developments in science and technology. Furthermore, patent data is rich in information adjacent to technological information, such as temporal, geographic and bibliographical data. Through the extraction and analysis of data associated with patent applications, it is possible to measure aspects of invention and economic researchers have long used patent applications as an indicator of innovative activity.

Using patents as a proxy for innovation is established in the literature (Acs, et al., 2002) where patent data has been used as indicators of R&D output (Griliches, 1998), to measure the mobility of inventors (Miguélez & Fink, 2013), and to assess international knowledge

---

[2] See Eurostat (2018).

flows (Jaffe & Trajtenberg, 1999). In doing so, we acknowledge the limitations of using patents as a proxy for innovation raised and addressed in existing literature (Lerner & Seru, 2017). If not all inventions are patented, it is largely agreed that a patent embodies an original result of an R&D activity undertaken by an entity. This applies as well to the case of the mining industry.

With our search strategy, we can identify patents belonging to the mining sector. We find patents to the mining sector in two ways. The first is based on technology. We combine keywords found in abstracts and titles with patent classification marks to create our search strategy. The second search is a firm-based search. For the firm search, we make use of lists of mining and METS firms provided by the participating IP offices, as well as data from Orbis. The results are combined to create a database of mining patents.

The analysis of this newly assembled database enables us to study the structural change in mining innovation in the first half of the 2000s. We compare the mining ecosystem before and after 2005.

The rest of the paper is structured as follows. Section 2 defines technological innovation in the mining industry, presenting trends that show evidence of a structural change around the first half of the 2000s. Section 3 describes how we created the taxonomy, used for the search strategy, giving a brief introduction about the mining sector and identifying the parts of the mining value chain where innovation can take place. Section 4 describes the realization of the database as the combination of two distinct searches: the technology search and the firm-based search. Section 5 presents the results of our analysis and section 6 offers concluding remarks.

2. Increasing Trends in Mining Innovation

Types of Innovation

As in any other sector, mining firms innovate in their products, production processes or organizational practices. As input for these innovation outputs, mining firms perform research and development (R&D) activities, acquire of-the-shelf technologies – typically embodied in equipment and machinery – or acquire disembodied technologies such outsourced R&D or other technological services. However, measuring these innovation traits is not always straightforward and this is particularly the case in the mining industry. We discuss the general global trends of mining innovation as follows, discussing some limits of these standard indicators.

An unequivocal global R&D expenditure trend is an almost impossible task. The global mining related R&D expenditure of the last decade is likely to be around USD 140 billion[3]. China (47 percent), the United States of America (22 percent), Australia (17 percent), Canada (8 percent) and Europe (5 percent) are the largest contributors to this global figure. In Europe alone, around USD 657 million was spent on R&D in mining in 2015 (Eurostat, 2018). Although it is still much lower than so-called high-tech sectors, such as pharmaceuticals (USD 10,868 million) or chemical manufacturing (USD 7,416 million), it is still higher than agriculture (USD 654 million) and consumer electronics manufacturing (USD 347 million)[4].

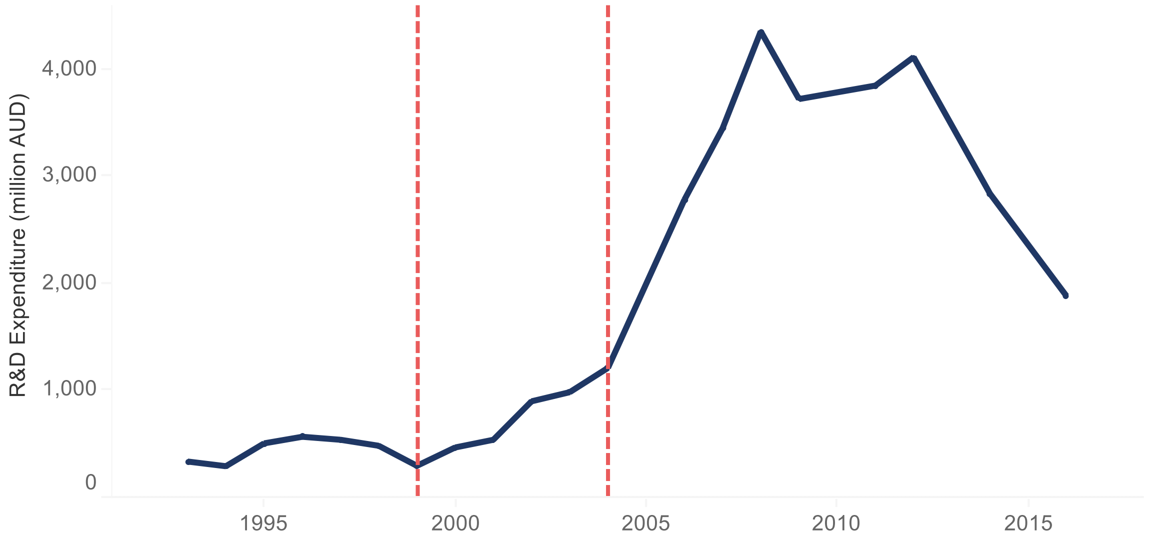
---

[3] Estimation based on OECD (2019) data in constant 2010 USD.

[4] These figures have been created by aggregating Business expenditure on R&D by NACE Rev. 2 activities Mining and quarrying, Manufacture of basic pharmaceutical products and pharmaceutical preparations, Manufacture of chemicals and chemical products, Agriculture forestry and fishing, and Manufacture of consumer electronics, respectively. The data come from Eurostat (2018) and have been reported for the following countries: Belgium, Bulgaria, Czech Republic, Denmark, Germany, Ireland, Greece, Spain, France, Croatia,

However, a national R&D series may be able to shed some light on how the trend might look. Figure 1 shows the spectacular increase of Australian mining R&D expenditure in the 2000s. In the first half of the last decade, the Australian mining sector more than doubled R&D investment. In the second half, we observe that the investment in R&D by the sector increased at a much higher rate than had been observed previously. In contrast, we also observe that mining R&D expenditures have declined recently, coinciding to some extent with the recent global financial crisis and slowdown.

Figure 1: Business R&D expenditure in mining in Australia, 1993-2016



Source: Australian Bureau of Statistics, Research and Experimental Development, Businesses (cat. No. 8104.0). Note: Business expenditure on R&D for ANZSIC Division B.

It is worth noting that aggregate mining R&D statistics often also include expenditure for the oil and gas industry. In the case for Australian mining R&D expenditures in 2015-2016, about 33 percent relates actually to oil and gas R&D expenditures[5]. Similarly, many of these aggregate R&D figures may or not include R&D performed by firms outside of the typical mining industry definitions. For instance, the Australian statistics include R&D expenses incurred by METS firms, but do not include R&D expenses relating to mining technologies incurred by firms which are not classified as mining or METS nor public R&D related to mining.

With regard to product innovation, the mining industry is a little different to other economic sectors. The discovery of entirely new products is extremely rare, suggesting that the scope for product innovation in mining itself is very limited.[6] While the discovery and development of newly mined products may be rare, the discovery of new commercial deposits of existing products is a key element of the mining activity. In fact, when talking about product innovation in mining, it could be argued that it is the deposit or the mine that is really the

---

Italy, Lithuania, Hungary, Netherlands, Austria, Portugal, Romania, Slovakia, Finland, U.K., Iceland and Norway. The numbers, which were given in million Euro, were then converted into million USD using the official exchange rate EUR-USD for 2015 from the European Central Bank.

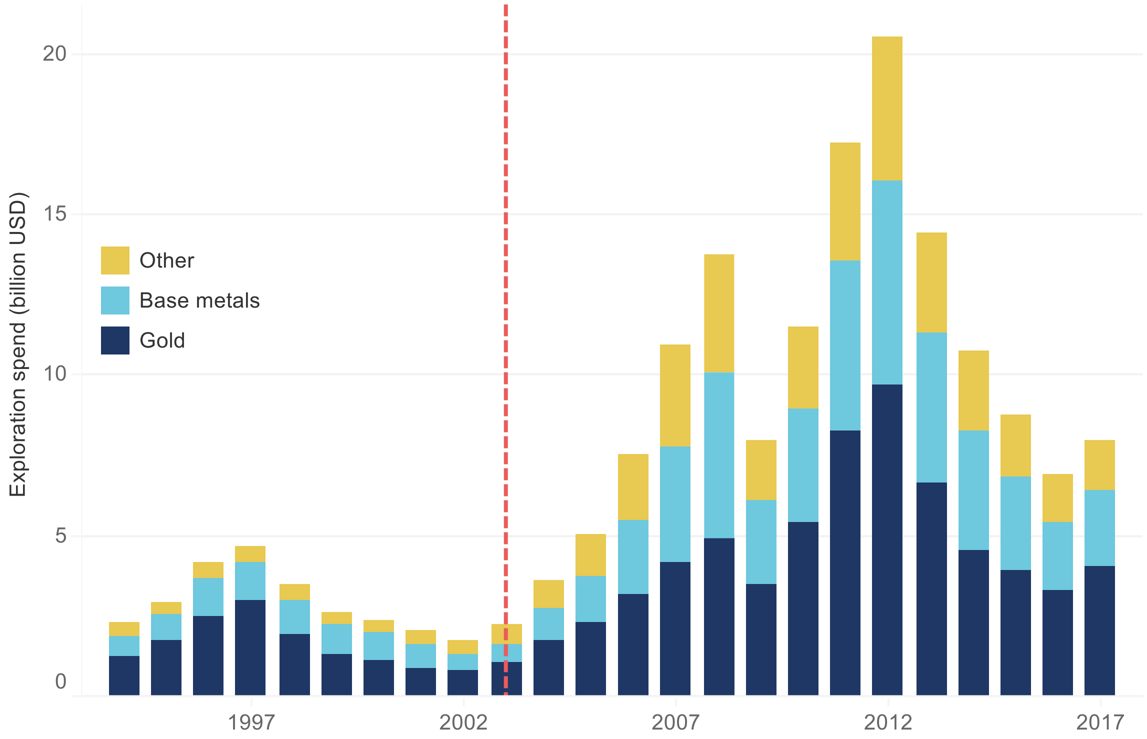
[5] Only data from 2005 is separated into sub-divisions

[6] Most mine products are simple commodities, but there are some exceptions such as industrial minerals sold based on their chemical and physical properties, precious and semi-precious stones and new uses of existing mining products.

‘product’ rather than the mineral recovered from them. Viewed in this way, a company’s expenditure on exploration becomes a part of its R&D expenditure, even though such expenditure may not be recognized formally as R&D (Kreuzer & Etheridge, 2010).

While typical aggregate R&D figures do not include the exploration investments, there are some estimations of the global magnitude of exploration expenditure. The rise in exploration expenditure in the first half of the 2000s is also remarkable and similar to the R&D trend in Australia. This noteworthy increase happened across all types of minerals (Figure 2). The early 1990s also show an increase in the level of exploration expenditure, but of a much smaller magnitude compared to what was observed in the next decade. We also observe a substantial decline after 2012.

Figure 2: Worldwide mineral exploration expenditure (USD bn) by commodity, 1994-2017



Source: S&P Global Market Intelligence, World Exploration Trends; The Economist.

These exploration figures have some limitations as well. First, they include all the activities related with exploration, many of which might not be innovative. Second, exploration is only one of the many segments of the mining supply chain where innovation can take place. Third, it is not uncommon that mining companies outsource exploration efforts to smaller companies specialized in prospecting. Mining companies take over or invest in these smaller companies only in the case of successful deposit identification, in a similar manner as large pharmaceutical companies do with small biotechnology companies.

Furthermore, process innovation and organizational innovation are critical to the mining industry and are generally aimed at cost reduction. In many industries, the boundaries between process innovation and organizational innovation are often blurred. This is certainly the case for the mining industry. Typically, process innovation refers to any improvement of the production process within the industrial plant. These include changes to the layout, machinery and any method employed to produce a good or service.

Organizational innovation includes everything that happens outside of the production plant. These include the logistics, management, financial and similar innovations.

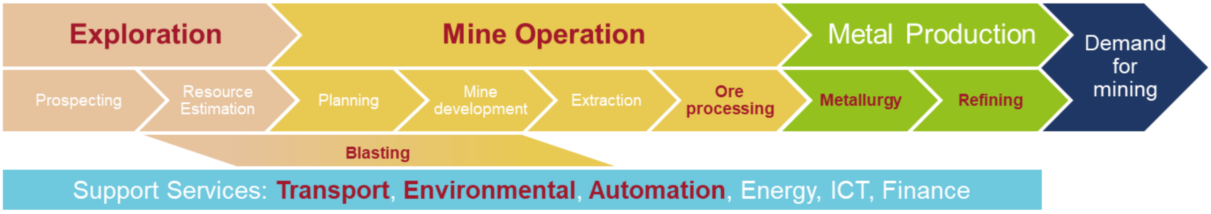
In the case of mining, process innovation refers to any improvement happening within the mine site, while organizational innovation is any improvement of operations outside the mine premises. However, several mining innovations will easily fit both definitions. For instance, new exploration methods, such as a drone sending images to a computation facility, or new transport systems, such as a system controlling loading deep inside the mine and offloading in a port far away, are likely to happen at both the mine site and elsewhere.

R&D is an indicator of innovative activity. Specifically, it measures the input of the innovative process. An alternative innovation indicator is patenting activity, which is rather an output indicator as it measures potential innovation outputs. Patents are easily comparable across years and countries. In order to identify the number of patents associated with mining activity, we first need to define the different parts of the mining value chain and classify the different technological contributions to the mining industry. This will be discussed in the next section. Then section 4 will use this categorization to build the methodology for the extraction of mining patents.

3. Mining life cycle and value chain: Identifying mining technologies

Most mining operations typically follow a similar process. The primary input for any mining activity is the land comprising the ore bodies to be extracted. The primary output is the purified metal or coal, which are in turn primary inputs for a diverse array of manufacturing industries. Value is created by converting the ore bodies to purified mineral or metal. Each stage of the lifecycle can include innovation inputs in multiple areas of technology. The lifecycle of mining, from discovery of an ore body to extraction of minerals and finally to returning the land to its natural state consists of several distinct steps. The general view of the mining lifecycle is shown in Figure 3. The exploration stage includes activities such as ore body discovery, mineral determination, resource estimation and feasibility studies. The mining operation stage includes activities such as mine planning, design & development; mine construction, extraction of ore bodies and mineral processing. Once the ore has been processed, then refining can occur. Each stage of the process is supported by services such as transport, waste treatment and energy generation.

Figure 3: Simplified view of the lifecycle of a mine



Note: The mining sub-sectors presented in red text indicate the sub-sectors defined in the patent mining taxonomy.

Based on previous work (INAPI, 2010; Francis, 2015; European Commission, 2016), we noted the challenges in using a technological approach to define the mining industry. These challenges include defining the non-core industries and deciding how much of them to bring into the definition of mining, with the aim to minimize both false positives and false negatives. However, we decided that it is necessary to define mining technologies as mining firms also appear to innovate in industries other than mining, and therefore have patents in other technology areas. This hypothesis is confirmed by our data. If we only look at the patents resulting from the firm search, we see that mining firms also have many patents outside our mining categories. Moreover, there are many METS firms innovating within the mining industry and therefore we could not rely on mining firms alone.

In this paper, only mining for minerals and coal are included; quarrying and oil & gas extraction are excluded[7]. The definitions of technology sectors in the mining industry for the purposes of this paper are based on the mine lifecycle and supply chain (Figure 3) and stages in the mineral extraction process.

Based on the knowledge domain and ownership required for each stage of the mining lifecycle, and our knowledge of patent classifications, we chose to use the mining sub-sector definitions presented in red in Figure 3 and defined in Table 1 for categorizing patents for this working paper and the resulting patent dataset. Within each of the sub-sectors, we have also defined further categories. For example, within processing, there are six categories. The categories have been determined based primarily on how the International Patent Classification (IPC) divides the sub-sectors. The definitions for the categories are further elaborated in Appendix C.

---

[7] However, the database may still contain oil & gas related patents as they may refer to techniques that can also be applied to minerals extraction.

Table 1: Sub-sector definitions

Sub-sector	Definition for patent mapping
Exploration	The process of finding and exploration of the mineral deposit. Geological logging; geophysical surveys to record the response of electrical, magnetic and gravity measures; resource modelling; geological interpretation; block models; surveying and testing the nature of borehole walls; analyzing minerals/ore by determining their chemical or physical properties; geochemistry. Computer simulations of blasting, blast fragmentation analysis. Exploratory drilling: earth or rock drilling tools and methods, such as sonic drilling and rotary air blast; Apparatus for core barrel extraction; drilling control. May also include **Mine Operation** activities such as: • Drilling for blast holes • Mine monitoring systems for ventilation, rock stress & seismic activity. • Mapping of rock joint sets
Blasting	Blasting used as a method of accessing ore bodies in both open pit and underground mines. Fuses, detonating devices; explosive compositions and blasting methods.
Mining (Mine operation)	Mine site construction: access roads, tree clearing and top soil removal, processing plants, material handling facilities, stockpile areas, train loading facilities and waste disposal areas. Technologies directly related to mining operations and excavation activities: ground control support, rock bolts, tunneling, stoping, removal of overburden, shaft sinking. Underground mining equipment, open pit loading equipment: rope shovels and hydraulic shovels, excavators, front-end loaders, ground engaging tools; surface miners, draglines, bucket wheels. For hauling and conveying equipment, see also **Transport**. Personal protective equipment; underground mine ventilation; safety refuge chambers; methane gas drainage. Subsea mining methods and equipment; extraterrestrial mining methods and equipment. Data processing systems registering or indicating the working of machines relating to mines/mining.
Processing	Beneficiation. Processing of ore after it has been extracted from mines. Coal handling, including washing and screening. Concentration of minerals by physical methods such as crushing, mill grinding, mechanical separation, flotation and differential sedimentation; related methods, apparatus and reagents. Also includes bioleaching.
Metallurgy	Chemical treatment of minerals to produce commercial pure metals. Smelting; Electrometallurgy, pyrometallurgy and methods and apparatus.
Refining	Production or refining of metals, steel and alloys. Refining consists of purifying an impure metal, where the final material is usually identical chemically to the original one, only it is purer. It is distinguished from other metallurgical processes that involve a chemical change to the raw material.
Transport	In mine transport: hoistway equipment, haul trucks; conveyors for transporting ore to processing facilities. Ex-mine transport: Vehicles adapted for load transportation; rail and railways. Automated trucks and rail; checking devices for registering or indicating the working of vehicles; automatic pilot; other vehicle control (see also **Automation**). Construction of roads; Construction of, or surfaces for, roads. Systems for controlling or regulating non-electric variables specifically for mining vehicles. Shipping.
Automation	Remote controlled mining systems. Navigation systems (see also **Transport**). Electric digital data processing. Measuring systems (see also **Exploration**).
Environmental	Environmental aspects of mining such as rehabilitation of mining areas and treatment of waste materials from mine sites, and mineral and ore processing.

4. Methodology

The selection of patents for economic analysis requires a search strategy to identify relevant patents in databases. In general, economists do use high recall-low precision search strategies when retrieving patents for economic analysis. They often rely on patent classification marks at a high level (such as class only) from well-established classification systems that correlate industrial sectors to patent classifications (such as those described in Schmoch (2008), Van Looy, et al. (2015) and Lybbert & Zolas (2014). This approach was used by the European Commission in their Raw Materials Scoreboard (European Commission, 2016).

Searches with IPC marks may also provide results with low precision, as some IPC classes can cover a broad range of industries. For example, the WIPO technology field that comprises mining is Civil Engineering and comprises a number of other industries in (Schmoch, 2008).

This approach does not account for the intricacies of the patent classification system, where examiners classify inventions based on what is claimed, which may be a more generalized invention that is useful in the industry under investigation. All patents are assigned classifications, based on classification schemes defined by patent authorities. These classification schemes are used by patent offices to support the patent search and examination process and are therefore structured according to technological principles. As a result, if a technological principle is used in several products or processes, using such a classification to select patents inherently includes patents which are not related to the industry in question. In addition, patent classifications denote the inventive concept in a patent. For example, a grinder may be used in the mining industry, but the technical features of that grinder may also be the same for a coffee grinder. If the inventive technical feature of that grinder is the conical burr, the patent will be classified for that particular feature.

