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"INNOVATION AND TRADE PATTERNS IN THE LATIN AMERICAN MINING SECTOR"

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Innovation and trade patterns in the Latin American mining sector♦

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Abstract

This paper examines the trade and innovation specialization patterns in the Latin American mining sector, in terms of exports of mining products, of its exports of mining equipment, and of its production of mining technologies (i.e. innovation). Results suggest that Latin American countries are specialised in the extraction and export of mining products (i.e. minerals), and de-specialised in the production of mining equipment and of mining technology, while they heavily rely on imports of equipment and technology. We also find that the mining innovation taking place in Latin America is of relatively low quality. Considering that innovation in the mining sector is supplier-dominated, the weak technological specialisation of Latin American countries in the mining sector reflects mainly the low innovation capacity of local suppliers to mining companies, in comparison to the global average.

Keywords: Mining innovation; Mining production; Specialization patterns; Patent quality indicators; Local METS (suppliers); Patents; Trade data; Inward FDI; Latin America

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1 Introduction

Large parts of Latin America are often considered to be following a natural resource based development strategy, taking advantage of the economic rents conferred by privileged access to abundant natural resource endowments (Cimoli et al., 2006). A number of Latin American countries exhibit a strong specialisation in the extraction and export of mining products, although there is heterogeneity across countries within Latin America on this. Such an approach can be considered to represent an important development opportunity for developing resource-abundant countries, an opportunity arising from favourable global conditions associated with the increased demand for minerals alongside dwindling supplies from easy-extraction mines (Marin, Navas-Aleman and Perez, 2015).

However, a natural resource based development strategy is quite risky if not accompanied by substantial efforts to upgrade and diversify both within and beyond the natural resource sector (Pietrobelli and Rabellotti, 2011). Cimoli et al. (2006), for example, argue that the abundance of resources can sustain growth without significant efforts for learning in the short term, but that in the long-run economic rents derived from these resources tend to be eroded. Moreover, in the context of dwindling supplies and the necessity to extract natural resources from more difficult locations, innovation is increasingly necessary as a means of achieving profitable mineral extraction from less favourable locations or from lower quality mines. Such innovation efforts would encompass processes related to exploration, extraction and transportation technologies (Molina, Olivari and Pietrobelli, 2016). In other cases, especially when natural resources are abundant, but labour is scarce, significant technological efforts may be required to boost labour productivity (e.g. the case of Latin America). To summarise, production specialisation without innovation specialisation can lead to a lack of long-run development[1] (Cimoli and Porcile, 2011; Dosi and Tranchero, 2021). When economic rents are purely based on the relative abundance of resources without fostering innovation, the capacities to induce or respond to shocks and changes is reduced, since the country basically lacks the technological capabilities necessary to readapt the production system to changing contexts (Cimoli et al., 2006). Furthermore, in Latin America, firms operating in the natural resources sector have become more closely integrated in to global value chains in which the stimulus to speed up indigenous learning was abandoned in favour of a focus on homogenization of inputs and goods within a hierarchical system of production (ECLAC, 2008). This occurred in parallel with the progressive commoditization of the production of goods and services in the Latin American region. These processes jointly resulted in a disarticulation of local production chains along with the marginalization of small and medium domestic firms. Rationalization based on the more intense use of imported inputs and equipment produced blanks in the production matrix and had negative effects on the levels of employment and heterogeneity (Cimoli and Porcile, 2011).

Moving beyond innovation to consider a broader value chain perspective, it is also the case that the extraction and export of mining products is not necessarily the optimum positioning for countries to target in the value chain. While the processing and refining of mining products has often been considered a possible channel for upgrading within mining value chains (Kaplan, 2012; Pietrobelli, Marin and Olivari, 2018), a further relevant dimension relates to the production and export of upstream mining related products, such as mining equipment. Besides technological learning processes, knowledge-intensive

[1] Learning and innovation reshape international competitiveness and allow countries to exploit the opportunities of international trade and growth (Alcorta and Peres, 1998). Furthermore, technological efforts are mediated by the transformation of the production structure. A structural change that promotes sectors that create and diffuse technology allows to capture the opportunities of international demand dynamism (Cimoli et al., 2006).

suppliers have been key for turning natural resource industries into knowledge-based industries with high innovation capabilities. Knowledge-intensive suppliers, from equipment to engineering services, have also been fundamental for the competitiveness of the industry itself, and the emergence of knowledge intensive clusters (Urzua, 2013). Bartos (2007) points out that much of the mining industry's present productivity and innovation have originated from outside the industry, specifically through equipment manufacturers and suppliers to the mining industry, with Mining Equipment Technology Services (METS) companies (i.e. suppliers) being key innovators for the mining industry (Bartos, 2007; Calzada Olvera, 2021; Daly, Valacchi and Raffo, 2019; Francis, 2015; Iizuka, Pietrobelli and Vargas, 2019; Scott-Kemmis, 2013; Urzua, 2003).

METS companies include equipment manufacturers, core engineering design & project management (EPCM), general and consulting services and specialized technology among others (Scott-Kemmis, 2013), which highlights the importance of linkages between the mining sector and other sectors in upgrading through mining activity. Marin and Stubrin (2015) point out that the extent of the linkages between the local economies and mining companies strongly depends on the technological capabilities of the local firms and the general economic and political context. Some production linkages can arise spontaneously, but if countries fail to actively encourage structural change it is likely that their specialization pattern will not automatically create the incentives to shift towards more sophisticated technological production stages and activities (Alcorta and Peres, 1998).

Moreover, the quality of mining innovation carried out at the local level in Latin America is another relevant factor to be examined in order to promote technological development. We study innovation quality in two different but complementary manners, i.e. selecting a set of cutting-edge (key) mining technologies and examining whether Latin America is specialised in producing them, and through patent quality. Concerning patent quality, as the number of patent applications has surged worldwide, economists and management scholars have become more and more dissatisfied with using simple patent application or grant numbers as an indication of innovation output (Gambardella, Harhoff and Verspagen, 2008). We measure the quality of local mining innovation using patent value indicators (Squicciarini, Dernis and Criscuolo, 2013). We use the term quality to emphasize both the technological and economic dimensions of an innovation (Lanjouw and Schankerman, 2004). For economists a good patent is generally one that fulfils the key objectives of the patent system, i.e. to reward and incentivise innovation while enabling diffusion and further technological developments. We use two main patent value indicators: the number of forward citations, i.e. references to previous patents (Jaffe and De Rassenfosse, 2017; Trajtenberg, 1990) and patent family size, i.e. the number of countries in which a patent is taken out (Putnam, 1996).

Based upon these arguments, this paper considers four main issues. Firstly, the paper presents information on the production and specialisation patterns of Latin America in mining products, highlighting that Latin America is indeed specialised in the extraction and export of mineral commodities, with the mining sector also being a major target for inward FDI into this set of countries. Secondly, the paper examines whether a similar specialisation pattern is also observed when using patent data to examine whether and to what extent Latin America is specialised in the production of technology (i.e. innovation) in the mining sector. The results suggest that Latin America is not specialised in the production of mining technologies, but is instead a user of technologies developed elsewhere. Thirdly, and relatedly, the paper addresses whether Latin America is specialised in the production and export of mining equipment, addressing the question of whether Latin America has been able to develop production capabilities in this upstream activity, where the potential to capture a higher value-added share from the mining value chain is potentially larger (Blundi et al., 2019; Xu and Chiang, 2005). The results suggest that Latin America has not been able to develop specialisation in mining equipment, instead relying on imports to serve its own needs regarding mining equipment. This confirms that the creation of backward linkages between mining companies and their suppliers at the local level (Hirschmann, 1977) is hindered, with machinery purchased from abroad, possibly reflecting that the host region may not have an advanced secondary sector[2]. Fourthly, we investigate the quality of Latin American innovation in the mining industry.