Alternatively, the use of keywords to retrieve patents for economic analysis may seem like an attractive option. However, the way that patents are drafted may mean that many lists of uses or ingredients are included in the text of a patent to allow the broadest scope of protection, again leading to a high recall-low precision outcome. In addition, the same words can be used in multiple industries. For example, in this case we would like to retrieve patents about mines, but not about land mines.

To overcome these low precision results, searches in technology fields often take the advice of subject-matter experts who understand the field, and perhaps more importantly, from professional searchers, who know how to find patent information in these areas (Trippe, 2015). In the National Institute of Industrial Property of Chile (INAPI) patent landscape study of the copper mining industry, patent examiners and industry experts were consulted to identify relevant IPC subclasses and keywords (INAPI, 2010). They used the IPC subclasses for the search strategy, and then applied the keywords as filters to narrow down the results. One of the problems they reported with this approach was that they did not identify relevant documents because they did not use keywords search terms.

INAPI did an additional search using the names of companies in the copper mining industry in Chile. This approach of identifying patents in the mining industry was also utilized by IP Australia. IP Australia posited that it is difficult to provide a definition of mining patents in terms of a set of relevant IPC marks as typical mining technologies encompass a wide variety of technologies. They obtained lists of operating miners and METS firms and used them to search patent databases. However, there are problems inherent in using applicant names, as companies change names and spelling of company names may not be unified, *inter alia*. To overcome this issue, IP Australia advantageously used the Intellectual

Property Government Open Data (IPGOD), which is linked to the Australian Business Register, to uniquely identify Australian mining and METS firms. They also used the firms that identified their main business activity in these industries to include further relevant firms[8].

However, this approach only works for local firms and some firms that operate in the mining industry may self-identify in other industries. Additionally, organizations such as universities or public research organizations are generally listed in the education industry. To account for this issue, IP Australia extracted the IPC subclasses from the patent documents of mining and METS firms and applied them as filters to patents filed by Australian universities and public research organizations. However, this then created a precision problem, as mining and METS firms filed patents in industries both inside and outside the mining industry.

To overcome the limitations with technology searching and firm searching described above, we used a multi-pronged approach in order to retrieve patents in the mining and METS industries with high precision and high recall. In this paper, we describe a methodology for obtaining a database of patents representing the mining industry, building on the work done at IP Australia (Francis, 2015). The approach relies on a search based on technological information in patent databases, as well as data on mining and METS firms. Taking into account the drawbacks mentioned above, the challenge of how to capture worldwide firms and technologies produced by METS firms in a vast array of technological fields and scattered all around the world remained. For this reason, we sought the expertise and collaboration of a number of IP offices: INAPI, the National Institute of Industrial Property of Brazil (INPI), IP Australia, the Canadian Intellectual Property Office (CIPO) and the United States Patent and Trademark Office (USPTO).

The database was created using two searches. The first search was a technology search. We chose to combine keywords found in abstracts and titles with classification marks to create our search strategy. In addition, the search strategy considered multiple languages. This approach presented several benefits, including:

- the retrieval of patents defining mining specific products and processes, for example, the retrieval of grinders for use in the mining industry and eliminating coffee grinders, and,
- the elimination of irrelevant patent documents, such as patents relating to land mines, by advantageously using classification schemes as pre-search filters.

We assigned our mining taxonomy pre-search in order to make it the search modular and therefore easier to combine or remove results after the initial search, if appropriate. The search strategy is repeatable over time and in multiple databases, allowing contributions from other offices using their own patent data.

The second search was a firm-based search. For the firm search, we made use of lists of mining and METS firms provided by the participating IP offices, as well as data from Orbis.

The technology search

Data used

The technology search uses two datasets. The first is the 2017 autumn edition of the European Patent Office's Worldwide Patent Statistical Database (PATSTAT). PATSTAT offers access to over 100 million patent records from more than 90 patent authorities.

---

[8] For further details on the IP Australia approach see Francis (2015).

We also used patent data from WIPO's patent family database, which is a combination of the EPO PATSTAT database together with PCT national phase entries stored in the WIPO Statistics Database.

Patent families

A patent family is a set of interrelated patent applications filed in one or more countries/jurisdictions to protect the same invention. Applicants often file patent applications in multiple jurisdictions, thus resulting in some inventions being recorded more than once. In order to take this factor into account, WIPO has developed indicators related to "first filed" patent families, which are defined as a set of patent applications interlinked by – or by a combination of – priority claim, PCT national phase entry, continuation, continuation-in-part, internal priority, addition or division. Patent families include patent and utility model applications. To avoid double counting, our statistics always refer to patent families as a unit, unless otherwise stated.

Search Strategy Development

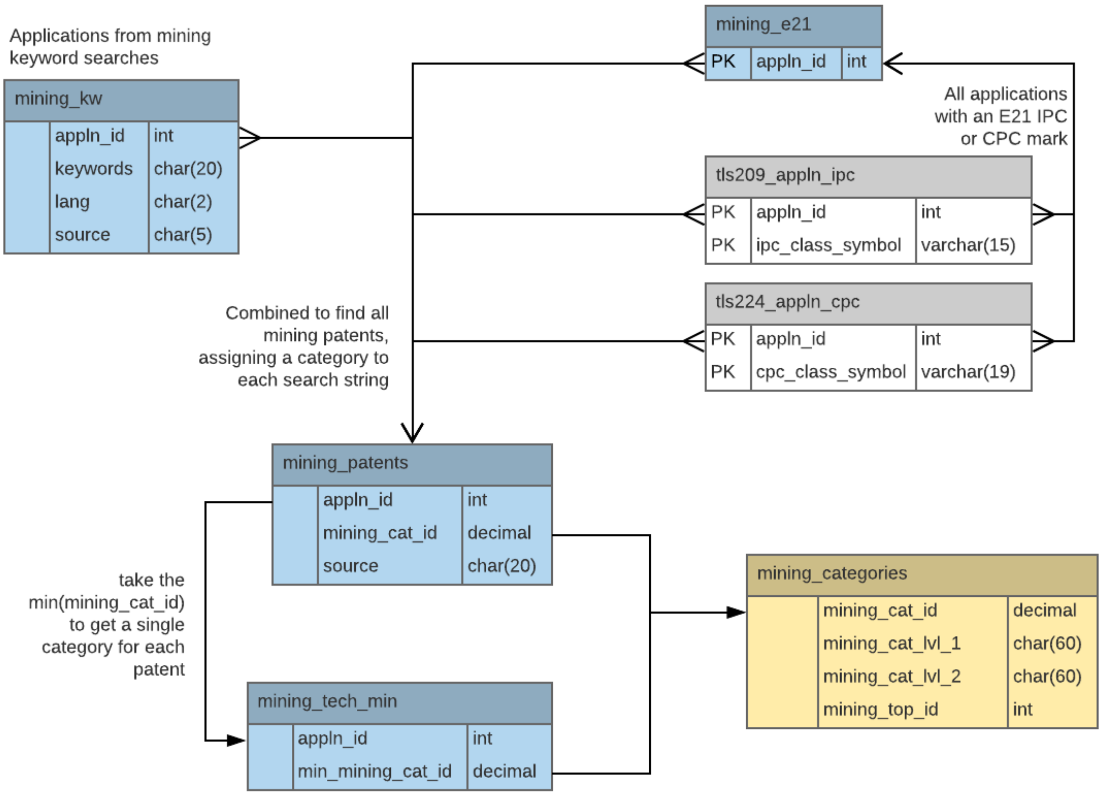
For the reasons outlined above, we choose to combine keywords found in abstracts and titles with classification marks to create our technology search strategy. In addition, the search strategy will consider multiple languages.

The first step in the process was to create a subset of patents that contained keywords related to mining in the title or abstract. The keyword subset was created based on the keywords listed in Appendix D. Six categories of keywords were used in five languages: English, German, Spanish, French and Portuguese, the most frequently occurring languages in the abstract and title tables of PATSTAT. Unlike most keyword searching, the keywords were only searched in fields made in that language, i.e. English keywords were only searched in English titles or abstracts. The keywords were searched in the titles and abstracts and assigned a general keyword term, listed in Appendix D.

A second subset of data was created by retrieving all patents comprising at least one E21 (Earth or rock drilling; Mining) IPC or CPC mark. These two subsets of data were used as a subset of the whole PATSTAT database to search within, schematically represented in Figure 4.

Some keyword exclusions are noted, such as *mining NOT data mining*. In the case of patents found based on keywords, observations of IPC subclasses that were not at all related to the mining industry were excluded instead of using NOT strategies, which can be problematic. For example, the keyword search retrieves a number of documents with the French word *porte-mine* (mechanical pencil), so it is simpler to exclude the class B43 (writing implements) from the subset of data, rather than exclude the term *porte-mine* in the search strategy. Similarly, we exclude the IPC class for land mines. IPC marks that are excluded are noted in Appendix E.

Figure 4: Schematic representation of search strategy



Taxonomy Assignment

For the purposes of statistical analysis, we wanted to identify a unique technology sub-sector and category for each patent record. However, it is not straightforward to assign patents to a single category. When examiners classify patents, they assign classification symbols according to the technological features in patent applications. A patent application that relates to multiple technological features can be assigned several IPC symbols. As a result, the patents in our mining dataset will inevitably be classified in multiple classes, and therefore multiple mining categories.

On the other hand, rules that patent examiners follow when classifying patents[9], such as the requirement to classify all inventive concepts, claimed or disclosed within the patent document can be a great help in assigning a single sub-sector for a patent. This is because, in general, such different inventive concepts are represented by different claims, alternative variants or different categories of subject matter (for example, a product and a method of its production), and, as such, one might consider the product to be the fundamental inventive concept[10]. Therefore, we can assign a single category based on a hierarchical approach where the product is the primary invention. IP Australia used this principle in the Patent Analytics Study on the Australian Pharmaceutical Industry (IP Australia, 2015), where new pharmaceuticals are generally classified in the IPC scheme in both section C and subclasses A61K and A61P, whereas known chemical entities with a newly claimed medicinal use are classified in A61K and A61P only. Therefore, if the patent application had an IPC mark in section C, the fundamental inventive concept would be a new chemical

---

[9] Guide to the International Patent Classification http://www.wipo.int/export/sites/www/classifications/ipc/en/guide/guide_ipc.pdf

[10] U.S. MPEP §905 https://www.uspto.gov/web/offices/pac/mpep/s905.html#ch900_d22347_283e8_366

compound, whereas if there is no mark in section C and there is a mark in section A61K, then the fundamental inventive concept would be a new pharmaceutical composition.

The same principle may apply in using the first type attribute in the 209 table in PATSTAT, where the first-listed classification assigned by the examiner is the one that most completely covers the technological subject matter of the disclosed invention. The first position symbol is identified as the first mandatory symbol listed on the classification form[11]. However, experience has shown that the first listed mark cannot always be relied on for this purpose in statistical analysis because in some data systems and jurisdictions the classification marks are merely listed alphabetically.

For these reasons, we chose to assign one category to each patent based on a manually assigned hierarchy of technologies that occur in the mining sector. To do this, each category was assigned a *mining category id* number when performing the search and then the minimum of all the *mining category id* numbers assigned to each patent was taken to determine the principal category for each patent. The *mining category id* numbers are listed in Appendix F. For example, if a patent application is assigned both categories 3.3 (separation) and 6.1 (exploration), then the minimum of 3.3 would be the final category for that patent application. This in effect creates our own first mining category or fundamental mining inventive concept for each patent.

Keeping in mind that the aim of the search strategy is for it to be modular and replicable, this is when the IPC exclusions become important. The exclusions need to be given a *mining category id* in order for them to be excluded by the minimization process. All IPC classes listed in Appendix E are excluded. Generally, patents with excluded IPC marks are excluded outright, even if they are classified in a mining category, (*mining category id* < 1) and some are excluded after the possibility of some mining categories higher in the hierarchy have already been assigned. However, all exclusions were given a *mining sector id* (mining_top_id) of 100, enabling the easy filtering out of exclusions at any stage in the analysis process.

Search Queries

With the two subset of data generally referring to the mining industry, we took advantage of our mining sub-sector and category classifications to assign each patent to its relevant categories during the search process.

The search queries were based on the IPC and keyword combinations outlined in Appendix B based on the overall understanding of the technology. For example, in the *Floatation* category in the *Processing* sub-sector (see Table 2), the following search strings were used:

- (IPC or CPC)=B03D AND (IPC or CPC)=E21
- (IPC or CPC)=B03D AND ((abstract or title) contains (mineral OR ore))
- IPC=(B03D 103/02 OR B03D 103/04 OR B03D 103/06 OR B03D 103/08 OR B03D 103/10)
- CPC=(B03D 1/021 OR B03D2203/02 OR B03D2203/04 OR B03D2203/06 OR B03D2203/08 OR B03D2203/10)

---

[11] U.S. MPEP §905 https://www.uspto.gov/web/offices/pac/mpep/s905.html#ch900_d22347_283e8_366

Table 2: Flotation category search strategy (portion of Appendix B)

Sub-sector	Category	IPC/CPC	IPC combination	keyword combination
Processing	Flotation	B03D	E21	mineral OR ore
		B03D 103/02 to /10 B03D 1/021 B03D2203/04 to /10		

For the mining commodities, some differentiation is also possible, but it was considered too difficult to separate based on product due to the nature of patent drafting. In addition, outputs of mineral mining such as gold, iron and aluminum were not included as keywords due to the likelihood of including many patents unrelated to the mining industry *per se*.

A more detailed assignment of search strategy and technology categories can be found in the accompanying search strategy scripts.[12]

The final technology subset for analysis consisted of patents includes patents in Mining sub-sectors (see Appendix F):

- Blasting (mining_top_id = 1)
- Environmental (mining_top_id = 2 or 102)
- Processing (mining_top_id = 3 NOT mining_cat_id = 3.31)
- Mining/Mine operation (mining_top_id = 4 or 9)
- Transport (mining_top_id = 5)
- Exploration (mining_top_id = 6 NOT mining_cat_id = 6.29)
- Automation (mining_top_id = 10)
- Refining (mining_top_id = 11)
- Metallurgy (mining_top_id = 12).

The firm search

Data used

The second search was a firm-based search. For the reasons outlined above, we choose to use both mining and METS firms in our search. In order to do this, we made use of lists of mining and METS firms provided by the participating IP offices, as well as data from Orbis.

Orbis

Orbis is a commercial database from Bureau van Dijck that contains information on more than 120 million companies around the world. It focuses on the biggest players in the market, which are also the most active ones in terms of research activity. It is a large database but may not be comprehensive. For example, it may lack information about companies from developing countries. Each firm in the Orbis dataset has a unique firm id called *bvdid*. The firms are categorized by the main sector of operation. We extracted firm and patent data from Orbis for firms in NACE classes corresponding to the relevant ISIC classes for Mining and METS firms outlined in Appendix G. Data was extracted from the Septemebr 2017 edition of Orbis.

Orbis also provides information on the patents held by a firm. Through the patent application numbers, we matched the *bvdid* from Orbis with *person_id* in PATSTAT.

---

[12] Available upon requests.

Australia

Australian firms were extracted from the Australian Business Register using ANZSIC classes equivalent to the ISIC classes in Appendix G. Additional lists of Australian mining and METS firms were also obtained from Geoscience Australia and the Department of Industry, Innovation and Science.

If the Australian mining or METS firm is a registered business in Australia, it has an associated Australian Business Number (ABN). With the ABNs in hand, we extracted any Australian patents associated with these firms from the 2017 edition of the IPGOD database, which links all Australian IP rights to firm information (Man, 2014). From the IPGOD, we extracted *person_id*s from PATSTAT by either matching the Australian patent numbers or the PATSTAT *appln_id* numbers given in the IPGOD.

United States

The USPTO provided a list of establishments from the National Establishment Time-Series (NETS) Database, retrieving establishments with a North American Industry Classification System (NAICS) code for mining or METS equivalent to the ISIC classes in Appendix G, for headquarters active in 2014.

Establishments were retrieved, rather than firms or headquarters, because the NAICS code for different establishments associated with the same headquarters can be different. When extracting the data, the USPTO observed that the NAICS for many headquarters were not in the list of NAICS codes selected to represent the mining industry.

Canada

CIPO provided a list of company names involved in the mining sector in Canada, including mining companies headquartered and/or active in Canada

Chile

INAPI provided a list of METS companies obtained from Fundación Chile and a list of large mining companies operating in Chile obtained from the Mining Council of Chile.

Brazil

INPI provided a list of mining companies obtained from the Brazilian National Department of Mineral Production (DNPM). DNPM only selected holders of active mining rights when providing the data.

Combined firm list

Each firm name provided was furnished with a unique firm identification number, which also identified the source of the firm name.

Name matching

While we were able to extract *person_id* data from PATSTAT for the lists of firms from Orbis and Australia, this was not the case for all the data. Clearly, name disambiguation and harmonization would add important value to our dataset, though the best matching approach partly depends on the research question at hand.

The existing literature has disambiguated both inventor and applicant names, through their names as well as other information contained in patent documents and many statistical databases are produced with names already disambiguated or harmonized. However, many of these approaches are far from perfect (see (Raffo & Lhuillery, 2009) and name matching over databases such as the PATSTAT database, which contains 55 million name records from over 100 years, is not straightforward.

To create this dataset we used a combination of the MATCHIT matching algorithm in STATA (Raffo, 2015) and the "SearchEngine" (Doherr, 2017; Czarnitzki, et al., 2015). In essence, the matching algorithms select pairs of patent applicants and firms, who are likely candidates to be the same firm, due to homonymy or similarity of names. While every attempt was made to match all firms to patent applicants, we cannot exclude that some patents may have been missed due to false negatives. Since the lists of firms provided to us were for currently active mining firms, we restricted the name matching to a subset of PATSTAT data from 1990.

The resulting data was a list of firms matched with a *person_id* from PATSTAT, if the name was found in PATSTAT. Disregarding false negatives, unmatched firm names means that those firms have no patents.

The combined firm list matched with PATSTAT *person_ids* was then used to extract all the patent applications relating to mining and METS firms from the database.

Name cleaning

The results from the technology search and firm search were combined and the applicant names were cleaned with a combination of probabilistic record linking in STATA (Wasi & Flaaen, 2015) and fuzzy matching in Open Refine.

5. Analysis

This section describes the results of our analysis. The goal is to study the outcomes of the structural change in investment in mining innovation observed in the early 2000s.

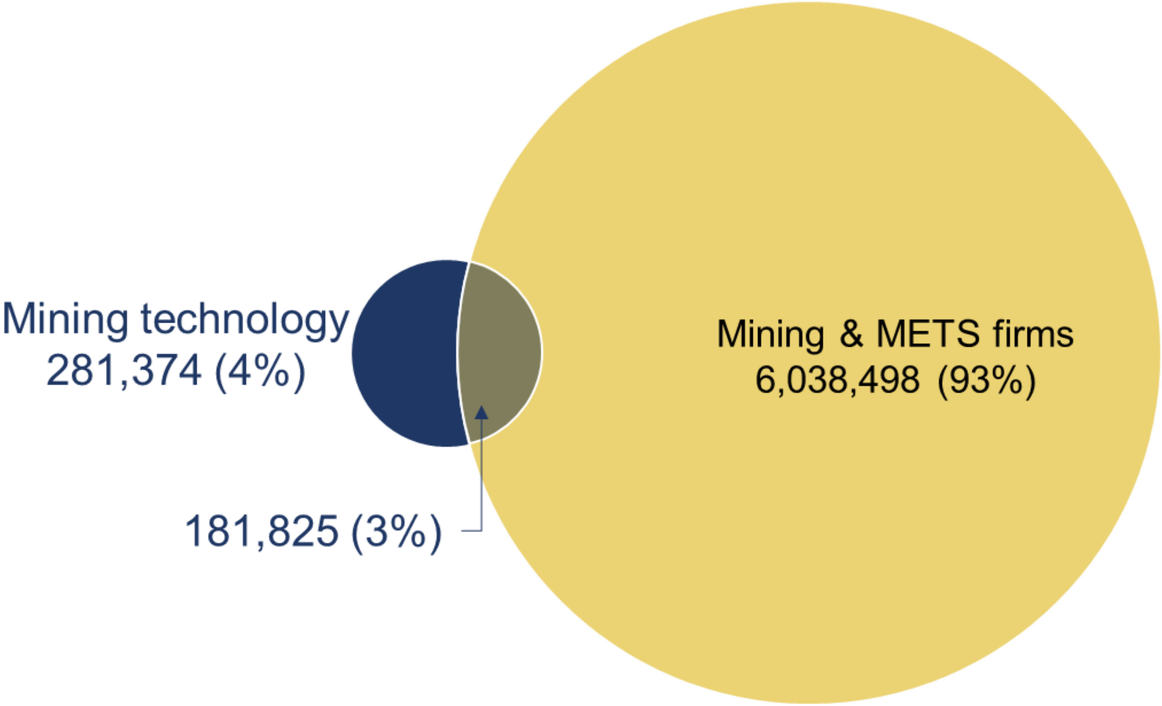
The patents in the mining dataset go back as far as 1826. However, in this section most of the analysis is based on indicators related to patent families[13] with an earliest priority date between 1990 and 2015. This period of time is crucial for studying the surge of mining innovation after 2005.