The remainder of the paper is organized as follows: Section 2 describes the data used; Section 3 shows the results; based upon the results from the four main questions addressed, Section 4 summarises and proposes some explanations and implications of the observed results; Section 5 concludes.

2 Data

The paper relies on three main sources of data for the analysis. The first of these is the UN Comtrade database, which reports detailed product-level information on imports and exports of countries over time. For the analysis in this chapter, we rely on two main aggregates of this product-level data.

The first aggregate captures the export of mineral products, and includes metallic and non-metallic minerals, and coal (we exclude natural gas and oil to be consistent with the patent data). More precisely, I use the following Harmonized System (HS) Codes (1992): 25 – Salt, Sulphur, Earths, Stone, plastering materials, lime and cement; 26 – Ores, Slag and Ash; 2701 – Coal, briquettes, ovoids and similar solid fuels manufactured from coal; 2702 – Lignite, whether or not agglomerated, excluding jet; 2703 – Peat (including peat litter), whether or not agglomerated; 2704 – Coke and semi-coke, of coal, lignite or peat, whether or not agglomerated, retort carbon; 2705 – Coal gas, water gas, producer gas and similar gases, other than petroleum gases and other gaseous hydrocarbons; 2706 – Tar distilled from coal, from lignite peat and other mineral tars, whether or not dehydrated or partially distilled, including reconstituted tars; 2707 – Oils and other products of the distillation of high temperature coal tar; similar products in which the weight of the aromatic constituents exceeds that of the non-aromatic constituents; and 2708 – Pitch and pitch coke, obtained from coal tar or from other mineral tars.

The second aggregate captures data on exports and imports of mining equipment. Mining equipment includes a wide range of equipment used from exploration to smelting operations in the discovery, extraction and processing of coal, minerals and ores (UNCTAD, 2007). The classification used builds upon a selection of HS classifications regarding mining equipment previously made by Bamber, Fernandez-Stark and Gereffi (2016). Details of this selection are presented in appendix A. Following the approach of Bamber, Fernandez-Stark and Gereffi (2016), the equipment used in the mining value chain are divided into four principal categories:

i. Surface and underground mining equipment (SUM) which includes drilling equipment used in exploration activities. SUM also includes equipment involved in extracting the materials

[2] The development of spin-off industries that are suppliers of services and inputs to mining companies, as well as commodity processing industries is essential for diversification, employment generation, improvement of social capabilities and the overall resilience of the economy (Calzada Olvera and Foster-McGregor, 2018).

from the earth (e.g. continuous miners, dozers, draglines, drills, excavators, loaders, scrapers, shovels, and mining trucks among others).

ii. Mineral processing equipment (MP) includes equipment used to separate the mineral from waste material, remove impurities, or prepare the ores for further refinement (e.g. crushers, cyclones, feeders, flotation cells, grinders/mills, etc.).

iii. Bulk materials handling (MH) includes equipment that is involved in moving ore and waste materials in all stages of the mining operations (e.g. conveyers and wagons).

iv. Wear parts: SUM, MP and MH include components and parts that must be regularly replaced due to abrasion during use. These are low value parts[3] and are referred to as wear parts and include items such as steel balls and liners for grinding mills and liners for dump truck bodies.

Other equipment such as that used in the smelting and refining process or ship-loading is not included within our scope, as this equipment is usually operated off-site or may be used for multiple different sectors. Mining infrastructure is also not included in this chapter.

The second major source of data is the WIPO Mining dataset, which collects information on patents related to mining technologies from all over the world for the period 1970-2015. In particular, the database contains information on patents related to technologies regarding metallic and non-metallic minerals, and coal. Each patent has an application identifier which corresponds to the application identifier in EPO-PATSTAT.

The starting point for building the WIPO Mining Database 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. Patent data from WIPO's patent family database are also used in the construction of the database. These latter data are a combination of the EPO-PATSTAT database[4] and the PCT national phase entries stored in the WIPO Statistics Database (Daly, Valacchi and Raffo, 2019; p. 12).

As regards the search strategy used when constructing the WIPO dataset, WIPO chose to combine keywords found in abstracts and titles, further collecting information in 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. 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. The keywords were searched in the titles and abstracts and assigned a general keyword term (see Daly, Valacchi and Raffo (2019; pp. 52-53) for a list of keywords). A second subset of data was extracted by retrieving all patents comprising at least one E21 (Earth or rock drilling; Mining) International Patent Classification (IPC) or Cooperative Patent Classification (CPC) mark. These two subsets of data were used as a subset of the whole PATSTAT database to search within.

The WIPO dataset identifies 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 to several IPC codes. As a result,

[3] It is worth stressing that each of the four categories concerning mining equipment reflect the different stages of use in the mining industry and each of them includes equipment with a range of equipment from low to high value.

[4] This link to the PATSTAT database also allows me to obtain data on forward citations used in part of the analysis.

the patents in the mining dataset will inevitably be classified in multiple classes, and therefore multiple mining categories.

Some key information contained in the WIPO dataset distinguishes between inventor country of origin, applicant country origin and the office code or application authority of patents. Also included is a variable that indicates in how many offices (countries) that patent has been filed. Since patents are grouped in patent families, a family identification is also included along with information on the size of the family to which the patent belongs.

Patents are further categorized into nine mining subclasses in terms of technology: exploration, blasting, mining (mine operation), processing, metallurgy, refining, transport, automation and environmental (see Daly, Raffo and Valacchi (2019), in particular: Appendix B for details about the search strategy and categorization; Appendix C and Table 1 for a description of each mining technological field). These nine mining technological classes were carefully selected thanks to a search strategy made up of a combination of IPC codes and keywords in PATSTAT.

For part of the analysis, we are interested in distinguishing between different types of firms, notably between mining firms (coal, metal ore and non-metallic mineral), Mining Equipment Technology Services (METS) firms, and Oil & Gas and Quarrying. This distinction allows for an examination of the role of suppliers of mining firms (METS), firms that are considered to be key innovators for the mining industry. To do this, we merged the WIPO Mining Database with data from ORBIS. ORBIS is a commercial database from Bureau van Dijk that contains information on more than 120 million companies around the world. These data can be combined with the WIPO Mining Database using a unique firm identifier. ORBIS focuses on the biggest players in the market, which are also the most active ones in terms of research activity.

The final major source of data is the fDi Markets Database, which is an online database provided by fDi Intelligence – a specialist division of Financial Times Ltd – that monitors cross-border investments covering all sectors and countries worldwide from 2003 onwards. fDi Markets is an event-based (or deal-based) database, i.e. each entry is a project, which collects detailed information on announced cross-border greenfield investments[5] (i.e. new wholly-owned subsidiaries, including joint ventures whether they lead to a new physical operation) from several publicly available information sources, including nearly 9000 media sources, over 1000 industry organizations and investment agencies, and data purchased from market research and publication companies. The time span covered by this database covers the period 2003-2018 (for further details regarding fDi Markets dataset see Zanfei, Coveri and Pianta, 2019). For the purposes of this chapter, the main data of interest from the fDi Markets database relate to the Metals, Minerals and Coal, oil and natural gas (in particular Coal mining and Support activities for mining) sectors, though data from other sectors is also used when constructing FDI-based specialization indices.

3 Results

[5] One possible limitation of fDi Markets regards the inclusion of greenfield investments only, while it does not cover information on mergers and acquisitions, providing a partial picture of global flows of FDI. However, the importance of mergers and acquisitions should not be over-emphasized. In fact, according to the World Investment Report 2018, over the period 2008-2014 the value (the number) of greenfield FDIs were twice (more than twice) as large as the value (the number) of net cross-border mergers and acquisitions deals (UNCTAD; (2018; pp. 7-8); Zanfei, Coveri and Pianta, 2019). It follows that focusing on greenfield investment allows to capture a large portion of FDI flows, reassuring us about the representativeness of the data we employ.