The total number of patent families in the mining database file between 1990 and 2015 is 6,501,697. Out of those, 181,825 families were found in both the technology and firm searches, 6,038,498 families were found in the firm search only and 281,374 families were found in the technology search only (Figure 5). From these results, we can see that there is only a small amount of overlap between the two search strategies. This demonstrates that neither approach can be considered fully comprehensive, and the type of search done for patent analysis really depends on the type of analysis that will be done on the data, in addition to the types of data that will be linked to the patent data for analysis. For example, if you have firm level expenditure data available, a firm-based patent search will be useful, but used cautiously as firms may patent in multiple technology areas.

---

[13] In the following analysis the terms patents and patent families are considered the same/used interchangeably.

Figure 5: Patent families potentially related to mining by source (earliest priority year 1990–2015, inclusive)

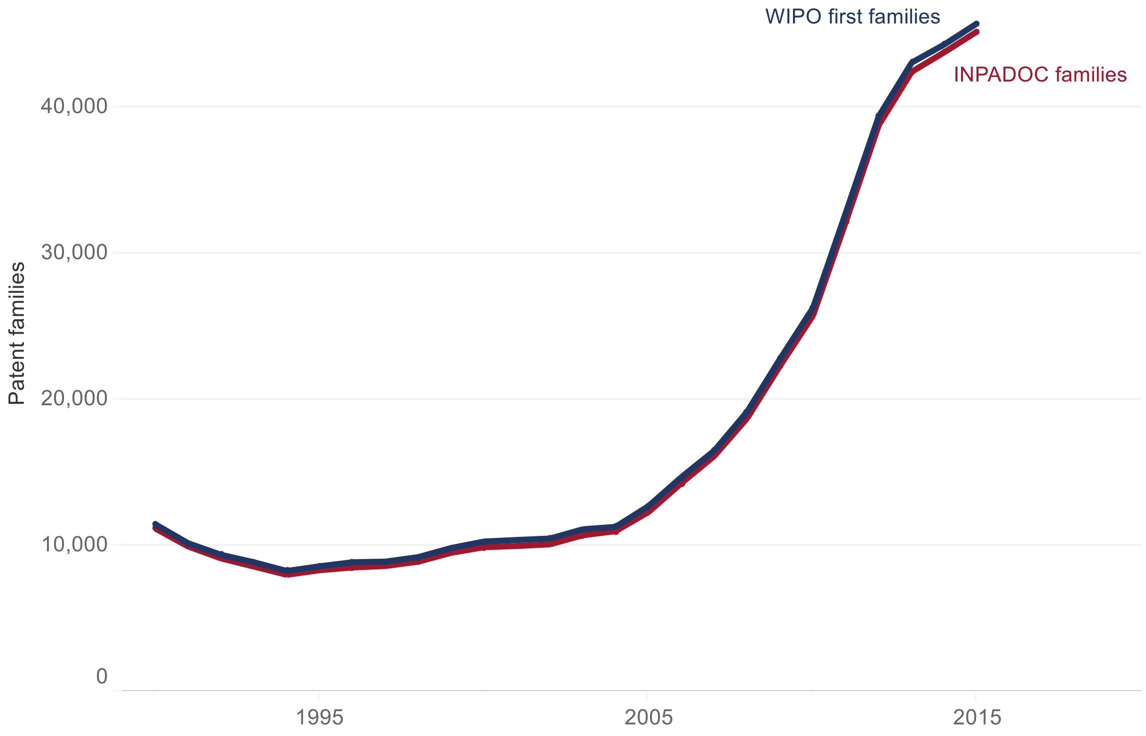


Source: WIPO Mining Database.

Comparison of patent families

We use patent families as our unit of analysis in order to identify single inventions or to group closely related inventions together to avoid double counting of patent publications (UKIPO, 2015; Dechezleprêtre, et al., 2017; Martínez, 2011). However, there are multiple definitions of a patent family. Figure 6 illustrates the differences in magnitude between two types of patent families over time: INPADOC extended families (EPO, 2017) and first filed families (chosen for analysis in this paper). Although there is between a one and four percent difference between INPADOC families and first filed families in the technology subset, the general trend of families is the same over time (see also Fink, et al.(2013) for further discussion of WIPO patent families).

Figure 6: Comparison of patent family types, by earliest priority year

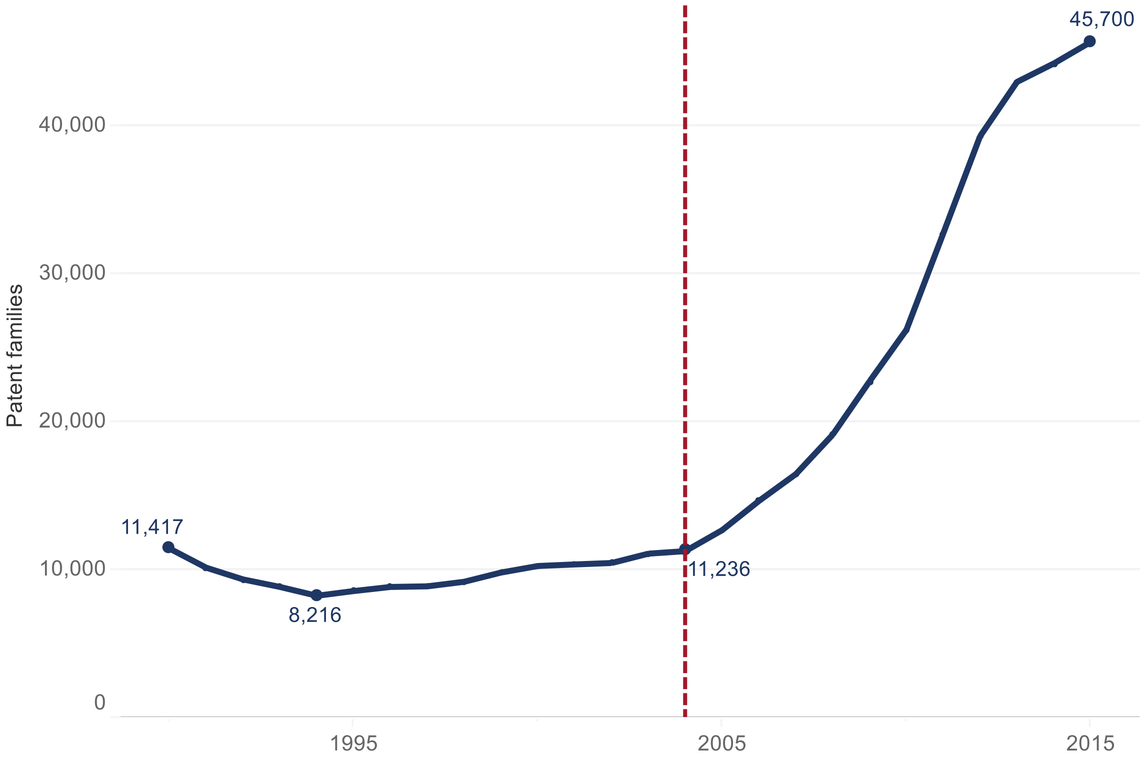


Source: WIPO Mining Database (technology subset).

From the technology search, we identified a total of 463,199 patent families filed between 1990 and 2015, inclusive. Figure 7 shows the number of patent families relating to mining technologies filed since 1990. It shows a relatively steady number of inventions filed between 1990 and 2003, with an exponential growth observed from the second half of the 2000s. Differently from R&D and exploration figures, we observe a slowdown but not a reverse of trend after 2012.

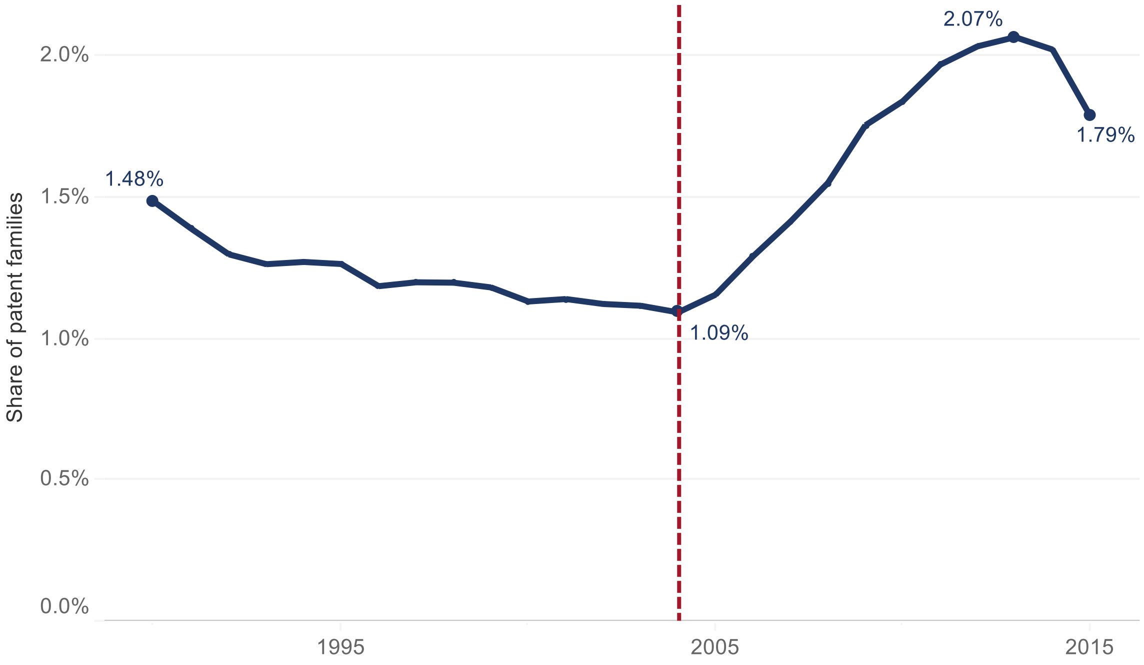
Keeping in mind that trend in overall patent applications has continued to increase (the patent surge) (Fink, et al., 2013), we also examine of the patent families from the technology search as a share of all patent families over the same time period (Figure 8). Mining patents have outpaced the overall patenting activity since 2004. After more of a decade of decline in the 1990s and early 2000s, we observe the share of mining patents to almost double from to 2004 to 2013. We can also see a slight fall since 2013, when the share fell back to 2009-10 levels in 2015 compare to the structural change.

Figure 7: Patent families from the technology search, by earliest priority year



Source: WIPO Mining Database (technology subset)

Figure 8: Technology subset patent families as a share of all families, by earliest priority year



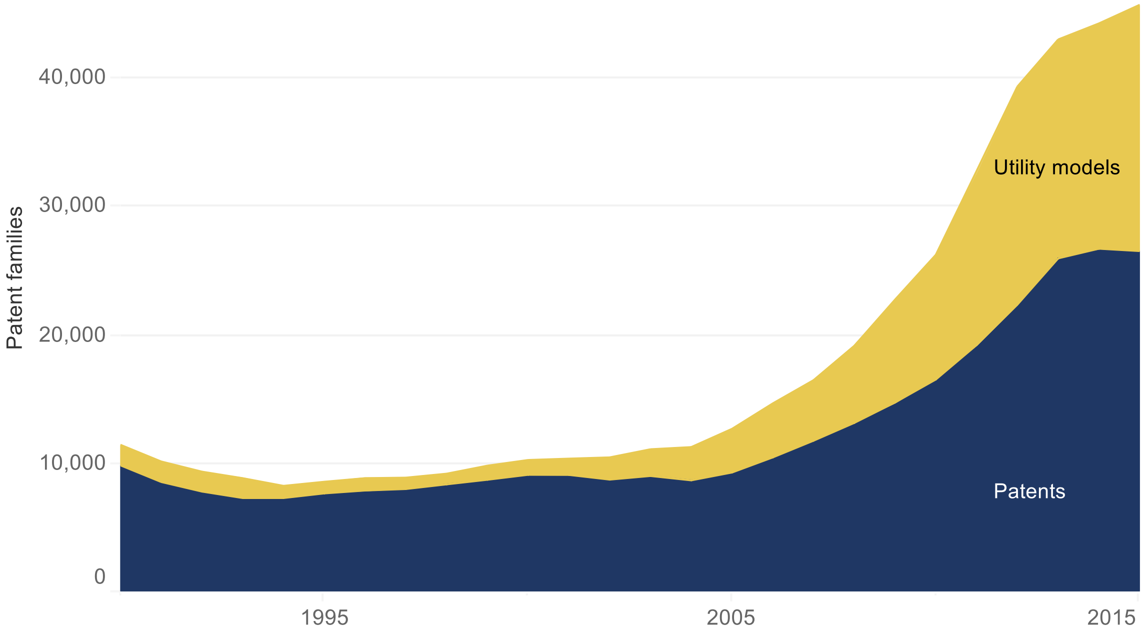
Source: WIPO Mining Database (technology subset)

Utility models

Utility models exist in some countries to protect innovations which do not fulfill standard patentability requirements, but which may have an important role in a local innovation system. Although a utility model is similar to a patent, it is generally cheaper to obtain and maintain, has a shorter term and less stringent patentability requirements.

In this paper, patent families include both families associated with patent applications for inventions and families associated with utility model applications. One of the reasons there may have been a large surge in patent filings after 2004 is the large rise in filings of utility models since that time (Figure 9), which has risen from around 11 percent of total families in 1995 to 42 percent of total families in 2015.

Figure 9: Comparison of patent types, by earliest priority year (technology subset)



Source: WIPO Mining Database (technology subset)

Top Innovating Mining Fields

As discussed above, we chose to assign a single mining category to each patent family in the analysis. To see the difference between doing this and having multiple categories per patent family, we have produced comparison data in Table 3. The most significant difference between the two is that there are four times the number of patent families in the mining category in the multiple-assignments compared to the single assignments (Table 3), which is to be expected based on the search field. There are also a lot more automation patents in the multiple-assignments compared to the single assignments, due to a vast majority of automation patents also falling under the transport category. For this reason, we also included an Automation flag as part of the data for analysis.

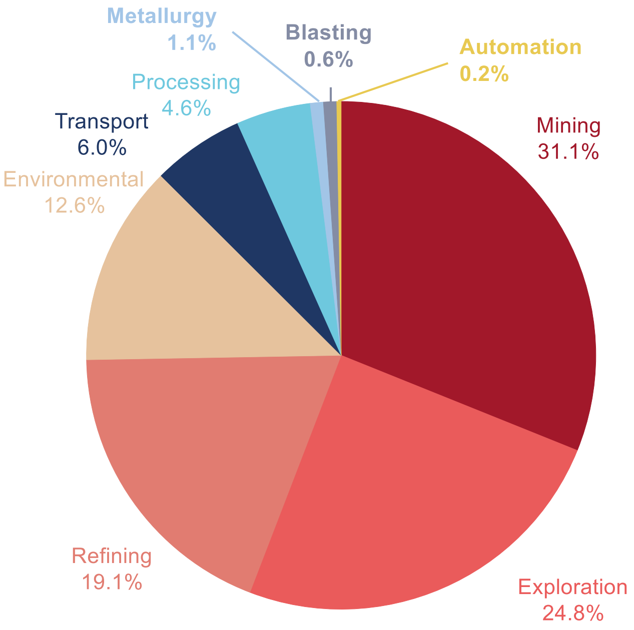
Table 3: Mining patents by category, 1990-2015

Mining sub-sector	**patent families** **multiple sectors per family**	 **single sector per family**
Automation	14,003	1,141
Blasting	2,831	2,814
Environmental	95,713	58,426
Exploration	140,345	114,676
Metallurgy	13,338	4,868
Mining	545,482	144,144
Processing	23,823	21,202
Refining	97,480	88,362
Transport	35,595	27,566
Grand Total	**663,322**	**463,199**

Source: WIPO Mining Database (technology subset)

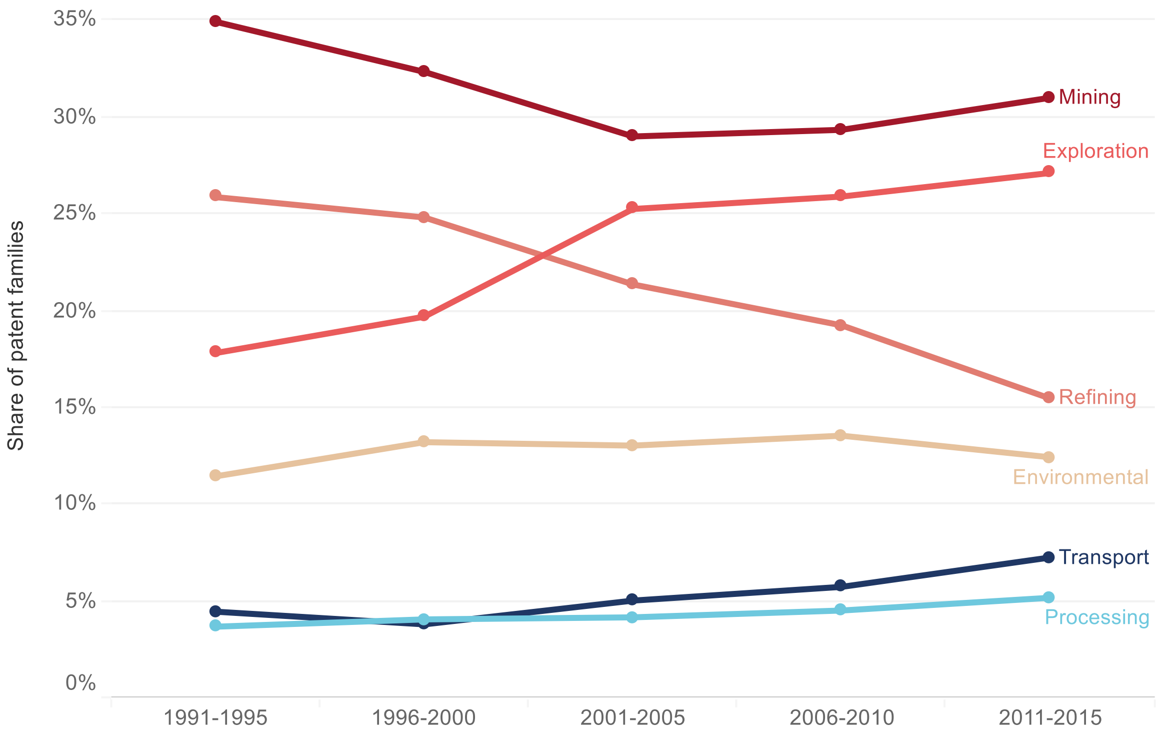
We observe mining innovation all across these subsectors. The mining subsectors where we observe more innovation are mining/mine operation (31.1 percent of total mining innovation), exploration (24.8 percent) and refining of extracted materials (19.1 percent). Other fields involve less innovation: blasting (0.6 percent), environmental improvements (12.6 percent), metallurgy (1.1 percent), processing (4.6 percent) and transport (6 percent) (Figure 10).