The analysis in this paper focuses on four main issues, as defined above. In the first, we consider whether Latin America is specialized in the production and export of mining products. To address this question, we focus on indicators of revealed comparative advantage to examine whether Latin America has comparative advantage in (exporting) mining products. We also consider alternative data reflecting mining production patterns, by examining whether Latin America has comparative advantage in attracting inward FDI in the mining sector. Secondly, we investigate whether the specialization in producing mineral commodities is associated with the development of production capabilities in upstream activities along the mining value chain, i.e. the production (export) of mining equipment. Moreover, we also consider whether Latin America has comparative advantage in importing (using) such mining equipment from abroad. Thirdly, and relatedly, this paper examines whether a similar specialisation pattern is also observed when using patent data to examine whether Latin America is specialised in the production of mining knowledge (i.e. innovation). Fourthly, the quality of mining innovation carried out in Latin America is examined. Specifically, we compute a revealed technological advantage concerning a set of leading-edge mining technologies, which are useful to solve important issues for the mining industry. Relatedly, we also examine the quality of the Latin American mining patents using patent value indicators.

The results section addresses each of these issues in turn, with Section 3.1 reporting results on Latin America's specialization in mining products, Section 3.2 considers whether Latin America is specialized in mining equipment, Section 3.3 examines whether Latin America is specialized in producing mining innovation and Section 3.4 investigates the quality of innovation in the Latin American mining sector.

3.1 Latin America's trade specialisation in mining products

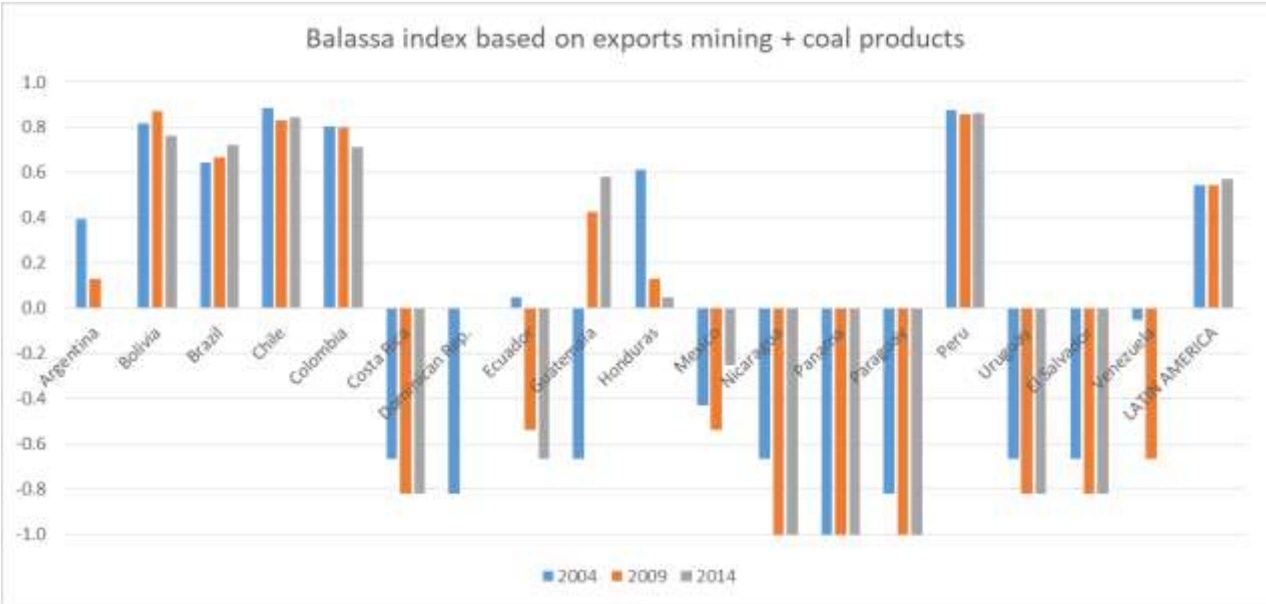
To examine the export specialization patterns of Latin America, we utilize the commonly used Balassa index (Balassa, 1965) of Revealed Comparative Advantage (RCA). This index compares the importance of a product or sector in a country's export basket to that of a comparison group (usually world exports). If the country is observed to export a higher share of a particular product or industry than the world as a whole, then it is concluded that the country has a revealed comparative advantage in the export of that product or industry. The RCA of exports (X) for industry i in economy k is thus computed as:

$$RCA_k^i = \frac{X_k^i / \sum_k X_k^i}{\sum_i X_k^i / \sum_k \sum_i X_k^i}$$

If the RCA is greater than one, the economy is considered to be specialized in the export of the particular product or industry. In the analysis below, we follow Foster-McGregor, Nomaler and Verspagen (2019) in transforming the RCA values as $(RCA - 1)/(RCA + 1)$, which makes the figures appear more symmetric. As a result of this transformation, a value of the RCA index above zero corresponds to a country having revealed comparative advantage in the export of the product.

Using the definition of mining products discussed in the previous section and data from UN Comtrade, Figure 1 reports information on the RCA for a selection of Latin American countries (as well as a Latin America aggregate) for three different years (2004, 2009 and 2014). This allows for a comparison both across countries and across time. The results reported in Figure 1 indicate that Latin America as a whole was specialized in exporting mining products from 2004 to 2014[6]. The RCA index rose slightly from 0.5 to 0.6 between 2009 and 2014, suggesting an increasing dependence on natural resources. Considering individual countries, the results indicate that Bolivia, Brazil, Chile, Colombia and Peru have a strong specialization in mining exports with a value of the RCA index often exceeding 0.6. Guatemala and Honduras are also found to be specialized in the exportation of mining products, albeit with differing trends, with Guatemala obtaining and increasing its specialization in mining products over time and Honduras beginning the period with a strong specialization that steadily declines. The rising trend observed in Guatemala is also found in Brazil, while a declining trend is observed in Bolivia and Colombia. The remaining countries in the sample (i.e. Costa Rica, Dominican Republic, Mexico, Nicaragua, Panama, Paraguay, Uruguay, El Salvador and Venezuela) are not found to be specialized in exporting mineral commodities during the time span under study.

Figure 1 – RCA based on export data of mineral commodities for Latin American countries



Note: The RCA variable is transformed such that it lies between -1 and +1, with values greater than zero indicating RCA.

Source: Own elaboration based on UNCOMTRADE database.

The results presented in Figure 1 suggest that Latin America has a specialization in the export of mining commodities, but a remarkable heterogeneity exists across Latin American countries. In particular, the overall specialization of the continent is driven by a subset of Latin American countries (i.e. Argentina, Bolivia, Brazil, Chile, Colombia, Guatemala, Honduras and Peru). This specialization pattern observed in exports, can also be found when considering alternative data that may reflect production patterns. In particular, a similar pattern is found when considering data on inward FDI flows into Latin American countries.

[6] This is in line with Cimoli and Porcile (2011) who state that, in Latin America, sectors intensive in natural resources and raw labour have generally had a dominant position in exports. Structural change and diversification were remarkably slow compared to those countries that succeeded in catching up, particularly the Asian countries.

Mineral production characteristically lends itself to transnational activity. FDI has historically played a key role in enabling exploration and extraction activities worldwide, with MNEs their ultimate orchestrators. According to a recent survey regarding the 100 largest (publicly-listed) mining corporations, 70% are MNEs and over one half of their subsidiaries are foreign-owned (60%). Not only are large mining companies predominantly transnational, but they are more prolific in developing countries than are large MNEs in other industries. Some 35% of foreign affiliates of mining MNEs in UNCTAD's ranking of the top 100 global MNEs are located in developing countries (Formenti and Casella, 2019).