Figure 10: Mining technologies by subsectors, 1990-2015



Source: WIPO Mining Database (technology subset)

Figure 11: Distribution of mining technologies in subsectors by period, 1990-2015

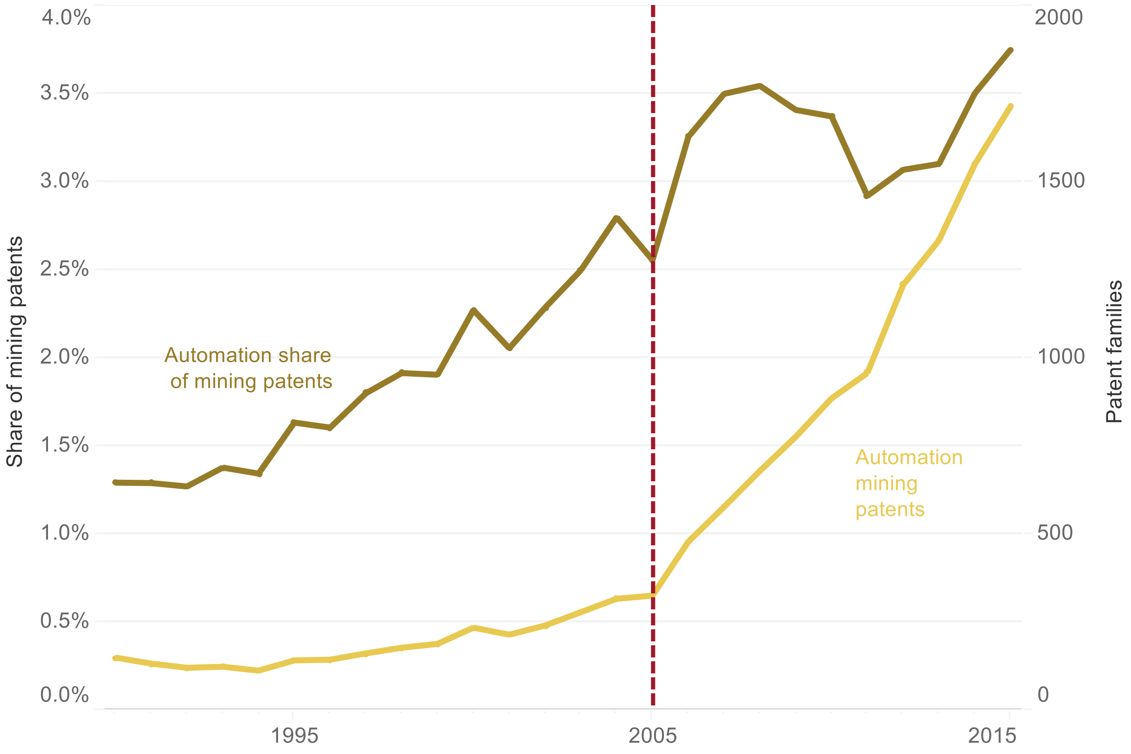


Source: WIPO Mining Database (technology subset). Note: only the top six subsectors included.

Some subsectors have contributed to the recent mining innovation uptick more than others. Comparing the distribution trends, there has been a switch away from refining mostly to exploration and transport (see Figure 11). There is also a smaller share increase from environmental innovation and processing subsectors. The industry's technological response to the extractive products demand surge seems to have put less emphasis on improving refining methods. This may be a consequence of the declining quality of mined ores, which may make it inefficient to invest in new refining techniques. Firms could prefer to dig new mines instead. The exploration and transport trends are likely to relate with the industry's increasing need to discover new deposits in farther locations to face rising demand. Similarly, the increase in share of environmental technologies are probably linked with a wider social and industry awareness of the environmental impact of mining activities.

In addition, the so-called fourth industrial revolution – namely advances in information technology and artificial intelligence – may offer even more potential for raising productivity in knowledge-based activities like deposit modelling (exploration), logistics (transport) or waste management (environmental), among many other examples. Interestingly, automation innovation in mining increased both in volume and share during the 1990s and early 2000s when the overall mining innovation activity was relatively flat (see Figure 12). Automation innovation had a slow start when mining innovation started to pick up its pace in the second half of the 2000s. However, we now observe a spectacular second boom of automation in both volume and proportion of mining patents, which is likely to relate with the spread of digitalization.

Figure 12: Patents families in automation class over time



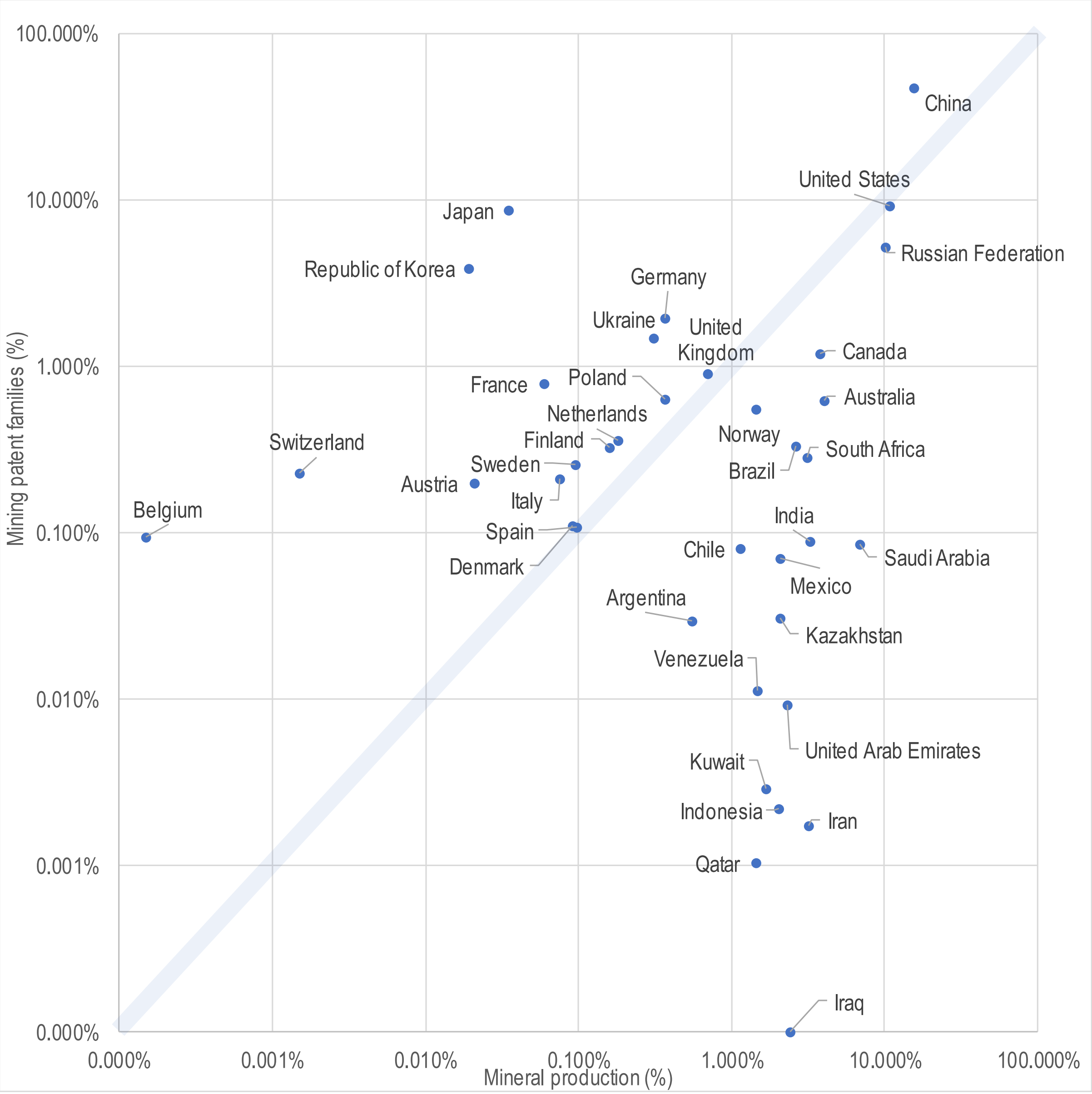
Source: WIPO Mining Database (technology subset)

Where is all this mining innovation originating from?

The distribution of economies contributing to mining technologies does not match one to one with the typical mining producing ones (Figure 13). Only China and the United States gather more than 10 percent in both mining output and innovation. The Russian Federation is the only other economy to have more than 10 percent of mining output but it generated less than 1 percent of the mining innovation. Japan, generating more than 10 percent of the innovation but producing less than 0.1 percent of the output, is the opposite case. On a different scale, some other economies have a relatively balanced output-innovation ratio as China and the United States. Australia, Canada and Norway produce more than 1 percent of the mining output and generate about 1 percent of the innovation. Conversely, the United Kingdom generates more than 1 percent of the mining innovation and produces slightly less than 1 percent of the output. One order of magnitude lower, Spain having about 0.1 percent of both output and innovation is another example.

Countries such as Brazil, Chile, India, Indonesia, Iran, Iraq, Kazakhstan, Kuwait, Mexico, Qatar, Saudi Arabia, South Africa, and Venezuela – in addition to the already mentioned Australia, Canada, Norway and the Russian Federation – produce substantially more mining output than Japan or even the United Kingdom, but they produce much less mining innovation. On the contrary, countries such as Austria, Belgium, Denmark, Finland, France, Germany, Italy, Netherlands, Poland, Republic of Korea, Sweden and Switzerland join Japan and United Kingdom in their disproportionate contribution to mining innovation given their production. It is also important to note that these economies – including US, China, Australia, Canada and Norway – not only generate most of the mining technologies but they are also where most of the patent protection is sought for. Very few mining technologies seek patent protection in countries with high mining output but relatively low innovative one.

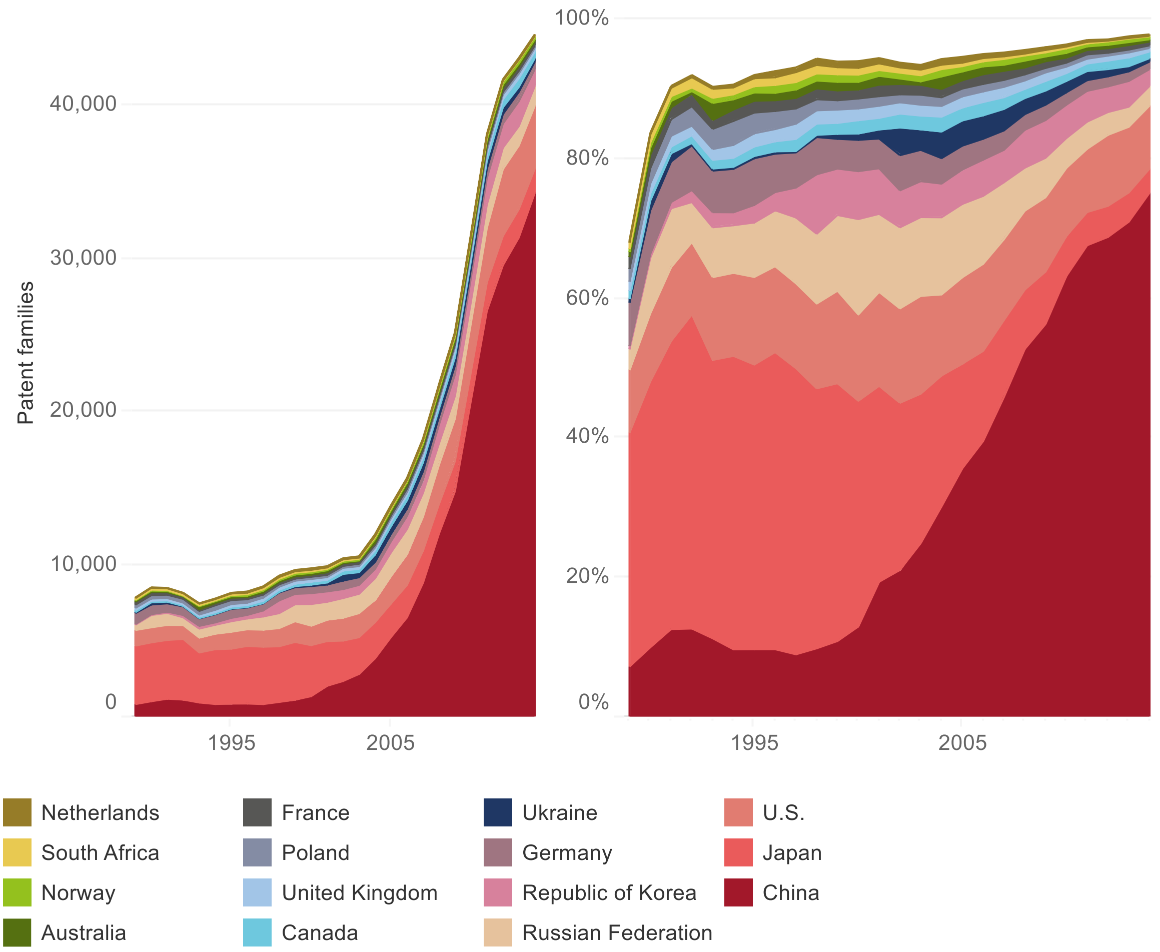
Figure 13: Mining production and innovation by country, selected countries



Source: WIPO Mining Database (technology subset) and Reichl et al (2018). Notes: sample contains only top mineral producing and top mining patenting countries.

What explains these different patterns between mining production and innovation? One of the most plausible explanations is that mining innovation – particularly breakthrough patentable one – is more likely to happen in functioning innovation systems not necessarily based on mining operation countries. The U.S., Japan, Republic of Korea, Germany, United Kingdom and, lately, China are well-known technological hubs where innovation across sectors spurs more rapidly than the rest of the world (WIPO, 2018). These innovation systems – and those from other OECD economies – host innovative stakeholders from different industries which are likely to develop mining innovation. Many METS companies originate and conduct their R&D in countries which are not necessarily where they apply the technology, such as Japan, Switzerland or the Republic of Korea.

Figure 14: Mining innovation by top country of origin



Source: WIPO Mining Database (technology subset)

Undeniably, China, Japan, United States, Germany, Republic of Korea, France, United Kingdom, Finland, Netherlands, and Canada were the largest contributors in volume to the recent mining innovation upsurge (Figure 14). These ten economies account for roughly 90 percent of all mining technologies. Within these, China observes the highest increase during the last decade.

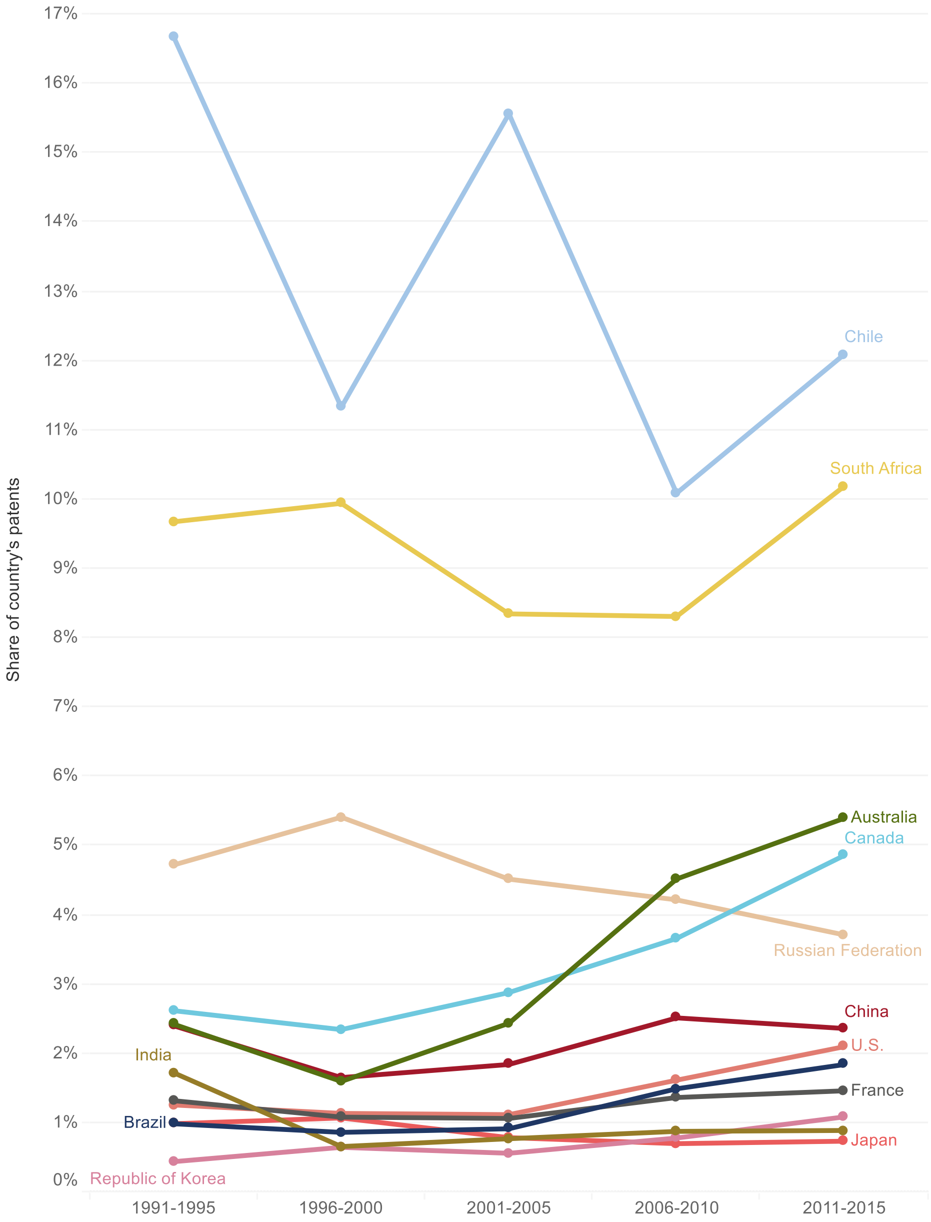
Contribution to the mining innovation boom did not come from the usual suspects

Despite China's impressive growth in volume, this is not what explains the rapid increase in the world's mining innovation relative to all innovation. Indeed, China's rapid innovation increase for all technologies outpaces its mining innovation trend.

This is because the concentration of absolute mining innovation tells very little about the countries' technological specialization in mining. Many nations where mining operations are conducted may have a disproportionate amount of mining innovation in comparison to their overall innovation. Moreover, given the different country size and propensities to patent, comparing the overall levels of patenting activity between countries can be, to some extent, misleading about where the most specialized mining innovation may reside.

In order normalize these effects, we use the relative specialization index (RSI), which indicates as positive value implies that the country where mining innovation is more important than the average (Figure 15)[14]. A negative RSI means that mining innovation is not particularly dominant compared to innovation in other industries.

Figure 15: Mining patents share by country, selected countries



Source: WIPO Mining Database (technology subset)

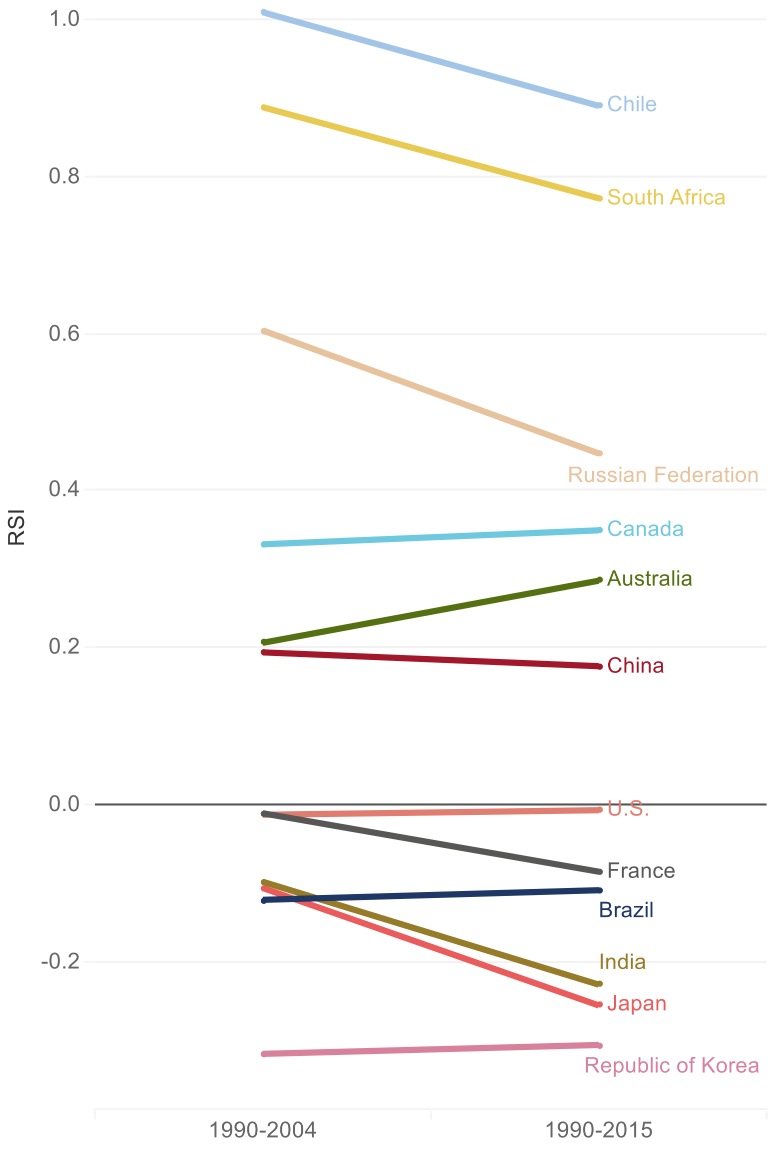
---

[14] The RSI measures the relative share of mining innovation of a given country with respect to the share of mining innovation of all countries. The RSI calculations are based on the following formula:

$$RSI = \log_{10}\left(\frac{P_C^M / P_{C,Tot}^M}{P_W^M / P_{W,Tot}}\right)$$

where P_C^M is all mining patents from country C (in all technology fields); $P_{C,Tot}^M$ is total mining patents from country C; P_W^M is total mining patents filed all across the world; $P_{W,Tot}$ is total patents filed across the world. The calculation considers the country of origin; for a technical definition of country of origin please refer to Appendix H.