To examine the importance of inward FDI in the mining sector of Latin America, we follow a similar approach to above and construct an FDI-based specialization index (Zanfei, Coveri and Pianta, 2019) by adjusting the RCA indicator defined above. The new indicator is constructed as:

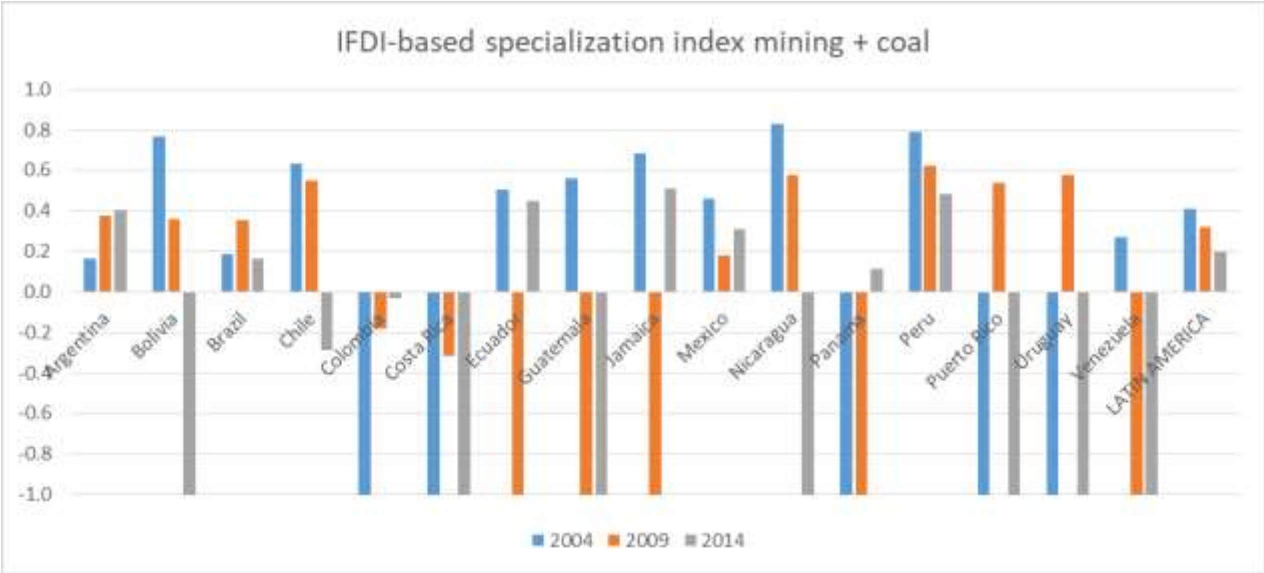
$$RCA_k^i = \frac{IFDI_k^i / \sum_k IFDI_k^i}{\sum_i IFDI_k^i / \sum_k \sum_i IFDI_k^i}$$

with IFDI referring to inward FDI. This is analogous to the RCA indicator constructed using export data, with Zanfei, Coveri and Pianta (2019) stating that the FDI specialization indices are computed in a given industry for a given economy as the share of IFDIs (Inward Foreign Direct Investments) drawn in that industry by such economy over the share of total inward FDIs attracted by such economy in all industries worldwide. As with the export-based RCA, we transform the variable such that values greater than zero indicate specialization.

Having a mining FDI specialization indicates that a country has the ability to attract FDI in mining that is greater than other areas, which in turn may have a substantial effect on the host economy in terms of structural change, agglomeration economies and potential technological spillovers accruing to local firms and institutions, for example (Antonietti et al., 2015; Baldwin and Venables, 2013). Figure 2 reports the results of the FDI specialization index for a set of Latin American countries and for Latin America as a whole.

Figure 2 – Inward FDI-based Specialization Index[7] based on number of IFDI projects concerning the mining sector for Latin America

[7] We rely on the number of FDI projects rather than on the value of capital involved, since criteria for value estimation of capital investment are not made explicit by fDi Markets. In addition, we follow Crescenzi et al. (2015, p. 33) holding that often the number of investment decisions in a given geographical destination (in our case Latin America) is likely to be a more proper unit of analysis than the value of the project insofar as such decisions have been demonstrated to be broadly



Note: consistent with Figure 1, we transform the RCA variable based on IFDI such that it lies between -1 and +1, with values greater than zero indicating RCA.

Source: Own elaboration based on fDi Markets database.

Figure 2 indicates that Latin America as a whole is specialized in attracting FDI in the mining sector, although the extent of this specialization is declining over time. This is also true for many of the individual countries. From 2009 to 2014, for example, Brazil, Chile and Peru saw a decline in their specialization in mining FDI. Conversely, in other countries – such as Argentina, Ecuador, Jamaica, Mexico and Panama – specialization in mining FDI increased, particularly in the latter period. Only two of the countries considered (Colombia and Costa Rica) were not found to be specialized in mining in the period considered[8].

To summarize, Latin America is specialized in the production and export of mining products and in attracting inward FDI into the mining sector. However, the data show a high heterogeneity across countries and FDI-based specialization appears to be declining in many countries. This specialization pattern in attracting FDI can offer both advantages and disadvantages, being a source of technology but also potentially substituting for own production of technology. In the mining industry, for example, the hunt for mineral resources has historically been the main driver of FDI, leaving little room to manoeuvre for knowledge transfers and technological catch-up. In the following sections, we consider whether this specialization in the production of mining products is associated with activity in higher value-added mining activities, namely mining equipment and mining innovation.

independent from the amount of capital invested (Amighini et al., 2014). Zanfei, Coveri and Pianta (2019; p. 5) also stress the fact that a number of empirical works using fDi Markets have been performed exploiting the number of FDI projects rather than the data on capital investment.

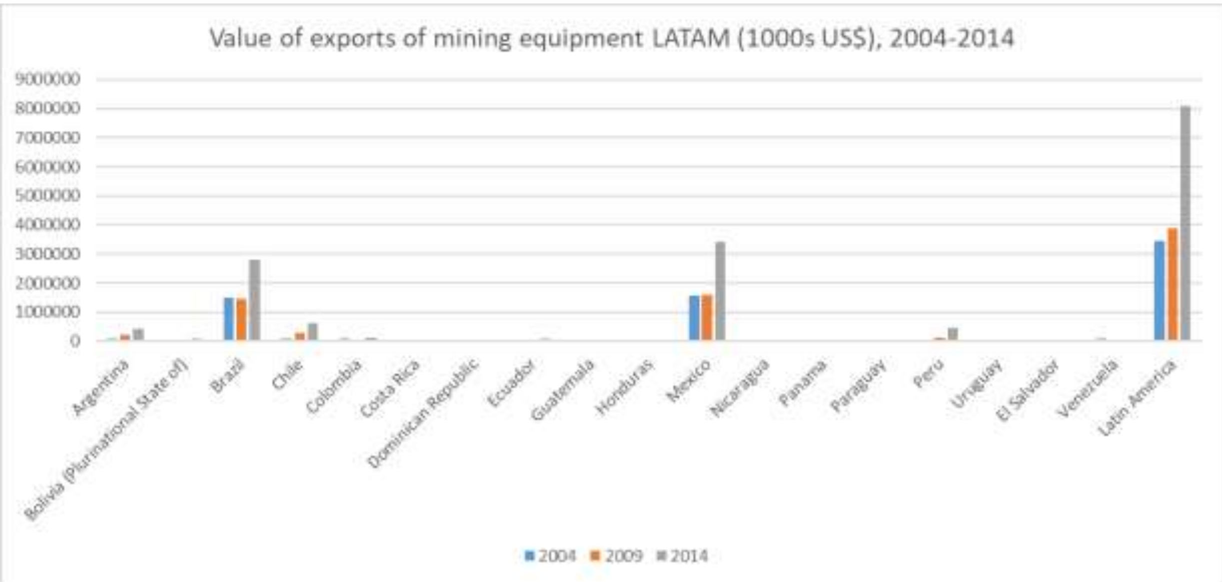
[8] It is worth noting that some of the Latin American countries that are not specialised in terms of mining exports are partially specialised in attracting IFDI in the mining sector, revealing some kind of specialisation in mining production.