Figure 16: Mining relative specialization index (RSI), selected countries



Source: WIPO Mining Database (technology subset)

It is not surprising that countries where mining represents a significant part of the economic activity are relatively specialized in mining innovation. Chile, South Africa, Australia, Canada, the Russian Federation and China are mining producing economies where the share of mining innovation exceeds the world's average. Brazil and India, however, are notable exceptions to this pattern. The US, another top producing mining economy, is only marginally not specialized in mining technologies. While the relative ranking of countries did not change radically before and after the mining innovation surge, we do observe that the degree of specialization of many countries did change. This is also informative about their contribution to the recent surge relative to all technologies.

In this respect, we observe that traditionally mining producing and specialized economies such as Chile, South Africa, the Russian Federation and China have actually diminished their specialization in mining innovation; and, thus, these economies have not contributed to the recent relative upsurge. Australia and Canada, on the other hand, have increased their mining relative specialization, which implies that these contributed to the overall surge.

Even if still not specialized in mining innovation, the United States of America and Brazil have also contributed to the recent relative boom. During the last decade, these economies decreased their negative relative specialization becoming almost positive. Japan and India have continued to specialize outside of the mining domain, also contributing negatively to the recent relative surge.

As discussed above, the increase of mining innovations related to exploration, transport and automation explain in part the recent surge. We now dig deeper to understand which are the countries contributing the most to these subsectors booming (Figure 17). The first stylized fact is that mining subsector specialization within countries is fairly stable in rank, but they can vary substantially in their relative intensity.

Most of the increase in the exploration subsector is not coming from the traditionally specialized economies. All four specialized economies in exploration – namely Canada, China, the Russian Federation and the US – diminished their relative specialization. China even recorded a negative index after the surge. While still not specialized in exploration, Australia, Chile and the Republic of Korea increased their relative specialization in this subsector and are probably among the largest contributors to the exploration booming relatively to the other sectors.

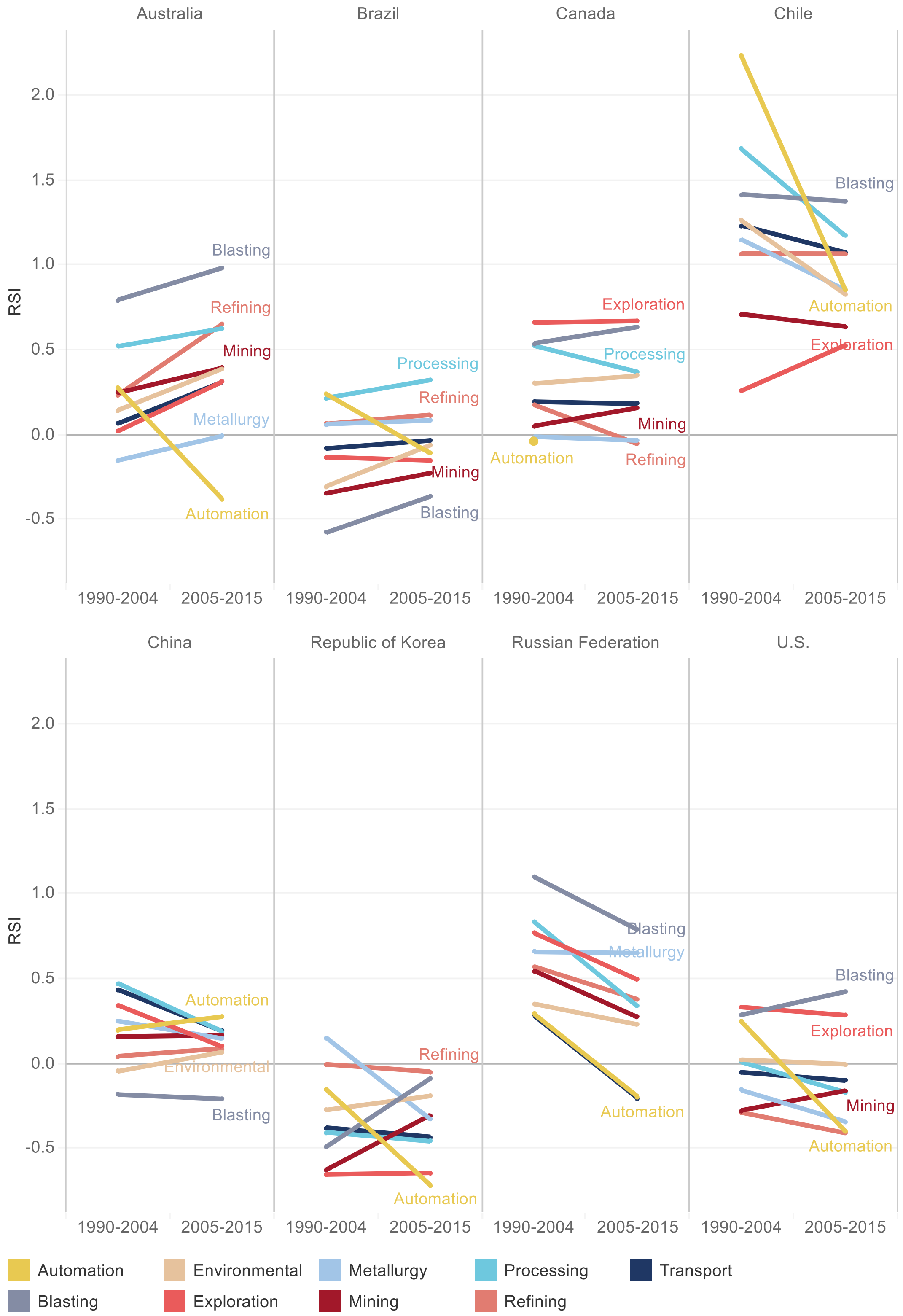
Among these economies, Chile was the only country specialized in mining transport that deepened its specialization. While still not specialized in transport, Australia was the only other selected country that improve its relative specialization in this subsector. Brazil and China remain specialized in mining transport but have both diminished their relative specialization. Canada, the Russian Federation, the Republic of Korea and United States of America have been specializing even more outside of the transport domain.

The US, Canada and Australia, are more specialized in automation compared to lower-middle income and upper-middle income nations such as China, Brazil, Mexico and India. This is also the case of countries which are not particularly mining oriented, such as Sweden, Singapore, Israel and Belgium. This is also because mining automation innovation is concentrated in METS firms (96.8 percent) rather than mining firms. It seems that mining firms prefer to outsource this type of innovation. METS firms innovating in automation do not need to be located in mining countries. They can conduct their R&D abroad and then sell their technologies to operating miners. High-income countries have an advantage in high-tech industries favoring the development of automated technologies. In addition, the higher income economies also producing mining output have stronger economic incentives to make use of automation technologies in order to mitigate higher labor costs.

These patterns only apply partially to the dynamics of automation specialization within these economies. Australia, the Republic of Korea and the United States of America reinforced their relative specialization in automation in a remarkable fashion during the mining innovation booming period. In contrast, Brazil and Chile's specialization in automation reversed in a similar spectacular way. Canada still is fairly specialized in automation but lost some of its intensity during the last decade. The Russian Federation only deepened its lack of specialization in automation. Even if still extremely not specialized in automation, China improved its automation RSI substantially.

The selected economies are particularly weak in environment specialization. Only Chile, the Republic of Korea and the United States of America show a positive RSI for environmental technologies. However, most of these economies are improving their specialization in the last decade. In particular, the Republic of Korea deepened its environmental specialization. Australia, Brazil, Canada, China and the Russian Federation improved substantially making their RSI almost positive. Conversely, Chile and the United States of America are the only ones in this sample that worsened the environmental specialization.

Figure 17: RSI by mining sub-sector, selected countries



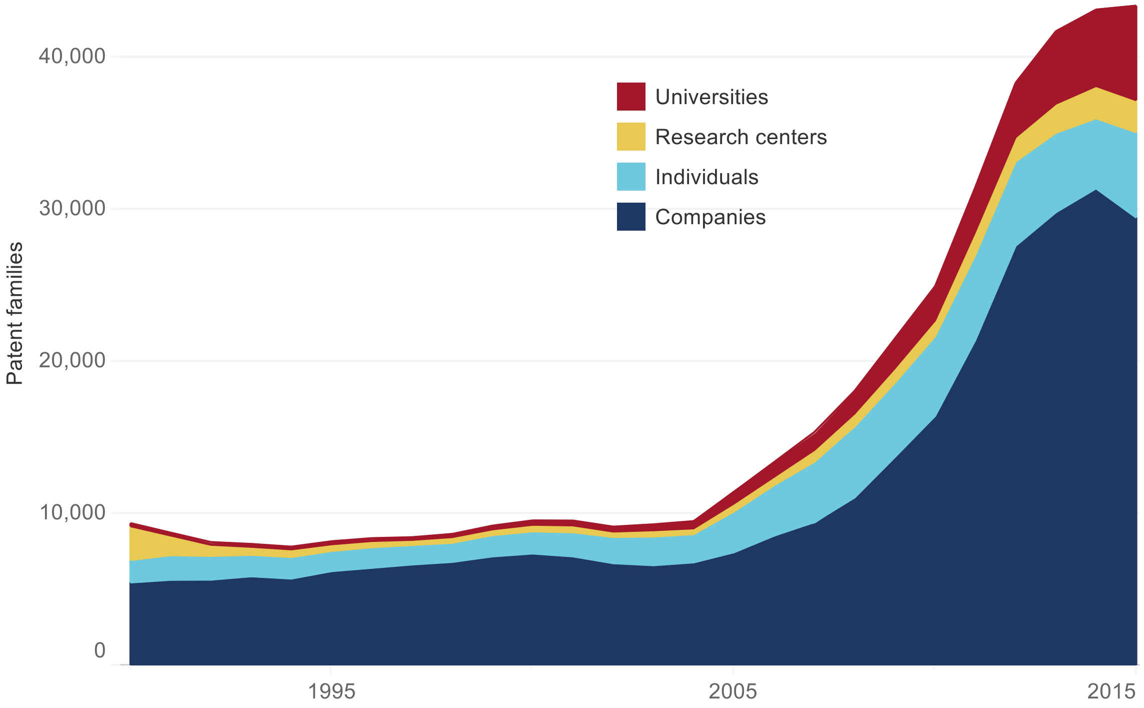
Source: WIPO Mining Database (technology subset)

A complex mining innovation ecosystem

Companies and other stakeholders are accountable for the mining innovation boom. Established companies – both mining and METS – created about two thirds of the mining related technologies in our data. Individuals – likely on behalf of startup and micro companies – originated almost a quarter of these technologies. Academic institutions produced the remaining technologies, where public research organizations (PROs) and universities generated 9 and 6 percent, respectively.

Companies and individuals mostly carried out mining innovation. However, in recent years, there has been a rise in the participation of universities in the innovation ecosystem (Figure 18). They were almost totally absent from the scene before the 21st century. This may be the result of the increasing number of collaborations between universities and companies. More and more mining firms finance university programs focused on mining studies to shape high-skilled human capital. For example, the collaboration between Vale and many universities in Brazil; the historical collaboration between Noranda and McGill University in Canada; or the success of Cooperative Research Centres in Australia (Amburle, et al., 2019).

Figure 18: Number of mining patents over the years by type of stakeholder



Source: WIPO Mining Database (technology subset)

In most of the cases, mining companies establishing collaboration with academia hired the highly qualified human capital directly, creating channel for the development of innovations. This also explains why we observe very little co-patenting activity. In the period 1970–2015, only 4 percent of total mining patents had two or more applicants. This share has been constantly decreasing over time, from 9.3 percent in 1970 to almost 1 percent in 2015. Most of the collaboration activity relates to individuals (71.7 percent) and private companies (25.7 percent). PROs (1.7 percent) and universities (0.8 percent) rarely appear as co-applicants, despite the above mentioned many collaborations with the private sector.

This may due to specific and reserved contractual agreements among the parties involved which may assign the patent only to the private partner.

Within the academic sector, PROs have seen a comeback in the mining ecosystem in recent years. Historically, these institutions have been a large promoter of mining innovation from the mid-70s to the beginning of the 90s. They were particularly present in the Soviet Union, where 80 percent of PRO mining patents originated from in the period 1970–1989. Since 1990, PRO innovation activity slowed down greatly until 2010. The fall of the Soviet Union explains in a great extent this sudden drop of PRO patents. However, many other state-funded research organizations in the West also closed or diminished their operations during the 1990s, such as the U.S. Bureau of Mines in 1995 and the U.K.'s Warren Spring Laboratory in 1994. Accounting for 56 percent of PRO mining patents in the period 2000–2015, China-based PROs explain at large their recent trend.

Despite the private companies are the largest contributor of mining technologies, only a small portion of mining and METS firms file for patents. Within these, METS firms are around 10 times more likely to file for patent protection than mining companies (Table 4). About 3.8 percent of METS firms file patents compared to only 0.4 percent of mining firms. Mining firms patent significantly less than firms in other sectors, such as pharmaceuticals (5.8 percent), chemical manufacturing (2.5 percent) and manufacturing of consumer electronics (5.5 percent). However, their patenting rate is still much higher than the one observed for firms in agriculture (0.05 percent).

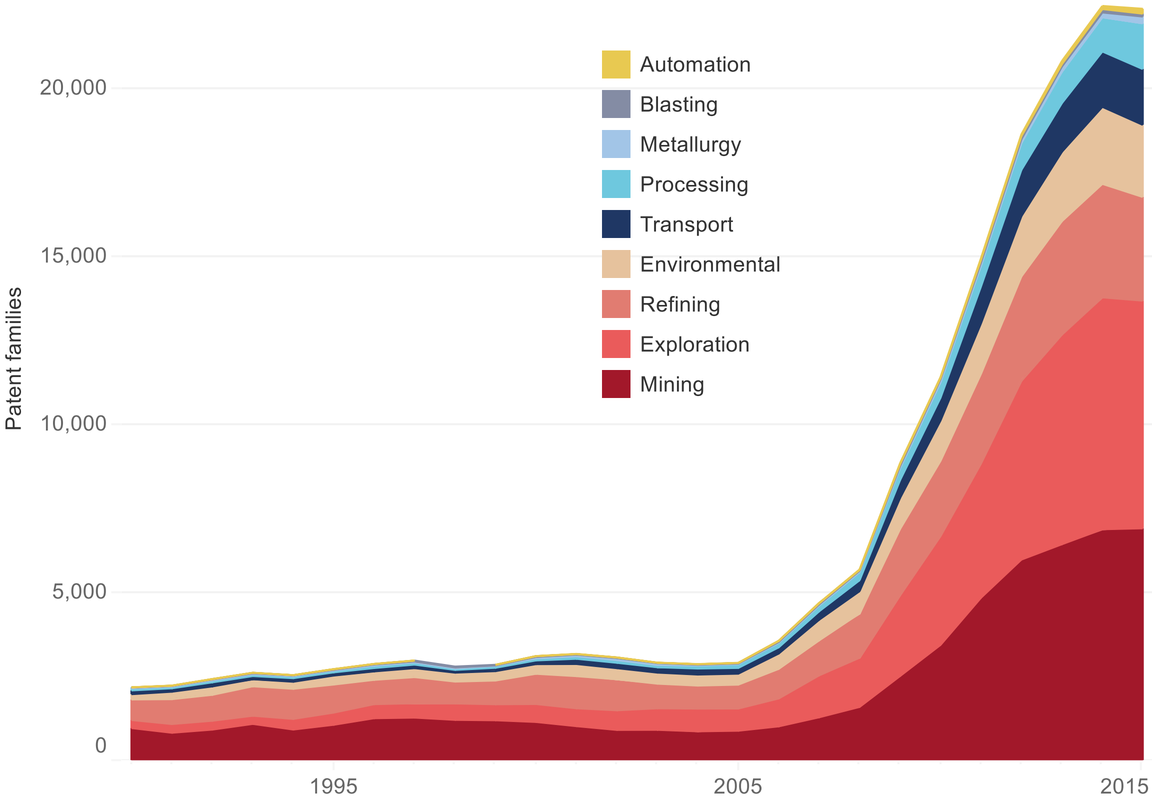
Table 4: Mining firms with and without patents

Firm sector		**Number of firms**			
		With patents		**Without patents**	
METS		4712	3.8%	125,011	96.4%
Mining	Coal	174	0.3%	49,897	99.7%
	Metal ore	321	0.4%	77,584	99.6%
	Nonmetallic mineral	53	0.9%	6,218	99.2%
Oil & Gas		838	1.5%	57,421	98.5%
Quarrying		649	0.3%	192,086	99.7%

Source: Orbis and WIPO Mining Database (firm subset)

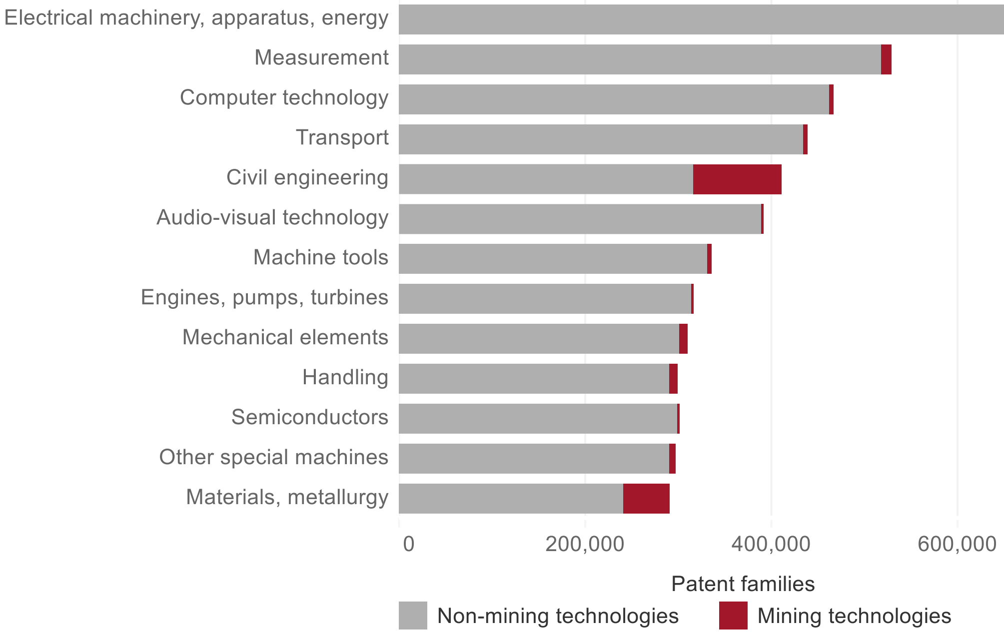
The fact that mining companies get exclusive operation rights as a result of exploration may explain in part this low. Firms finding new mineral deposits can obtain exclusive and time-limited rights over those resources in a manner similar to the patent system. Investments in exploration innovation may be fully appropriated with such exclusive rights without the need to get patent protection. This parallel may help explain the low levels of mining firms with patents. However, mining firms file most their mining technologies precisely in the exploration sub-sector (Figure 19).