3.2 Latin America's specialisation in mining equipment

In this section, we examine whether Latin America has been able to develop specialization in the production of mining equipment. Given that Latin America has developed a specialization in the production of mining products, it may be that it has also been able to develop specialization in upstream activities associated with this specialization, activities that may include the production of mining equipment. At the same time, it may also be that Latin America's specialization in mining products has been driven by the importation of mining equipment, possibly through inward FDI and the activities of TNCs.

Figure 3 reports the value of exports of mining equipment between 2004 and 2014. As already mentioned in the data description section, we follow Bamber, Fernandez-Stark and Gereffi (2016) in defining mining equipment. The figure indicates that after remaining relatively stable between 2004 and 2009, there was a rapid rise in the export of mining equipment between 2009 and 2014 for Latin America as a whole. The export of mining equipment in Latin America is driven by two of the largest countries – Brazil and Mexico – with Argentina, Mexico and Peru also having significant levels of mining equipment exports. All of these countries witnessed an increase in the value of mining exports over time, with the increase being most pronounced in Mexico[9].

Figure 3 – Export values (1000s US$) of mining equipment in Latin America, 2004-2014



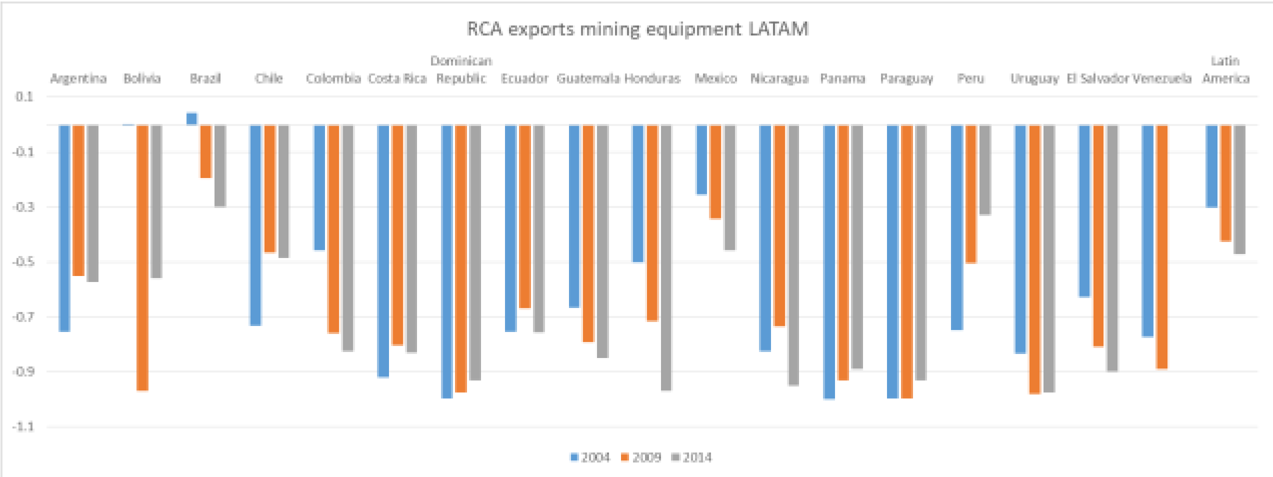
Source: Own elaboration based on UNCOMTRADE database.

Moving beyond the level of exports, we further consider whether Latin America has a comparative advantage in the export of mining equipment using the same approach of calculating the RCA as above. The major difference between the approach above and that here is that we no longer consider industries when constructing the RCA variable, but instead products. The set of products considered includes all

[9] Export data are all in current US$, meaning that price changes are also likely to play a role in driving these developments over time.

traded products, so that we calculate specialization in the export of mining equipment relative to all traded products. Results of these calculations are reported in Figure 4.

Figure 4 – RCA based on export data (US$) regarding mining equipment for Latin America over time, 2004-2014



Note: Consistent with Section 3.1, we transform the RCA variable based on export of mining equipment such that it lies between -1 and +1, with values greater than zero indicating RCA.

Source: Own elaboration based on UNCOMTRADE database.

The results in Figure 4 suggest that Latin America is not specialized in exporting mining equipment in any of the three periods under consideration, with the observed comparative disadvantage in exporting mining equipment actually increasing over time (as represented by the declining RCA values from -0.3 in 2004 to -0.5 in 2014). With the exception of Brazil in the initial period, the results further suggest that none of the individual countries in Latin America has a comparative advantage in the export of mining equipment, with the observed comparative disadvantage increasing over time in many of the countries considered. Such a result may indicate the lack of local METS firms in Latin America, something that we return to later in the paper.

Given the importance of mining production for the Latin American economy and given the lack of comparative advantage in the production of mining equipment, it should be expected that Latin America is relatively specialized in the importation of mining equipment. This is confirmed by Figures 5 and 6 which report the value of imports of mining equipment (Figure 5) and the indicator of revealed comparative advantage of imports of mining equipment (Figure 6).

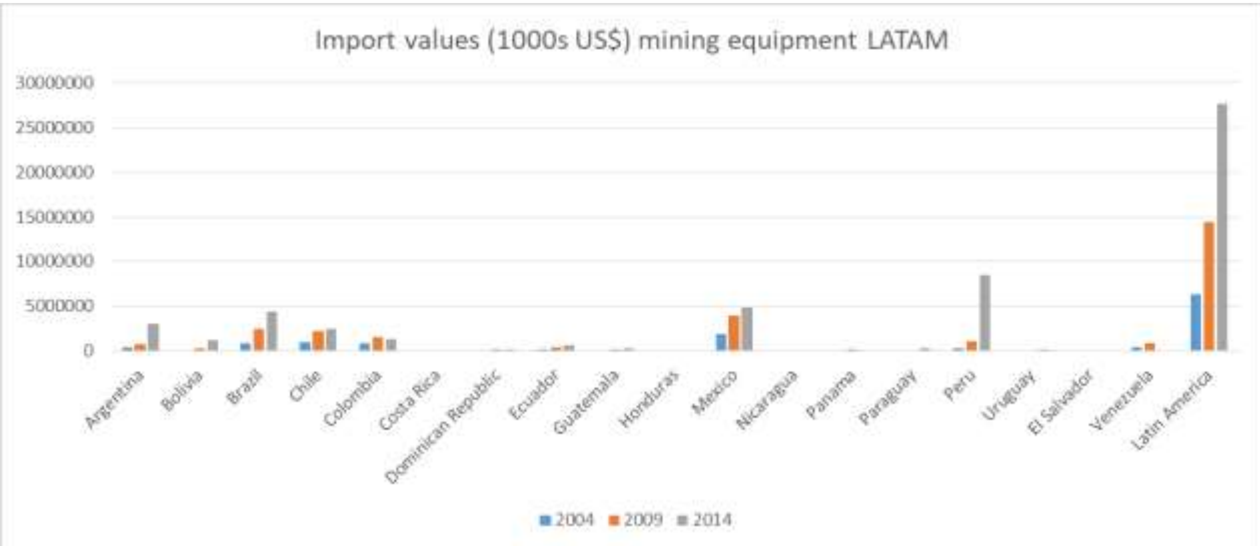
Figure 5 shows that there was a relatively rapid increase in the import of these mining technologies in Latin America between 2004 and 2014[10]. If we analyse individual Latin American countries, we observe that Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Mexico, Paraguay and Peru increased their import of mining equipment in terms of absolute values between 2004 to 2014. Perhaps of more

[10] It can mean that there was a more intensive use of them. Nevertheless, given that both import and export values jumped between 2004 and 2014, it may also suggest that the price of mining equipment increased rapidly.

importance, Figure 6 indicates that Latin America as a whole is specialized in importing mining equipment[11], with the comparative advantage increasing between 2004 and 2009, but falling slightly between 2009 and 2014. Most Latin American countries are specialized in the import of mining equipment, with Argentina, Bolivia and Peru, among others, also seeing an increase in specialization over time. Countries that are not specialized (or have seen a decline in specialization such that they were not specialized at the end of the period) in importing mining equipment include Costa Rica, Guatemala, Honduras, Nicaragua, Uruguay and El Salvador[12].