Figure 19: Mining and METS firms by technology, by earliest priority year



Source: WIPO Mining Database (firm subset)

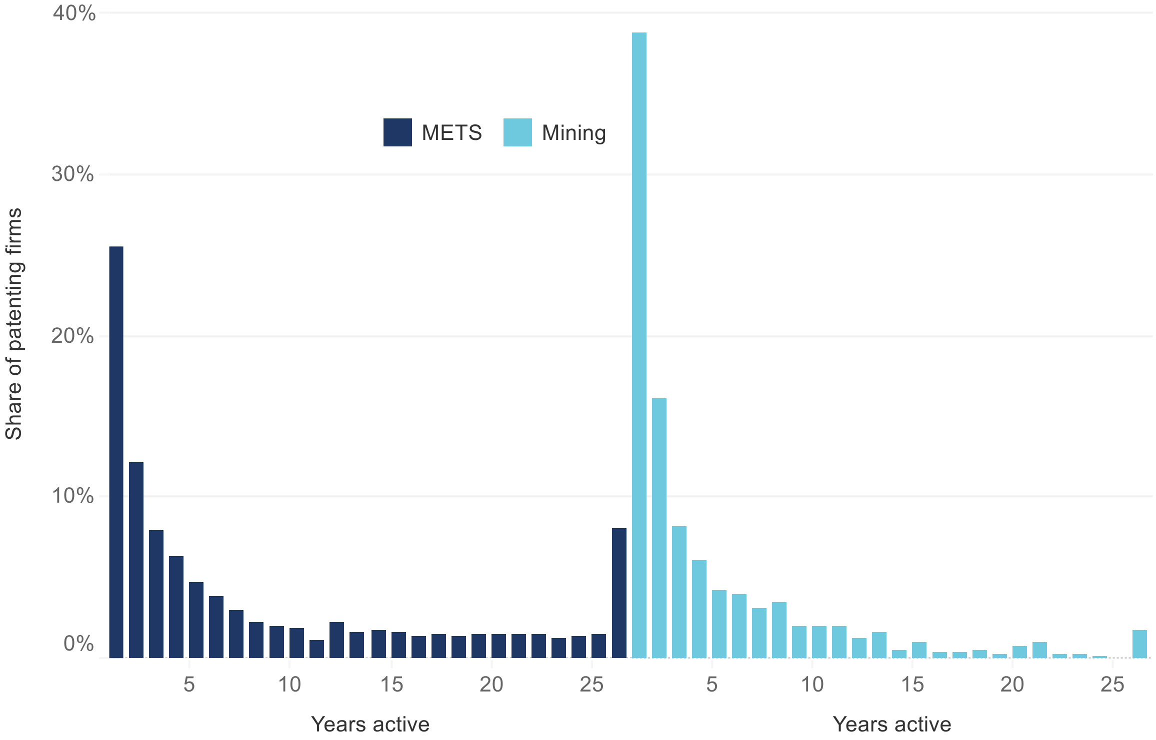
Figure 20: Patent families of mining firms by WIPO technology field



Source: WIPO Mining Database (firm subset)

Still, the most of the patenting activity by mining firms is not related with mining technologies. An analysis of the WIPO technology fields show that electrical machinery, apparatus and energy is the largest field for mining firm patents in non-mining technologies (Figure 20)[15].

Figure 21: Number of years METS and mining firms are active in patenting



Source: WIPO Mining Database (firm subset)

Figure 21 plots the number of years METS and mining firms in our database have filed a patent out of the 26 years between 1990 and 2015, inclusive. By comparing the two not only do we notice that the number of METS firms with patents is substantially higher than that of mining firms, but also they patent on average for a longer period of time. Only seven mining firms patent in every year of the 26 years; compared to 224 METS firms. This again highlights the central role that METS firms play in mining sector innovation.

A further reason for the recent surge in patents may be the increase in patents filed in China by Chinese residents. Patent rights are territorial in nature, meaning that they only apply in the jurisdiction of the patent office that grants the right. A patent applicant seeking to protect an invention in more than one country has to file the patent application in each country of interest. We use this to approximate the countries in which the applicant wishes to market their invention.

The propensity of patent applicants to seek protection beyond their national jurisdiction differs markedly. For instance, in 2011, residents of China filed fewer than 20,000 applications outside of China, or only 4.54 percent of all the applications by Chinese residents worldwide (Fink, et al., 2013; Miguélez & Fink, 2013). Chinese patent strategies are further elaborated in (Kashcheeva, et al., 2014).

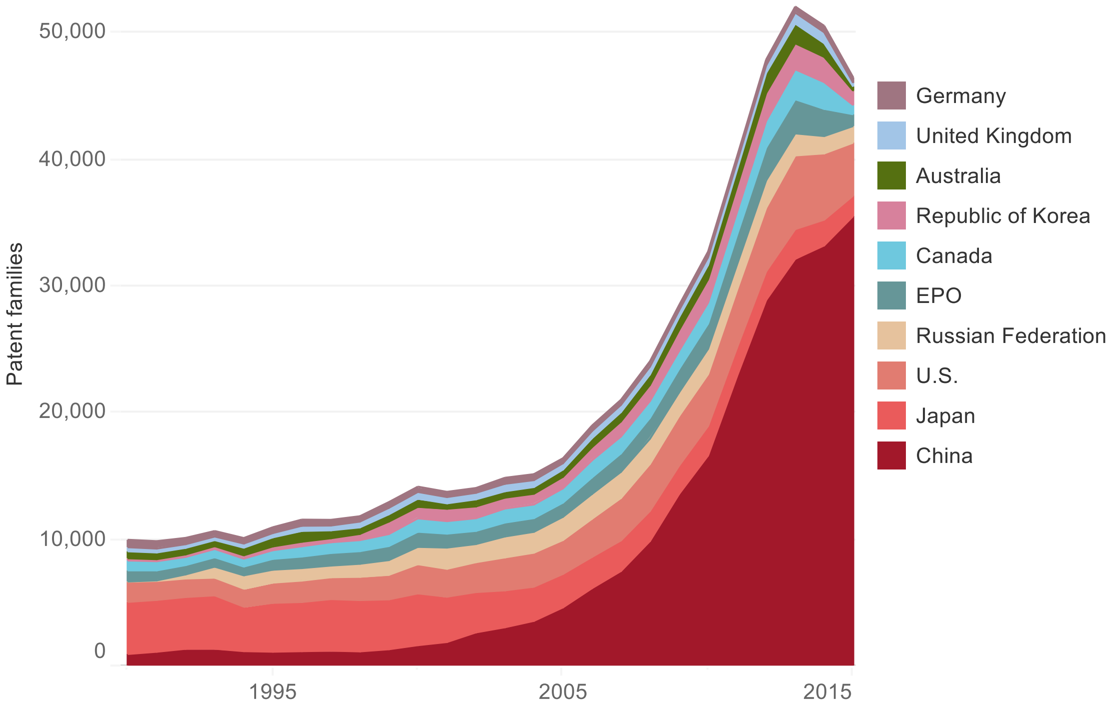
Countries where most of the mining innovation is protected are: China (33 percent of total mining innovation), Japan (20.4 percent), the Russian Federation (13.4 percent) and the U.S.

---

[15] Civil engineering contains the IPC classes broadly related to mining including also oil and gas drilling.

(10.7 percent)[16]. China entered only recently among the top filing countries (Figure 22) following the boom in its economy after the 80s. After accession to the WTO, the Chinese economy boomed and patent applications followed a similar pattern.

Figure 22: Top 10 jurisdictions for mining patents by earliest priority year



Source: WIPO Mining Database (technology subset)

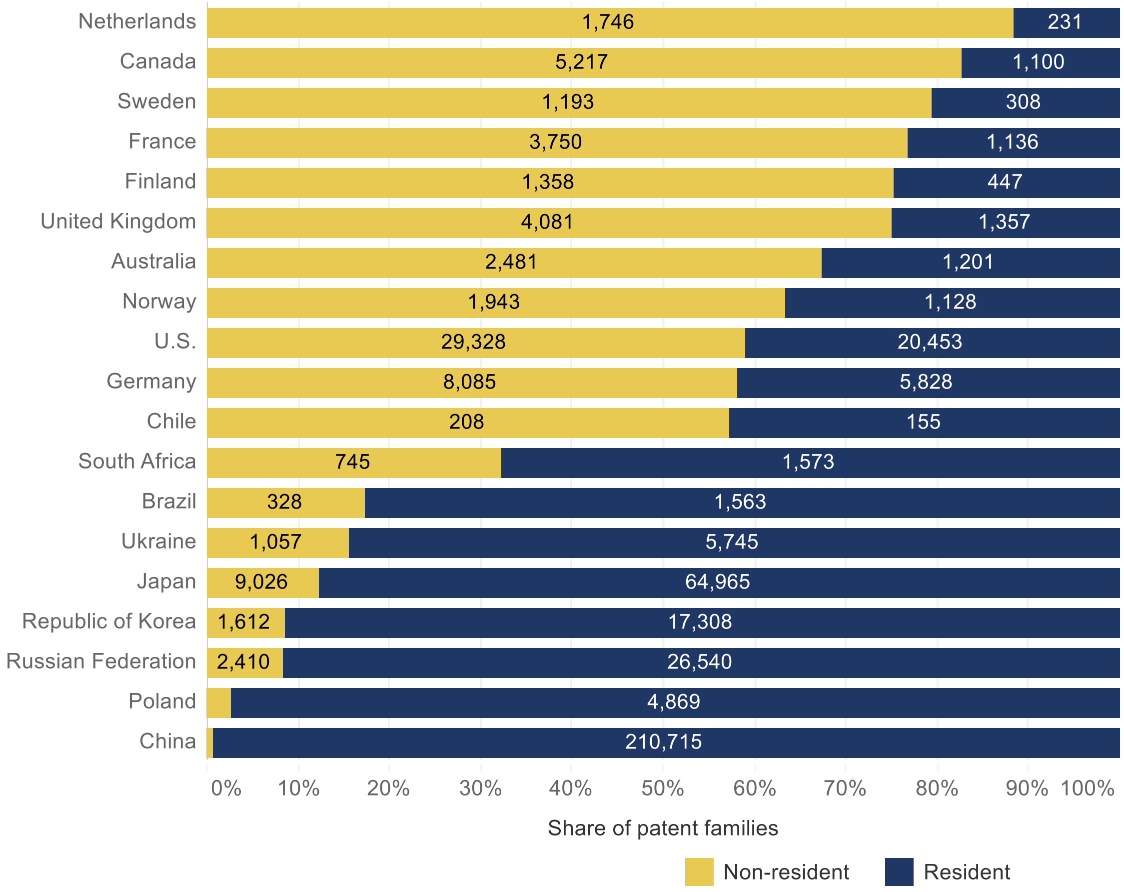
In the mining technology subset, 46 percent of first filings have a Chinese origin. Out of those, 99 percent are filed in China (Figure 23) and only 1.7 percent have multiple family members, showing that Chinese applicants focus on filing in China. Contrasting that is first filings originating in the United States, of which 59 percent are filed overseas and 76 percent have multiple family members.

Combining the two approaches we can highlight whether innovation protected in certain countries is mostly filed by resident or non-resident entities. Overall the share of resident applications in mining is more than 59 percent which highlights a global preference for resident filings. But for some countries, resident filings are a large majority. This is the case in China with 90.7 percent and Japan with 89 percent of resident filings, while other countries, such as the U.S., are below the average with only 52 percent resident filings. The percentage of resident applications varies quite a lot across countries. While China, Japan, the Republic of Korea, Germany and the United States of America have more resident filings than non-resident ones, other countries like Australia, Canada, Chile and Brazil have a larger number of non-resident applications. This is probably due to the presence of big multinationals, mainly METS firms, which are headquartered somewhere else but wish to market their mining-related products in these mining countries. This pattern follows closely the one of general patent application (WIPO, 2018).

---

[16] We compute these statistics using the jurisdiction in which the patent is filed.

Figure 23: Origin of application for technology subset: Resident versus non-resident patent filings



Source: WIPO Mining Database (technology subset)

China substantially increased its percentage of resident patents in the most recent period. Chile followed the opposite path: its number of resident filings halved. This signals either a slowdown in patenting activity of national enterprises or the entrance of foreign firms on the local market. Given that patents are often used as a competitive instrument, it could also reflect the willingness of foreign firms to block local enterprises from using their technologies without their consent.

6. Concluding remarks

This paper explored the recent boom in mining innovation. Even if an elusive target to innovation typical measurements, mining innovation has been booming over the last more than a decade. Australia, Canada, China, Europe and the United States of America concentrate the largest share of global innovation measured as mining R&D expenditures, exploration expenditures or mining technologies in patent data.

We then turned to the technological changes that be happening in the mining innovation supply chain structure and in the geography of innovation. For this purpose, we provide a fresh perspective on how to create a patent dataset for economic analysis by relying on expert domain knowledge in both the mining industry and patent data. This data includes the patenting activity of mining firms and the mining related patents not necessarily filed by these firms. We documented how mining technologies can spur from other stakeholders than mining related firms and how mining firms can be very active beyond mining innovation.

Our analysis showed how mining innovation spurs along the mining production lifecycle and value chain. In particular, recent mining innovation focused in exploration and refining technologies. However, some subsectors have contributed more to the recent mining innovation uptick more than others. In particular, there has been a decrease of the from refining technologies share in favor of those from exploration and transport technologies. We interpret these results as a direct consequence of the demand surge of mineral products in the same period. We also observe an increase of automation innovation in the mining sector. These trends are not new for the industry, which observed an increase in the 1990s and early 2000s. Nonetheless, we now observe a remarkable automation uptick.

The distribution of economies contributing to mining technologies does not corresponds with the typical mining producing ones. Only China and the United States of America lead both in mining output and innovation. Australia, Canada and Norway also offer a relatively balanced mining output and innovation. Other typical mining economies struggle to be present in the innovation spotlight. The Russian Federation, Brazil and Chile are probably the best among these, while the other ones generate very limited innovation outcomes. Indeed, mining innovation is more likely to spur in functioning innovation systems not necessarily based on mining operation countries. Many developed economies not particularly relevant in mining production contribute in a great extent to the global mining innovation. Japan, the Republic of Korea and many European economies are the top ones among these.

Despite China’s impressive growth in volume, it did little to the rapid increase in the world’s mining innovation intensity as it has grown in all technologies at a faster pace. This was not only the case of China. Traditionally mining producing and specialized economies such as Chile, South Africa and the Russian Federation have all diminished their mining innovation specialization. Conversely, Australia, Canada, the United States of America and Brazil have increased their mining relative specialization, which also means the contributed more to the global mining innovation intensity surge.

Most of the increase in the exploration subsector is coming from the increase in specialization. Australia, Chile and the Republic of Korea increased their relative specialization in this subsector and are probably among the largest contributors to the exploration booming relatively to the other sectors. On mining transport, Chile and Australia were the only country improving their mining transport specialization. The US, Canada and Australia, are more specialized in automation compared to lower-middle income and upper-middle income nations. The selected economies are fairly weak in environment specialization. Only Chile, the Republic of Korea and the United States of America show a positive RSI for environmental technologies.

Companies and other stakeholders are accountable for the mining innovation boom. Established mining and METS firms created about two thirds of the mining related technologies in our data. Academic institutions produced the remaining technologies, where public research organizations (PROs) and universities generated 9 and 6 percent, respectively. Despite the private companies are the largest contributor of mining technologies, only a small portion of mining and METS firms file for patents.

References

Acs, Z. J., Anselin, L. & Varga, A., 2002. “Patents and innovation counts as measures of regional production of new knowledge.” Research Policy, Volume 31.7, pp. 1069-1085.

Amburle, R. et al., 2019. “Recent trends of innovation and IP use in the mining sector in Australia.” In: *Global Challenges for Innovation in the Mining Industries*. s.l.: Cambridge University Press.

Arundel, A. & Kabla, I., 1998. “What percentage of innovations are patented? Empirical estimates for European firms.” Research Policy, 27(2), pp. 127-141.

Bartos, P. J., 2007. “Is mining a high-tech industry? Investigations into innovation and productivity advance.” Resources Policy, 32(4), pp. 149-158.

Blundi, D. et al., 2019. “Technology appropriation and technology transfer in the Brazilian mining sector”, s.l.: WIPO Economics Research Working Paper No. 53.

Bravo-Ortega, C. & Price Elton, J. J., 2019. “Innovation and intellectual property rights in the Chilean copper mining sector: the role of the mining, equipment, technology and services firms”, s.l.: WIPO Economics Research Working Paper No. 54.

Czarnitzki, D. et al., 2015. “Individual Versus Institutional Ownership of University-Discovered Inventions”, Zentrum für Europäische Wirtschaftsforschung (ZEW), Mannheim: ZEW Discussion Papers, No. 15-007.

Dechezleprêtre, A., Ménière, Y. & Mohnen, M., 2017. “International patent families: from application strategies to statistical indicators.” Scientometrics, 111(2), p. 793–828.

Doherr, T., 2017. “Inventor mobility index: A method to disambiguate inventor careers”, Zentrum für Europäische Wirtschaftsforschung (ZEW), Mannheim: ZEW Discussion Papers, No. 17-018.

EPO, 2017. Patent families at the EPO [Online]. Available at: http://documents.epo.org/projects/babylon/eponet.nsf/0/C9387E5053AA707BC125816A00508E8D/$File/Patent_Families_at_the_EPO_en.pdf

European Commission, 2016. Raw Materials Scoreboard, s.l.: s.n.

Eurostat, 2018. Science and technology database, Business expenditure on R&D by NACE Rev. 2 activity, s.l.: s.n.

Fink, C., Khan, M. & Zhou, H., 2013. “Exploring the worldwide patent surge”, s.l.: WIPO Economics Research Working Paper No. 12.

Francis, E., 2015. The Australian Mining Industry: More than Just Shovels and Being the Lucky Country, s.l.: IP Australia Economic Research Paper No. 4.

Griliches, Z., 1998. “Patent Statistics as Economic Indicators: A Survey.” In: Z. Griliches, ed. *R&D and Productivity: The Econometric Evidence*. s.l.:University of Chicago Press, pp. 287-343.

INAPI, 2010. *Patentamiento en el cluster mineria del cobre: Análisis de presentaciones realizadas en Chile*, s.l.: s.n.

IP Australia, 2015. “A patent analytics study on the Australian Pharmaceutical Industry”, s.l.: s.n.

Jaffe, A. & Trajtenberg, M., 1999. “International Knowledge Flows: Evidence from Patent Citations.” *Economics of Innovation and New Technology*, 8(1-2), pp. 105-136.

Kashcheeva, M., Wunsch-Vincent, S. & Zhou, H., 2014. “International Patenting Strategies of Chinese Residents: An Analysis of Foreign-Oriented Patent Families”, s.l.: WIPO Economics Research Working Paper No. 20.

Kreuzer, O. & Etheridge, M. A., 2010. “Risk and Uncertainty in Mineral Exploration: Implications for Valuing Mineral Exploration Properties.” AIG News.

Lerner, J. & Seru, A., 2017. “The Use and Misuse of Patent Data: Issues for Corporate Finance and Beyond”, s.l.: NBER Working Paper No. 24053.

Lybbert, T. & Zolas, N., 2014. “Getting patents and economic data to speak to each other: An ‘Algorithmic Links with Probabilities’ approach for joint analyses of patenting and economic activity.” Research Policy, 43(3), pp. 530-542.

Man, B., 2014. “Overview of the Intellectual Property Government Open Data”, s.l.: IP Australia Economic Research Paper No. 2.

Martínez, C., 2011. “Patent families: When do different definitions really matter?” *Scientometrics*, 86(1), p. 39–63.

Miguélez, E. & Fink, C., 2013. “Measuring the International Mobility of Inventors: A New Database”, s.l.: WIPO Economics Research Working Paper No. 8.

OECD, 2019. Research and Development Statistics: Business enterprise R-D expenditure by industry - ISIC Rev. 4, OECD Science, Technology and R&D Statistics (database): https://doi.org/10.1787/data-00668-en (accessed on 23 March 2019).

Pavitt, K., 1984. “Sectoral patterns of technical change: Towards a taxonomy and a theory.” Research Policy, 13(6), pp. 343-373.

Raffo, J., 2015. MATCHIT: Stata module to match two datasets based on similar text patterns, s.l.: s.n.

Raffo, J. & Lhuillery, S., 2009. “How to play the ‘Names Game’: Patent retrieval comparing different heuristics.” Research Policy, 38(10), pp. 617-1627.

Reichl, C., Schatz, M. & Zsak, G., 2018. *World Mining Data*. Vienna: ISBN 978-3-901074-44-8.

Scherer, F., 1984. “Using Linked Patent and R&D Data to Measure Interindustry Technology Flows.” In: Z. Griliches, ed. *R&D, Patents, and Productivity*. s.l.:University of Chicago Press, pp. 417-464.

Schmoch, U., 2008. Concept of a Technology Classification for Country Comparisons, s.l.: World Intellectual Property Organisation.

Trippe, A. J., 2015. Guidelines for Preparing Patent Landscape Reports, s.l.: World Intellectual Property Organization.

UKIPO, 2015. The Patent Guide. Second Edition, Newport, United Kingdom: The Intellectual Property Office.

Van Looy, B., Vereyen, C. & Schmoch, U., 2015. IPCV8-NACE Rev.2 Update (version 2.0), s.l.: eurostat.

Wasi, N. & Flaaen, A., 2015. “Record Linkage using STATA: Pre-processing, Linking and Reviewing Utilities.” Stata Journal, 15(3), pp. 672-697.

WIPO, 2018. World Intellectual Property Indicators 2018, s.l.: Geneva: World Intellectual Property Organization.

WIPO, 2019. *Global Challenges for Innovation in the Mining Industries*. s.l.:Cambridge University Press.

Abbreviations

ABN	Australian Business Number
ANZSIC	Australian and New Zealand Standard Industrial Classification
CDIP	Committee on Development and Intellectual Property (CDIP)
CIPO	Canadian Intellectual Property Office
CPC	Cooperative Patent Classification
DOCDB	EPO master documentation database
DNPM	Brazilian National Department of Mineral Production
EPO	European Patent Office
GDP	Gross Domestic Product
INAPI	National Institute of Industrial Property of Chile
INPADOC	International Patent Documentation
INPI	National Institute of Industrial Property of Brazil
IP	Intellectual property
IPC	International Patent Classification
IPGOD	Intellectual Property Government Open Data
ISIC	International Standard Industrial Classification
METS	Mining equipment, technology and services
NAICS	North American Industry Classification System
NETS	National Establishment Time-Series
PATSTAT	EPO's Worldwide Patent Statistical Database
PRO	Public research organizations
R&D	Research and development
RSI	Relative Specialization Index
USPTO	United States Patent and Trademark Office
WIPO:	World Intellectual Property Organization

Appendix A: Technical notes

Patents included in analysis

When the full search results from the technology-based search were extracted, the dataset included results that were not related to the mining industry, i.e. those which have a *min_mining_cat_id* that signifies an exclusion. These patents were removed from analysis of the technology data subset by removing cases where *mining_top_id*=100, and in order to eliminate patents that are related to oil and gas drilling, the cases where *min_mining_cat_id*=6.29 were also removed.

All patents were retained from the firm-based search in order to analyze which patents are related to the mining industry, per our definition, and which patents are not.

Units of analysis

The main unit of analysis in patent data is the **first filing** of a given invention. Utility model data is included.

The date of reference for patent counts is earliest filing date.
The origin of the invention is attributed to the first applicant in the first filing; whenever this information is missing, the origin of invention is assigned by the following steps:

(i) extract country information from the applicant's address
(ii) extract country information from the applicant's name
(iii) make use of the information from matched corporations (as described further below);
(iv) rely on the most frequent first applicant country of residence within the same patent family (using the extended patent family definition);
(v) rely on the most frequent first inventor's country of residence within the same patent family (again, using the extended patent family definition);
(vi) for some remaining historical records, consider the IP office of first filing as a proxy for origin.

Definitions

Key definitions of patent related terms and concepts can be found in the glossary of the World Intellectual Property Indicators 2018 (WIPO, 2018).

Appendix B: Search strategy and categorization

Sub-sector	Category	IPC/CPC	Combined with	
			IPC	keyword
Blasting	Fuses	F42C	E21	mining
	Blasting	C06B C06C C06D F42B 3/ F42B2003/ F42D	E21	mining
		E21B 29/02 E21B 31/16		
Environmental	Reclamation of mining areas	E21C 41/32		
	Treatment of waste water from metallurgical processes	C02F 103/10 C02F2103/10		
	Treatment of waste water	C02F	E21	mining OR mine OR mineral OR ore OR coal
	Biological treatment of soil	B09C 1/10	E21	mining OR mine OR mineral OR ore
	Soil treatment	B09C	E21	mining OR mine OR mineral OR ore OR coal
	Waste Disposal	B09B	E21	mining OR mine OR mineral OR ore
	Protection against radiation	G21F	E21	mining OR mine
	Environmental	Y02	E21	mining OR mine OR mineral OR ore
	Technologies related to mineral processing	Y02P 40/		
	Technologies related to metal processing	Y02P 10/		
Processing	Crushing/grinding mineral	B02C		mineral OR ore
	Crushing/grinding	B02C	E21	mining OR mine OR coal
	Flotation	B03D	E21	mineral OR ore
		B03D 103/02 to /10 B03D 1/021 B03D2203/04 to /10		
	Separation	B03B B07C	E21	mineral OR ore
		B01D	E21	ore
		B01D 21/ to 43/ B01D2021/ to 2039/ B01D2221/04		
		B07B	E21	mineral OR ore OR coal
		B03C	E21	
	Processing	B04B	E21	mining OR mine OR mineral OR ore OR coal
		B04C	E21	mining OR mine OR mineral OR ore
		F26B	E21	mining OR mine
	Bio-processing	C12N 1/ C12N 9/	E21	mining OR mine
		C40B	E21	mining OR mine OR mineral OR ore OR coal
Metallurgy	Metallurgy	C21C C22C C22F	E21	mining OR mine OR mineral OR ore
	Pyrometallurgy	F27D	E21	mining OR mine OR mineral OR ore
	Casting/powder metallurgy	B22	E21	mining OR mine OR mineral OR ore
	Furnaces	F27B	E21	mining OR mine OR mineral OR ore
	Coating	C23	E21	mining OR mine OR mineral OR ore
	Electrometallurgy	C21D C25	E21	mining OR mine OR mineral OR ore

Sub-sector	Category	IPC/CPC	Combined with	
			IPC	keyword
Transport	Rail	B61	E21	mining OR mine OR mineral OR ore OR coal
		B61D 11/ B65G 67/34 to 46		
	Rail infrastructure	E01B	E21	mining OR mine OR mineral OR ore OR coal
	Hoisting	B66	E21	mining OR mine OR mineral OR ore OR coal
		B66B 1/10 to 12 B66B 15/ to 19/ E04H 12/26		
	Conveying	B65G	E21	mining OR mine OR mineral OR ore OR coal
	Hauling	B60P B65B	E21	mining OR mine OR mineral OR ore OR coal
	Vehicles	B60 B62D G07C 5/	E21	mining OR mine OR mineral OR ore
		E21C 33/		
	Infrastructure	E01C E01F G08G	E21	mining OR mine OR mineral OR ore OR coal
	Shipping	B63	E21	mining OR mine
	Containers	B65	E21	mining OR mine
		B65D 5/28 B65D 88	E21	mining OR mine OR mineral OR ore OR coal
	Control	G05D 1/ G05D 13/	E21	mining OR mine
		G05D2201/021		
Exploration	Exploration	G06F	E21	mineral OR ore
		G01B to G01D G01H G01S G06T H04B 13/02	E21	mining OR mine
		G01V2210/	E21	mining OR mine OR mineral OR ore OR coal
		G01V	E21	mining OR mine OR ore
	Surveying and testing - automatic control	E21B 44/		
	Surveying and testing	E21B 45/ to 49/		
	Core extraction	E21B 25/ to 27/		
	Methods or apparatus for drilling	E21B 1/ to 7/		
	Drilling tools	E21B 10/ to 12/		
	Drilling	B24	E21	mining OR mine OR mineral OR ore
		E12B 15/to 23/ E12B 28/ E21B 31/ E21B 36/ E21B 37/ E21B 43/29		
	Drilling - oil & gas	E21B 29/ E21B 33/ E21B 34/ E21B 40/ to 43/		
	Assays	G01N	E21	mining OR mine OR mineral OR ore

Sub-sector	Category	IPC/CPC	Combined with	
			IPC	keyword
Refining	Ferrous	C21B C21C 1/ C21C 7/		
	Non-ferrous	C22B		
	Inorganic chemistry	C01D to C01G	E21	mining OR mine OR mineral OR ore
Mining	Ground control support	E01F 7/04 E02D 5/74 F16B 13/	E21	mining OR mine OR mineral OR ore
		E21D 15/ to 23/		
	Excavation	E02F F16	E21	mining OR mine OR mineral OR ore
		E21C 25/ to 39/ E21C2035/		
	Safety/rescue	A41 A42 A62 B05 F21V 25/12 H04N 7/18	E21	mining OR mine
		A42B 1/10 E21B 35/ E21F 5/ to 11/ E21F 17/18		
	Shafts	C21D 9/44 E21D 1/ to 8/		
	Tunnels	E21D 9/ to 13/ E21F 16/02		
	Ventilation	F24 F25B F04D F24F	E21	mining OR mine
		E21F 1/ E21F 3/		
	Subsea	B63B 35/ B63C 11/ B63B2035/ B63C2011/	E21	mining OR mine
		E21B 7/12 E21B 15/02 E21C 50/		
	Mining (original)	B27M 3/32 E02D 3/ E02F 5/22 F21 G06Q 50/02 H04M 1/18 H05B	E21	mining OR mine OR mineral OR ore
		E21C 41/ E21C 45/ E21F 13/ to 17/ F21L 23/		
	Extraterrestrial	B64G	E21	mining OR mine OR mineral OR ore OR coal
		E21C 51/		

Sub-sector	Category	IPC/CPC	Combined with	
			IPC	keyword
Mining	Mining (additional)	G06K to G06Q G07C H01 H04 B06 B32 B62 B64 B67 B68 B81 B82 E0 F01 F02 F03 F04B F04C F04F F15 F17 F23Q F25D F28D	E21	mining OR mine
		B08	E21	mining OR mine OR ore
	Mining (E21)	E21		
	Mining (mining)			mining
	Mining (mine)			mine
	Mining (Ore)			ore
	Mining (Ore*)			ore*
	Mining (Mineral)			mineral
	Mining (Coal)			Coal
Automation	Automation	G01C G01S G05B G05D G05G G06F G06N 7/ G06T H04L	E21	mining OR mine OR mineral OR ore OR coal

Appendix C: Sub-sector and Category definitions

ub-secto	Category	Definition
Blasting	Fuses	Fuses (relating to mining)
	Blasting	Explosive or thermic compositions; detonating or priming devices; fuses; pyrophoric compositions; generation of gas for blasting or propulsion (chemical part); Blasting cartridges; Blasting methods (all relating to mining) Cutting or destroying pipes, packers, plugs, or wire lines, located in boreholes or wells by explosives or by thermal or chemical means; Fishing for or freeing objects in boreholes or wells combined with cutting or destroying means
Environmental	Reclamation of mining areas	Reclamation of surface-mined areas
	Treatment of waste water from metallurgical processes	Treatment of waste water from quarries or from mining activities
	Treatment of waste water	Treatment of waste water relating to mines/mining
	Biological treatment of soil	Reclamation of contaminated soil (from mines/mining) microbiologically or by using enzymes
	Soil treatment	Reclamation of contaminated soil (from mines/mining)
	Waste Disposal	Disposal of solid waste (from mines/mining)
	Protection against radiation	Protection against x-radiation, gamma radiation, corpuscular radiation or particle bombardment; treating radioactively contaminated material relating to mines/mining
	Environmental	Technologies for mitigation of climate change relating to mines/mining
	Technologies related to mineral processing	Technologies or applications for mitigation or adaptation against climate change relating to the processing of minerals
	Technologies related to metal processing	Technologies or applications for mitigation or adaptation against climate change related to metal processing
Processing	Crushing/grinding mineral	Crushing, pulverizing, or disintegrating minerals/ore; milling and mills
	Crushing/grinding	Crushing, pulverizing, or disintegrating in general; milling and mills relating to mines/mining
	Flotation	Flotation and differential sedimentation of minerals/ore
	Separation	Physical & chemical processes and apparatus for separating and mixing, including: Separating minerals/ore using liquids or using pneumatic tables or jigs; Separation of suspended solid particles from liquids by sedimentation; Filters; Filtering minerals/ores; Separating mineral particles from liquids; Separation devices for treating liquids from earth drilling, mining; Separating minerals from solids by sieving, screening, or sifting or by using gas currents; other separating by dry methods applicable to bulk material; Magnetic or electrostatic separation of solid materials from solids or fluids
	Processing	Centrifuges; Apparatus using free vortex flow, e.g. cyclones; Drying solid materials or objects by removing liquid therefrom
	Bio-processing	Microorganisms; enzymes and combinatorial chemistry (for bio-leaching of minerals)
Refining	Ferrous	Metallurgy of iron: Manufacture of iron or steel; Refining of pig-iron; Cast iron; Treating molten ferrous alloys, e.g. Steel
	Non-ferrous	Production or refining of metals; pretreatment of raw materials; Obtaining metal compounds from mixtures, e.g. ores, which are intermediate compounds in a metallurgical process for obtaining a free metal
	Inorganic chemistry	Compounds of alkali metals, rare-earth metals and other metals

Metallurgy	Metallurgy	Metallurgy of iron: Processing of pig-iron; Alloys; Changing the physical structure of non-ferrous metals or non-ferrous alloys
	Pyrometallurgy	Details or accessories of furnaces, kilns, ovens, or retorts, in so far as they are of kinds occurring in more than one kind of furnace
	Casting/powder metallurgy	Casting; powder metallurgy: Foundry moulding; Casting of metals; Making and working metallic powder; manufacture of articles from metallic powder.
	Furnaces	Furnaces, kilns, ovens, or retorts in general; open sintering or like apparatus
	Coating	Metallurgy: Coating metallic material
	Electrometallurgy	Metallurgy of iron: Modifying the physical structure of ferrous metals; general devices for heat treatment of ferrous or non-ferrous metals or alloys; making metal malleable by decarburisation, tempering, or other treatments Metallurgy: Electrolytic or electrophoretic processes
Exploration	Exploration	Electric digital data processing, relating to minerals/ore Measuring length, thickness or similar linear dimensions; measuring angles; measuring areas; measuring irregularities of surfaces or contours; Measuring distances, levels or bearings; surveying; navigation; gyroscopic instruments; photogrammetry or videogrammetry; Measurement of mechanical vibrations or ultrasonic, sonic or infrasonic waves; Radio direction-finding; radio navigation; determining distance or velocity by use of radio waves; Image data processing or generation, in general; Transmission systems in which the medium consists of the earth or a large mass of water thereon all relating to mines/mining Details of seismic processing or analysis relating to minerals/ore/mining/mines Geophysics; gravitational measurements; detecting masses or objects; tags relating to ore/mining/mines
	Surveying and testing - automatic control	Automatic control; Surveying or testing of boreholes and wells
	Surveying and testing	Surveying of boreholes and wells; Testing the nature of borehole walls; Formation testing; Methods or apparatus for obtaining samples of soil or well fluids, specially adapted to earth drilling or wells
	Core extraction	Apparatus for obtaining or removing undisturbed cores, e.g. Core barrels, core extractors; Containers for collecting or depositing substances in boreholes or wells, e.g. Bailers for collecting mud or sand; Drill bits with means for collecting substances, e.g. Valve drill bits
	Methods or apparatus for drilling	Earth or Rock Drilling: Methods or apparatus for drilling; Rotary drilling; Drives for drilling, used in the borehole; Drives for drilling with combined rotary and percussive action; Special methods or apparatus for drilling
	Drilling tools	Earth or Rock Drilling: Drilling tools; Accessories for drilling tools
	Drilling	Earth or Rock Drilling: Well equipment or well maintenance; Drilling rods or pipes; Flexible drill strings; Kellies; Drill collars; Sucker rods; Casings; Tubings; Handling rods, casings, tubes or the like outside the borehole; Methods or apparatus for flushing boreholes, e.g. By use of exhaust air from motor; Apparatus for displacing, setting, locking, releasing or removing tools, packers or the like in boreholes or wells; Vibration generating arrangements for boreholes or wells, e.g. For stimulating production; Fishing for or freeing objects in boreholes or wells; Heating, cooling, or insulating arrangements for boreholes or wells, e.g. For use in permafrost zones; Methods or apparatus for cleaning boreholes or wells; Obtaining a slurry of minerals from wells, e.g. By using nozzles Grinding; polishing (drilling and drill bits)
	Drilling - oil & gas	Earth or Rock Drilling: Cutting or destroying pipes, packers, plugs, or wire lines, located in boreholes or wells, e.g. Cutting of damaged pipes, of windows; Sealing or packing boreholes or wells; Valve arrangements for boreholes or wells; Tubing catchers, automatically arresting the fall of oil-well tubing; Other equipment or details for drilling; Obtaining fluids from wells
	Assays	Investigating or analyzing minerals/ore by determining their chemical or physical properties

Mining	Ground control support	Ground control support and working-face supports in mines Devices affording protection against falling rocks; Means for anchoring structural elements or bulkheads; Caps for supporting mine roofs; Provisional protective covers for working space in mines; Anchoring-bolts for roof, floor, or shaft-lining protection; Mine roof supports
	Excavation	Dredging; soil-shifting (for accessing mine sites) Mining or quarrying: Cutting; slitting; dislodging; Machines which completely free the mineral from the seam; Other methods or devices for dislodging with or without loading; Devices for testing in situ the hardness or other properties of minerals; Mining picks
	Safety/rescue	Protective garments relating to mines/mining, such as headwear, gloves, respirators Life-saving; fire-fighting relating to mines/mining; Methods or apparatus for preventing or extinguishing fires for boreholes or wells; Devices preventing sparking of machines or apparatus in mines; Flameproof or explosion-proof arrangements Mine safety devices; Rescue devices; Special adaptations of signaling or alarm devices for mines; Mine rescue devices or other safety devices, e.g. Safety chambers or escape ways Devices for allowing seemingly-dead persons to escape or draw attention; Breathing apparatus for accidentally buried person Safety devices structurally associated with lighting devices: Closed-circuit television systems, i.e. Systems in which the signal is not broadcast
	Shafts	Mine shafts; Lining mine shafts; Sinking mine shafts; Raising mine shafts; Mine shaft equipment, e.g. Timbering within the shaft
	Tunnels	Mine tunnels; Galleries; Large underground chambers; Linings therefor; Drainage of mine tunnels
	Ventilation	Heating, cooling, ventilating relating to mines/mining
	Subsea	Vessels or like floating structures adapted for mining purposes; Equipment for dwelling or working under water; Means for searching for underwater objects; Equipment or details for drilling specially adapted for underwater drilling; Obtaining minerals from underwater
	Mining (original)	*The marks in this category were marks that were originally included in the definition of the mining industry/ mining related activities* Methods of mining or quarrying; Open-pit mining; Layouts therefor; Methods of hydraulic mining; Transport specially adapted to underground conditions; Methods or devices for placing filling-up materials in underground workings; Mine drainage; Methods or devices for use in mines or tunnels; Non-electric hand-lamps for miners Manufacture or reconditioning of tapered poles, e.g. Mine props; Improving or preserving soil or rock, e.g. Preserving permafrost soil; Dredging; soil-shifting for making embankments; for back-filling; Mine lighting; Data processing systems or methods, specially adapted mining; Telephone sets specially adapted for use in mines; Electric heating; electric lighting relating to mines/mining
	Extraterrestrial	Apparatus for, or methods of, winning materials from extraterrestrial sources
	Mining (E21)	Earth or rock drilling; Mining (i.e. all patents with an E21 mark)
	Mining (mining)	All patents with mining in the title or abstract
	Mining (mine)	All patents with mine in the title or abstract
	Mining (Ore)	All patents with ore in the title or abstract
	Mining (Ore*)	All patents with a specific ore in the title or abstract (as listed in Appendix D).
	Mining (Mineral)	All patents with mineral in the title or abstract
	Mining (Coal)	All patents with coal in the title or abstract