To summarize, despite being specialized in the extraction and export of mining products Latin America does not have a specialization in the production and export of mining equipment, instead relying on the importation of mining equipment to meet the needs of the sector. In other words, Latin America relies on the diffusion of technology embodied in imported mining equipment, rather than relying on its own technology. In the following subsection, we ask whether this may be reflective of the lack of innovation in the mining sector in Latin America.

Figure 5 – Import values (1000s US$) of mining equipment in Latin America, 2004-2014

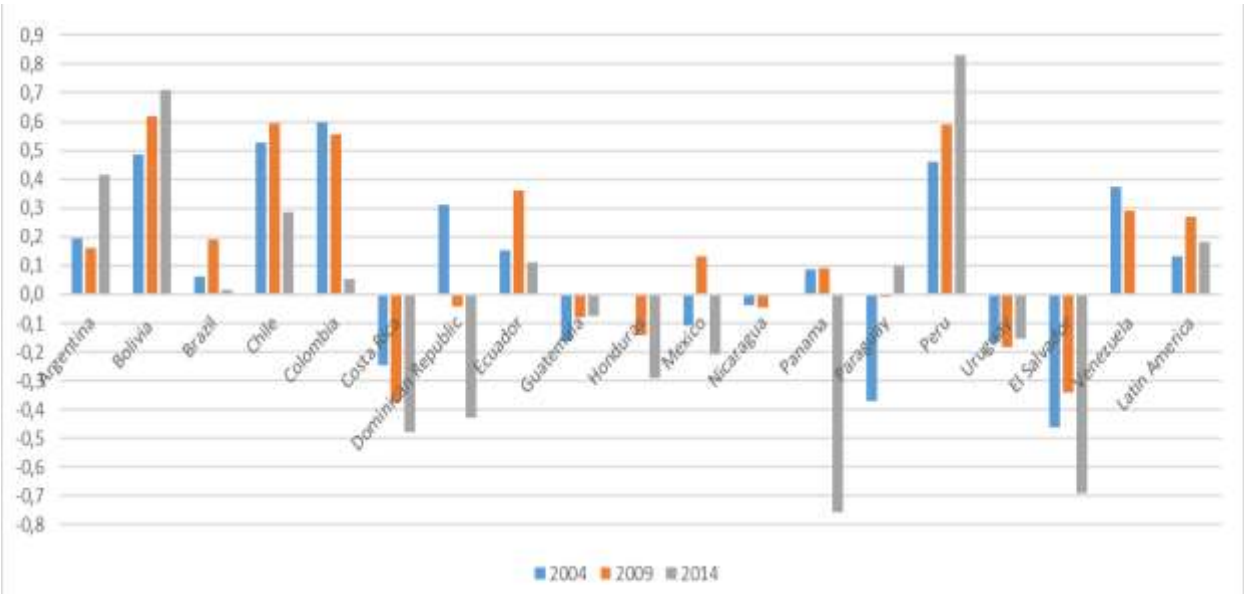


Source: Own elaboration based on UNCOMTRADE database.

Figure 6 – RCA based on import data (US$) regarding mining equipment for Latin America over time, 2004-2014

[11] It must be stressed that surface and underground mining equipment and mineral processing equipment represent the overwhelming majority of mining equipment (see Bamber, Fernandez-Stark and Gereffi, 2016).

[12] Most of these countries are also the less specialised in producing mineral commodities (see Section 3.1).



Note: Consistent with Section 3.1, we transform the RCA variable based on import of mining equipment such that it lies between -1 and +1, with values greater than zero indicating RCA.

Source: Own elaboration on UNCOMTRADE database.

3.3 Latin America's specialisation in mining innovation

To examine whether Latin America has a specialization in mining innovation or not, we follow a similar approach to above by constructing an indicator of revealed technological advantage (RTA) similar to the RCA variables defined above. In particular, we follow Le Bas and Sierra (2002) who used the index of RTA originally developed by Soete (1987) to measure the relative technological strength of a country in a certain industry. The RTA index can be defined for countries in a certain technological field, which in my case is mining. The index of RTA can be calculated as:

$$RTA_k^i = \frac{P_k^i / \sum_k P_k^i}{\sum_i P_k^i / \sum_k \sum_i P_k^i}$$

Where P_k^i is the number of patents applied for by applicants in industry i in economy k. As above, we transform this variable such that numbers greater than 0 indicate that a country has an RTA in mining innovation.

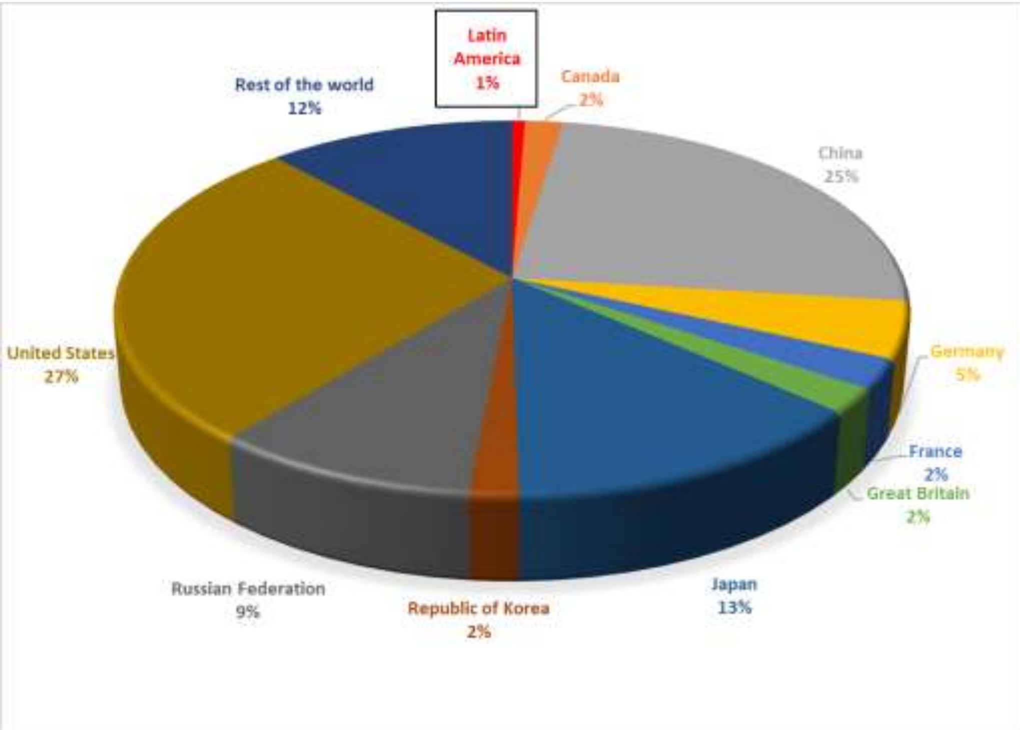
In order to construct this indicator, we require information on the production of mining technologies, for which we use information from patent data (i.e., the country of residence of the applicant[13]). This indicator is informative about the knowledge created locally at the country level and where mining innovation activities take place (OECD, 2009). Before presenting results of the RTA in mining for Latin

[13] Precisely, this is a count of the number of patent applications taken out everywhere.

American countries, we report in Figure 7 the distribution of the applicants (in terms of number of patent applications) concerning mining patents at the global level for the period 1970-2015.[14]

The results presented in Figure 7 indicate that patenting in mining is dominated by the USA and China. These two countries account for 52% of mining patents considering applicants origin. Other countries that account for a relatively high share of patents include Russia, Japan and Germany. Conversely, the whole of the Latin American region accounts for around 1% of global mining patents, providing some initial evidence that Latin America is not heavily engaged in mining innovation. In data not reported in the figure, we further observe that mining patents are unevenly distributed across the countries of Latin America, with more than 75% of Latin American patents being invented in just three (Brazil, Chile and Mexico) of the 18 Latin American countries.

Figure 7 – Share of mining patents in terms of applicant's country of origin worldwide, 1970-2015



Note:

- LATAM does not include Haiti, Paraguay, Puerto Rico, Guadeloupe, French Guiana, Saint Martin and Saint Barthelemy because they have no mining patents in terms of applicant country.
- "Rest of the world" represents all the other countries that are not labelled in the chart, with less than 1 percent each.
- We use counts of patent applications to make these statistics.

Source: own elaboration based on WIPO Mining Database.

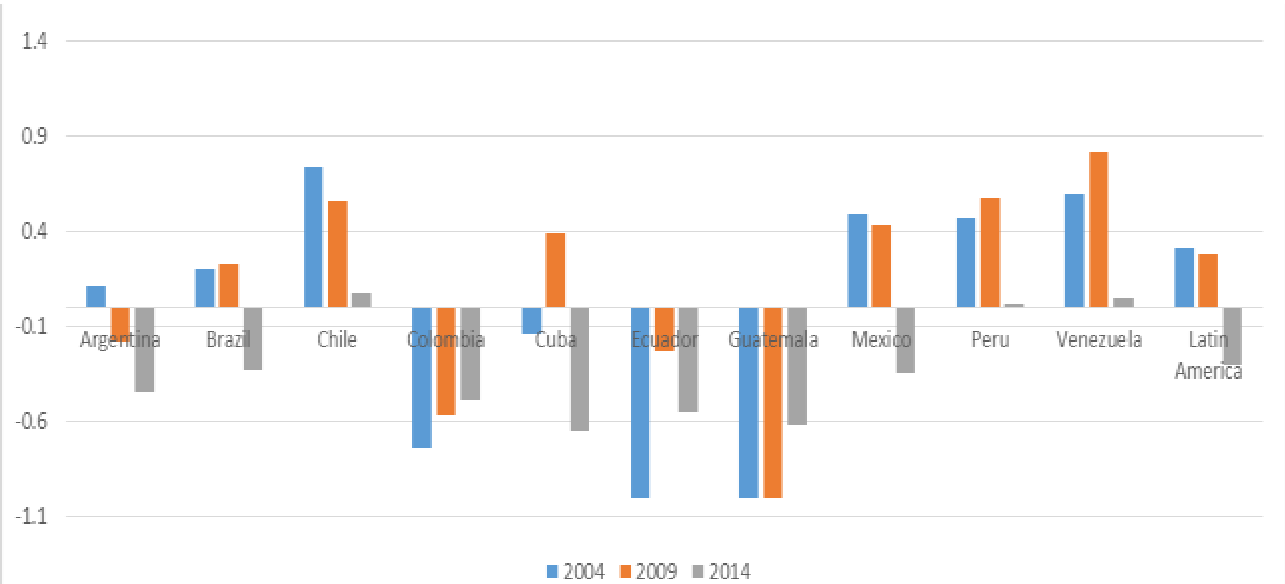
Turning to the data on RTAs for Latin America, Figure 8 reports information for 10[15] Latin American countries for the same three years as above (i.e., 2004, 2009, 2014). The figure reveals that Latin America as a whole had an RTA in mining innovation in 2004, but that this technological advantage declined over

[14] Figure B1 in Appendix B presents complementary evidence on the country of origin of the inventor, i.e. the individual who carried out the inventive activity.

[15] These are the Latin American countries for which the mining patent data and the patent data for all sectors worldwide (useful to construct the RTA indicator) are available. In this context, we are able to include also Cuba for which there were missing data concerning mining equipment and mineral commodities.

time such that by 2014 it had a technological disadvantage. In terms of individual countries, we observe that 6 out of the 10 countries had an RTA in mining in the initial period. Those countries that didn't have an RTA (Colombia, Cuba, Ecuador, Guatemala) in the initial period were generally not able to develop an RTA as time went by. The remaining countries had an RTA in 2004, but either lost that advantage by 2014 (Argentina, Brazil, Mexico) or saw it diminished (Chile, Peru, Venezuela). Overall, therefore, the results suggest a weakening performance of Latin America in mining innovation.

Figure 8 – RTA in mining technologies per each Latin American country over time, in terms of origin*, 2004-2014



*"origin" is the country of residence of the applicant.

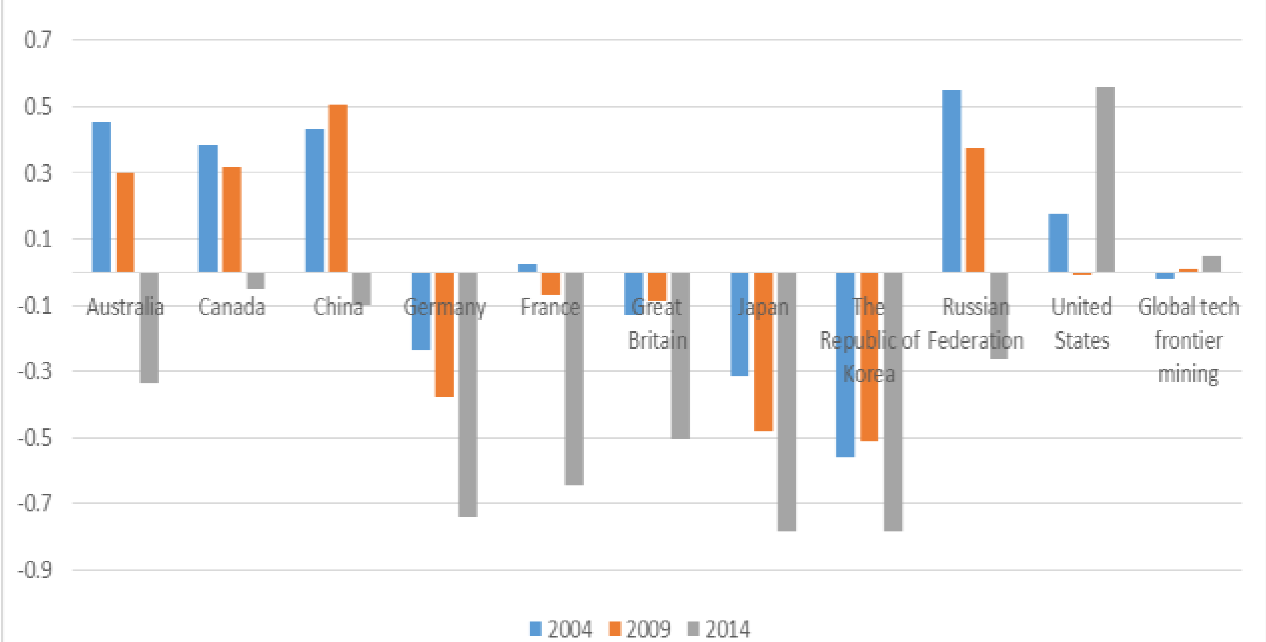
Note: consistent with the previous sections, we transform the RTA variable based on patents such that it lies between -1 and +1, with values greater than zero indicating RTA.

Source: Own elaboration based on WIPO Mining Database and WIPO IP Statistics Data Centre for data regarding patents in all sectors worldwide (https://www3.wipo.int/ipstats/index.htm?tab=patent).

For purposes of comparison, we compare results in terms of RTA for Latin America with those for applicants originating in countries that represent the global technological frontier in mining, i.e., Australia, Canada, China, Germany, France, the UK, Japan, the Republic of Korea, Russia and the US. For the sake of accuracy, the countries on the global mining technological frontier have been selected based on Figure 7, i.e. the countries that have a higher number of mining patents invented locally at the global level[16]. Results for the frontier are reported in Figure 9.