Mining	Mining (additional)	*These additional marks in this category were marks that were identified as relevant through observing relevant patents based on keyword and firms searches.* Generating or transmitting mechanical vibrations in general; Cleaning; prevention of fouling; Layered products relating to mines/mining Performing operations; transporting in general; Land vehicles for travelling otherwise than on rails; Aviation relating to mines/mining Microstructural technology; Nanotechnology relating to mines/mining Construction and Building relating to mines/mining Machines or engines in general; engine plants in general; steam engines; Positive-displacement machines for liquids; pumps; Rotary-piston, or oscillating-piston, positive-displacement machines for liquids; Pumping of fluid by direct contact of another fluid or by using inertia of fluid to be pumped; Fluid-pressure actuators; hydraulics or pneumatics in general relating to mines/mining Liquid handling; Storing or distributing gases or liquids; Refrigerators; cold rooms; ice-boxes; cooling or freezing apparatus; Heat-exchange apparatus relating to mines/mining Recognition of data; presentation of data; record carriers; handling record carriers; Counting of objects; Computer systems based on specific computational models; Data processing systems or methods; Registering or indicating the working of machines relating to mines/mining Basic electric elements; Electric communication techniques relating to mines/mining
Transport	Rail	Railway systems; Locomotives; motor railcars; railway vehicles; Couplings specially adapted for railway vehicles; Brakes or other retarding apparatus peculiar to rail vehicles; Shifting or shunting of rail vehicles; Guiding railway traffic; ensuring the safety of railway traffic Mine cars
	Rail infrastructure	Construction of railways; machines for making railways; Switches; Crossings
	Conveying	Transport or storage devices e.g. conveyors for loading or tipping
	Hoisting	Hoisting; lifting; hauling; Control systems of elevators in general specially adapted for mining hoists; Lifts in hoistways of mines; Hoistway equipment for mines; Mining-hoist operation; Winding towers for mines
	Hauling	Vehicles adapted for load transportation or to transport, to carry, or to comprise special loads or objects; Machines, apparatus, methods for packing/unpacking
	Vehicles	Wheels; Axles; Tyres; Vehicles for use on both rail and road; Air-treating devices for vehicles; Propulsion of electrically-propelled vehicles; Power supply lines, or devices along rails, for electrically-propelled vehicles; Motor vehicles; trailers Checking devices for registering or indicating the working of vehicles Trucks or other devices for transporting machines for slitting or completely freeing the mineral from the seam
	Infrastructure	Construction of roads; Construction of, or surfaces for, roads; Additional construction work, such as equipping roads or the construction of platforms, helicopter landing stages, signs, snow fences, or the like; Traffic control systems
	Containers	Conveying; packing; storing Rigid or semi-rigid containers of polygonal cross-section, formed by folding-up portions connected to a central panel from all sides to form a container body, with extensions of sides permanently secured to adjacent sides, with sides permanently secured together by adhesive strips, or with sides held in place solely by rigidity of material Large containers

	Control	Control of position, course, altitude, or attitude of land, water, air, or space vehicles, e.g. Automatic pilot; Control of linear speed; Control of angular speed; Control of acceleration or deceleration, e.g. Of a prime mover Systems for controlling or regulating non-electric variables specifically for mining vehicles
	Shipping	Ships or other waterborne vessels; related equipment
Automation	Automation	Measuring distances, levels or bearings; surveying; navigation; gyroscopic instruments; photogrammetry or videogrammetry; Radio direction-finding; radio navigation; determining distance or velocity by use of radio waves; locating or presence-detecting by use of the reflection or reradiation of radio waves; analogous arrangements using other waves; Control or regulating systems in general; functional elements of such systems; monitoring or testing arrangements for such systems or elements; Systems for controlling or regulating non-electric variables; Control devices or systems insofar as characterized by mechanical features only; Electric digital data processing Computer systems based on specific mathematical models; Image data processing or generation, in general; Transmission of digital information, e.g. telegraphic communication relating to mines/mining

Appendix D: Mining keywords

Search terms use regular expressions. Unless otherwise indicated, the search terms were word bound. Both regular, accented and Unicode characters were used for words with accented characters.

Keyword term	search language	search term	not
mining	de	.*bergbau.*	
		bergwerk.*	
		grubenbetrieb.*	
		tagebau.*	
	en	goaf[s]?	
		goaves	
		mining	data mining
	es	miner[ao][s]?	
		minería	minería de datos
	fr	mineur[s]?	
		minière[s]?	
	pt	mineiro[s]?	
		mineração	mineração de dados
		minerador[a]?[s]?	
mine	en	mine[rs]?[s]?	
	es	mina[s]?	
	fr	mine[s]?	
	pt	mina[s]?	
mineral	de	erz	
		erzen	
		mineral	
		mineralien	
	en	mineral[s]?	mineral wool OR mineral fibre OR mineral fiber OR mineral oil OR mineral water OR mineral filler
	es	mineral(es)?	aceite[s]? mineral(es)? OR agua[s]? mineral(es)? OR lana[s]? mineral(es)? OR fibra[s]? mineral(es)?
	fr	Mineral	huile[s]? minéral OR eau[x]? minéral OR laine[s]? minéral OR fibre[s]? minéral
		minéraux	
	pt	minera[is|l]	óleo[s]? minera[is|l] OR água[s]? minera[is|l] OR lã[s]? minera[is|l] OR fibra[s]? minera[is|l]
ore	en	ore[s]?	
	es	mena[s]?	
	fr	minerai[s]?	
	pt	minério	
coal	de	kohle	
	en	coal	coal gas OR coal tar OR coal bed gas
		collieries	
		colliery	
	es	hulla	alquitran de hulla
	fr	houille	gas de houille
	pt	hulha	

Keyword term	search language	search term	not
ore: acanthite		a[ck]ant[h]?it[ae]?	
ore: argentite		argentit[ae]?	
ore: barite		bar[iy]t[ae]?	
ore: bauxite		bauxit[ae]?	
ore: beryl		ber[iy]l[o]?	
		béryl	
ore: bornite		bornit[ae]?	
ore: cassiterite		cassiterit[ae]?	
		cassitérite	
ore: chalcopyrite		c[h]?al[ck]op[iy]rit[ae]?	
ore: chromite		c[h]?romit[ae]?	
ore: cinnabar		cinabre	
		cinabrio	
		cinnabar	
		zinnober	
ore: cobaltite		cobaltit[ae]?	
ore: coltan		coltã	
		coltan	
		coltán	
ore: dolomite		dolomit[ae]?	
ore: galena		galen[ae]	
ore: hematite		h[a]?ematit[ae]?	
		hämatit	
		hématite	
ore: ilmenite		ilmenit[ae]?	
		ilménite	
ore: magnesite		magnesit[ae]?	
		magnésite	
ore: magnetite		magnetit[ae]?	
ore: malachite		malachit[ae]?	
ore: molybdenite		mol[yi]bdenit[ae]?	
		molybdänit	
		molybdénite	
ore: pentlandite		pentlandit[ae]?	
ore: pyrolusite		pirólusita	
		pyrolusit[ae]?	
ore: scheelite		scheelit[ae]?	
ore: sperrylite		sperr[yi]lit[ae]?	
ore: sphalerite		esfalerita	
		sphalerit	
		sphalérite	
ore: tantalite		tantalit[ae]?	
ore: uraninite		uraninit[ae]?	
ore: wolframite		wolframit[ae]?	

Appendix E: IPC exclusions

Exclusion	IPC	Definition
Defensive ships	B63G	Mine-laying; Mine-sweeping; vehicles with offensive or defensive arrangements
Weapons & Ammunition	F41	Weapons
	F42B 4/ to 99/	Fireworks; Cartridge ammunition; Projectiles or missiles; Shotgun ammunition; Practice or training ammunition; Arrangements on projectiles or missiles for stabilizing, steering, range-reducing, range-increasing or fall-retarding; Depth charges; Projectiles or missiles; Blasting cartridges
Pharmaceutical	A61	Medical, veterinary or hygiene products
Foodstuffs	A01J A21 to A23	Manufacture of dairy products; Baking; equipment for making or processing doughs; doughs for baking; Butchering; meat treatment; processing poultry or fish; Foods or foodstuffs
Other human necessities	A01 A24 A41 to A47 A62 A63 A99	Tobacco; cigars; cigarettes; Footwear in general; Haberdashery; jewellery; Hand or travelling articles; Brushware; Furniture; domestic articles or appliances; Sports; games; amusements; Other human necessities in general; Clothing in general; Headwear in general; Life-saving; fire-fighting in general; Agriculture; forestry; hunting; Animal husbandry
Separating; mixing	B01F B01J	Mixing (dissolving, emulsifying, dispersing); Chemical & physical processes and apparatus, e.g. catalysis, colloid chemistry
Shaping (metal) products	B21 B23 B25 to B27 B30 B31	Mechanical metal-working; Machine tools; metal-working not otherwise provided for; Hand tools; portable power-driven tools; handles for hand implements; workshop equipment; manipulators; Hand cutting tools; cutting; severing; Working or preserving wood or similar material; nailing or stapling machines in general; Presses; Making articles of paper, cardboard or material worked in a manner analogous to paper
Turning; Boring	B32B	Layered products
Working cement, clay, stone	B28	Working cement, clay, or stone
Working plastics	B29	Working of plastics
Printing; writing	B41 to B44	Printing; lining machines; typewriters; stamps; Bookbinding; albums; files; special printed matter; Writing or drawing implements; bureau accessories; Decorative arts
Petroleum, gas or coke industries	C10	Petroleum, gas or coke industries; technical gases containing carbon monoxide; fuels; lubricants; peat

Exclusion	IPC	Definition
Chemistry	C01B C01C C03 to C05 C07 C08 C11 to C14 C30 C40 C99	Inorganic chemistry; Non-metallic elements; salts; Glass; mineral or slag wool; Cements; concrete; artificial stone; ceramics; refractories; Lime, magnesia; Fertilizers; Organic macromolecular compounds; Polymers; Organic chemistry; Animal or vegetable oils & fats; detergents; candles; Bioinformatics; Biochemistry; microbiology; enzymology; mutation or genetic engineering; Sugar industry; Crystal growth; Combinatorial technology; Tanning; Skins; hides; pelts; leather
Dyes; Dying	C09 D	Textiles; paper; Dyes; paints; polishes; resins; adhesives
Construction	E01D E01H E04	Bridges; Street cleaning; cleaning of permanent ways; Building
Lighting; heating	F01K F22 to F24 F27	Heating; ranges; ventilating in general; Steam generation; Steam engine plants; steam accumulators; engine plants not otherwise provided for; engines using special working fluids or cycles; Combustion apparatus; combustion processes; Furnaces; kilns; ovens; retorts
Measuring; testing	G01K	Measuring temperature; measuring quantity of heat; thermally-sensitive elements not otherwise provided for
Photography	G03G	Electrography; electrophotography; magnetography
Instruments	G1	Instruments
Bioassays	G01N 33/	Bioassays
Electrical	H05K H03	Printed circuits; casings or constructional details of electric apparatus; manufacture of assemblages of electrical components; Basic electronic circuitry
Electrical	H01	Basic electric elements in general
Power generation	H02	Generation, conversion, or distribution of electric power

Appendix F: Sub-sector assignment

mining_top_id	mining_cat_lvl_1	mining_cat_id	mining_cat_lvl_2
1	Blasting	1.50	Fuses
		1.60	Blasting
2	Environmental	2.05	Reclamation of mining areas
		2.10	Treatment of waste water from metallurgical processes
		2.11	Treatment of waste water
		2.15	Biological treatment of soil
		2.20	Soil treatment
		2.25	Waste Disposal
		2.50	Protection against radiation
		2.90	Environmental
		102.30	Technologies related to mineral processing
		102.40	Technologies related to metal processing
		112.11	Treatment of waste water
3	Processing	3.15	Crushing/grinding mineral
		3.19	Crushing/grinding
		3.20	Flotation
		3.30	Separation
		3.31	Separation
		3.32	Separation
		3.42	Processing
		3.43	Processing
		3.44	Processing
		3.50	Bio-processing
4	Mining	4.10	Ground control support
		4.20	Excavation
		4.40	Safety/rescue
		4.50	Shafts
		4.60	Tunnels
		4.70	Ventilation
		4.90	Subsea
5	Transport	5.10	Rail
		5.15	Rail infrastructure
		5.20	Hoisting
		5.30	Conveying
		5.35	Hauling
		5.40	Vehicles
		5.50	Infrastructure
		5.60	Containers
		5.70	Control
		5.90	Shipping

mining_top_id	mining_cat_lvl_1	mining_cat_id	mining_cat_lvl_2
6	Exploration	6.10	Exploration
		6.12	Surveying and testing - automatic control
		6.15	Surveying and testing
		6.17	Core extraction
		6.21	Methods or apparatus for drilling
		6.22	Drilling tools
		6.25	Drilling
		6.29	Drilling - oil & gas
		6.35	Assays
9	Mining	9.50	Mining (original)
		9.60	Mining (additional)
		9.70	Extraterrestrial
		9.80	Mining (E21)
		9.90	Mining (additional)
		9.97	Mining (mining)
		9.98	Mining (mine)
10	Automation	10.00	Automation
11	Refining	11.10	Ferrous
		11.20	Non-ferrous
		11.30	Inorganic chemistry
12	Metallurgy	12.10	Metallurgy
		12.11	Pyrometallurgy
		12.12	Casting/powder metallurgy
		12.13	Furnaces
		12.14	Coating
		12.15	Electrometallurgy
109	Mining (kw only)	109.10	Mining (Ore)
		109.20	Mining (Ore*)
		109.30	Mining (Mineral)
		109.40	Mining (Coal)

Appendix G: Relevant ISIC groups

This table outlines how the ISIC classes were assigned to a mining sector for the firm data subset. Equivalent assignments were used for corresponding industrial classifications, such as ANZSIC for Australian firm data. For example, ANZSIC class **0600 Coal Mining** is corresponds to ISIC division **5 Mining of coal and lignite**.

Firm Sector	ISIC Rev. 4				
	Section	**Division**	**Group**	**Class**	**Description**
Mining	**B**				**Mining and quarrying**
Mining	B	05			Mining of coal and lignite
Mining	B		051	0510	Mining of hard coal
Mining	B		052	0520	Mining of lignite
Oil & Gas	B	06			Extraction of crude petroleum and natural gas
Oil & Gas	B		061	0610	Extraction of crude petroleum
Oil & Gas	B		062	0620	Extraction of natural gas
Mining	B	07			Mining of metal ores
Mining	B		071	0710	Mining of iron ores
Mining	B		072		Mining of non-ferrous metal ores
Mining	B			0721	Mining of uranium and thorium ores
Mining	B			0729	Mining of other non-ferrous metal ores
Quarrying	B	08			Other mining and quarrying
Quarrying	B		081	0810	Quarrying of stone, sand and clay
Quarrying	B		089		Mining and quarrying n.e.c.
Quarrying	B			0891	Mining of chemical and fertilizer minerals
Quarrying	B			0892	Extraction of peat
Quarrying	B			0893	Extraction of salt
Quarrying	B			0899	Other mining and quarrying n.e.c.
METS	B	09			Mining support service activities
Oil & Gas support	B		091	0910	Support activities for petroleum and natural gas extraction
METS	B		099	0990	Support activities for other mining and quarrying
-	**C**				**Manufacturing**
-	C	28			Manufacture of machinery and equipment n.e.c
-			281		Manufacture of general-purpose machinery
METS	C			2816	Manufacture of lifting and handling equipment
-			282		Manufacture of special-purpose machinery
METS	C			2824	Manufacture of machinery for mining, quarrying and construction

Appendix H: Relative Specialization Index

This table lists the RSI in mining for all countries in the technology data sub-set. The country is indicated with the 2-digit ISO code. We present the RSI for both periods: 1990–2004 and 2005–2015.

	RSI (specialization in Mining)	
ISO code	1990-2004	1990-2015
AD		0.096
AE	0.482	0.43
AG	0.686	0.304
AM	0.51	0.383
AN	0.625	0.631
AO		0.855
AR	-0.226	-0.221
AT	0.312	0.118
AU	0.206	0.285
AZ	0.467	0.401
BA	0.244	-0.175
BB	0.243	-0.262
BD		0.447
BE	0.101	-0.057
BG	0.376	0.241
BH		0.253
BM	-0.385	-0.344
BO	0.555	0.643
BR	-0.122	-0.109
BS	0.389	0.228
BW	0.837	0.332
BY	0.272	0.327
BZ		-0.313
CA	0.331	0.349
CD		1.031
CH	-0.082	-0.198
CL	1.01	0.89
CN	0.194	0.176
CO	0.045	0.065
CR	-0.09	-0.308
CS	0.322	0.211
CU	0.461	0.497
CY	-0.205	0.094
CZ	0.163	0.037
DD	-0.127	-0.246
DE	-0.091	-0.215
DK	-0.434	-0.166
DO	-0.324	-0.753
DZ	0.224	0.059
EC	-0.242	-0.101
EE	0.436	0.224
EG	0.107	-0.025
ES	-0.475	-0.5
FI	0.106	0.125
FR	-0.011	-0.086
GB	-0.106	-0.101
GD	1.439	1.11
GE	0.331	0.223

GH		0.429
GN	0.385	0.241
GR	-0.334	-0.487
GT	0.435	0.304
HK	-0.647	-0.711
HN		-0.494
HR	-0.083	-0.232
HU	-0.261	-0.373
ID	0.065	0.103
IE	-0.263	-0.366
IL	-0.461	-0.587
IN	-0.099	-0.23
IR	-0.092	-0.12
IS	-0.438	-0.321
IT	-0.506	-0.541
JO	-0.382	-0.848
JP	-0.107	-0.256
KG	0.904	0.801
KN		-0.145
KP		-0.164
KR	-0.318	-0.307
KW	-0.07	0.171
KZ	1.065	0.913
LB	0.786	0.433
LI	0.605	0.512
LT	-0.432	-0.458
LU	0.837	0.611
LV	-0.206	-0.279
MA	-0.158	-0.4
MC	-0.409	-0.095
MD	-0.536	-0.465
MH	1.439	0.467
MK	0.555	0.186
MN		0.614
MO	-0.159	-0.73
MR	0.616	0.508
MT	-0.04	-0.484
MU	0.811	0.332
MX	0.295	0.187
MY	-0.379	-0.227
NA	0.939	-0.033
NE	0.574	0.291
NG	0.337	-0.195
NI		0.695
NL	0.012	-0.052
NO	0.732	0.808
NZ	-0.253	-0.135
OM	1.218	1.306
PA	1.207	0.845
PE	0.574	0.536
PH	-0.582	-0.459
PK		0.132
PL	0.681	0.532
PT	-0.275	-0.29

QA		0.089
RO	0.469	0.288
RS	0.012	-0.026
RU	0.604	0.447
SA	0.519	0.73
SB		1.508
SC	0.36	0.291
SE	-0.089	-0.117
SG	-0.464	-0.287
SI	-0.203	-0.381
SK	0.038	-0.022
SL	0.411	0.265
SM	-0.262	-0.641
SN	0.477	0.271
ST	-0.17	-0.277
SU	0.652	0.544
SY	0.304	-0.228
TD		0.906
TH	-0.758	-0.247
TJ	0.177	0.128
TM	0.42	0.31
TN		-0.599
TR	-0.608	-0.586
TT	0.315	0.224
UA	0.692	0.485
UG	1.071	0.633
US	-0.013	-0.007
UY	-0.807	-0.654
UZ	0.491	0.404
VC		1.181
VE	0.931	0.877
VN	0.699	0.09
VU	0.962	0.695
YU	-0.667	-0.728
ZA	0.889	0.773
ZR	1.616	1.508
ZW	0.392	0.411