[16] It is worth emphasizing that, when considering the global technological frontier, we refer to the number of patents, but not to specialisation in terms of revealed technological advantage. This definition of global mining technological frontier will also hold in the rest of the paper.

Figure 9 – RTA in mining technologies per each country at the global technological frontier in mining in terms of origin*, 2004-2014



*"origin" is the country of residence of the applicant.

Note: consistent with the previous sections, we transform the RTA variable based on patents such that it lies between -1 and +1, with values greater than zero indicating RTA.

Source: Own elaboration on WIPO Mining Database and WIPO IP Statistics Data Center for data regarding patents in all sectors worldwide (https://www3.wipo.int/ipstats/index.htm?tab=patent).

The results in Figure 9 indicate that the countries at the global technological frontier did not have an RTA in mining technologies in 2004, but developed a specialization over time that further increased between 2009 and 2014. This (slight) increasing trend is largely due to the increase in the RTA values of the US, however. In fact, the other countries witnessed a decline in the RTA between 2009 to 2014, with no other country having a specialization in mining innovation in 2014. That this set of countries (with the exception of the US) saw declines in RTA over time, such that they had no RTA by 2014, partly reflects the fact that they tend to be diversified economies with specialization in other sectors. The results are also consistent with those reported for Latin America, with nearly all Latin American countries witnessing a declining RTA over time also.

The fact that Latin America could have an RTA in mining innovation in the earlier period, but not be specialized in the production and export of mining equipment may indicate that its specialization was in particular parts of the mining process. In the following section, we examine this further.

3.4 The quality of Latin America's mining innovation

This section examines the quality of local mining innovation in Latin America by considering two different and complementary tools, i.e. the specialization on cutting-edge (key) mining technologies (Section 3.4.1) and the quality of the mining patents invented by Latin American applicants through patent value indicators, moving beyond patent counts (Section 3.4.2). Patent value indicators are aimed at detecting whether a patent fulfils the key objectives of the patent system, i.e. to reward and incentivise innovation while enabling diffusion and further technological developments (Guellec and van Pottelsberghe de la Potterie, 2007).

3.4.1 Latin America's specialisation in key mining technologies

In this section, we consider a group of key mining technologies that are essential to solve important issues for the mining industry, examining whether Latin America has been able to develop specialization in these particular fields. This is also a proxy for investigating the quality of the Latin American mining innovation. In addition, we compare the specialization in key mining technologies of Latin America to countries on the global mining technological frontier to examine whether the specialization patterns of both group of countries are moving towards (convergence) or away (divergence) from each other[17]. They regard three specific mining technological fields: environmental, exploration and transport innovations.

The first technology field we consider is exploration technology, which is a costly, risky and delicate phase in mining activities both for local communities and for companies, especially in developing countries (Calzada Olvera and Iizuka, 2020). A mineral exploration property is defined as a tenement or group of tenements that are at the early to intermediate stages of mineral exploration (i.e. prior to pre-feasibility) and without the prospect of any reasonably certain future mine production and cash flows. The average probability of success in mineral exploration is so low, and the attendant geological uncertainty so high that it has often been difficult for investors, managers and exploration geoscientists to actively manage for financial success (Eggert, 1993; Leveille and Doggett, 2006; Kreuzer and Etheridge, 2010). This uncertainty relates to: (i) inherent natural variability of geological objects and processes, which is a property of nature and exists independent of our geological investigations (Kreuzer and Etheridge, 2010); (ii) conceptual and modern uncertainty (McCuaig, Kreuzer and Brown, 2007), which is linked to our incomplete knowledge and subjective interpretation of geological objects and processes (Welsh et al., 2005); and (iii) errors that occur when we sample, observe, measure or mathematically evaluate geological data, and the propagation of these errors.

Calzada Olvera (2021) states that, in the particular case of the mining industry, the main innovation driver for mining firms is the reduction of operational costs. Based on four surveys conducted among mining firms in Canada, Australia, South Africa and Latin America, the top six inducements for innovation are (in this order of priority): (i) reducing costs to operate; (ii) reducing risk; (iii) safety; (iv) improved asset productivity; (v) reducing costs to develop assets (new mines); and (vi) improving sustainability and reducing environmental footprint in Latin America (Deloitte, 2015). Exploration mining innovations fit well in addressing these issues. In effect, Calzada Olvera (2021) argues that exploration is considered one of the riskiest stages of the supply chain[18], considering that it involves heavy investments (mostly from drilling), the use of high-technology equipment and very highly skilled labour and services.

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[17] It is worth remembering that, with the notion of global mining technological frontier, we consider the countries which have the highest share of mining patents invented locally at the global level (see Figure 7). Therefore, when considering the frontier, we refer to number of patents, but not specialisation in terms of RTA. This holds even in the rest of the paper.

[18] The exploration phase is at the start of the mining value chain and lays the foundation for the next stages (Daly, Valacchi and Raffo, 2021).

The second technology field we consider is environmental technology. Mining activities have intense socio-economic and environmental impacts on local and regional communities. As the mines are usually located in sparsely populated regions, the large-scale operation of mining activities can create both positive and negative disruptions (Katz and Pietrobelli, 2018). The absence of appropriate regulatory measures, policies and especially institutional capabilities may cause negative impacts for the local society. Iizuka, Pietrobelli and Vargas (2019; p.7) state that this may subsequently hamper the sustainable operation of the mine. Conversely, mining activities can generate positive outcomes insofar as they are coordinated and well-integrated into the local and regional economies.

Additional demands for innovation come from the social and environmental challenges faced by mining companies. Local communities are concerned with livelihood security, environmental degradation and the perception that the wealth created is not fairly shared. Governments react by introducing more stringent environmental regulations and requiring some local involvement in decision making (Katz and Pietrobelli, 2018), which raises the demand for innovative solutions and sustainable methods of production.

Andersen and Noailly (2019) state that the extraction and processing of metals (e.g., copper, gold, aluminium, iron, nickel), solid fuel minerals (coal, uranium), industrial minerals (phosphate, gypsum) and construction materials (stone, sand and gravel) is associated with air pollution, water contamination by toxic chemicals, landscape disruption and waste generation. Innovation in clean technologies, i.e., technologies aiming to reduce the environmental impact of mining operations, can provide an effective solution to address these environmental challenges. Innovative technologies can help to reduce water and energy consumption, to limit waste production and to prevent soil, water and air pollution at mine sites. Examples of such technologies are water-saving devices, electric haul tracks, desulphurization techniques to limit $SO2$ emissions and underground mining technologies to minimize land disruption (Hilson, 2002).

Clean technologies are characterized by a "double externality" (Jaffe, Newell and Stavins, 2005): first, just like all technologies, clean technologies generate knowledge spillovers (the knowledge externality) and second, they contribute to reducing the negative externality of pollution (the environmental externality). Due to this dual market failure, firms have little incentives to invest in clean technologies in the absence of government intervention and public policies are always justified to encourage the development of those technologies.

Based on this understanding, current location-specific challenges for mining in Latin America, such as efficient water use, among others, can be considered as an opportunity for innovation with potentially wider scope for technological and productive development with positive externalities for other industries and even to the society (Fundacion Chile, 2014).

The final technology field we consider relates to transport technologies. As industrialization spreads geographically and higher quality resources are discovered remote from the main markets, the importance of transport in the logistics chain of getting raw materials to downstream users increased. This also triggered the need to innovate in the transport sector with the aim of making mining locations that are more remote, more accessible. Transport has thus become the enabler for a number of mining products to be used on a much wider scale, with the development of the iron ore deposits of Western Australia and of the Amazon region largely a result of improvements in land-based and shipping transportation, for example. Transport technologies are also useful to facilitate backward and forward linkages

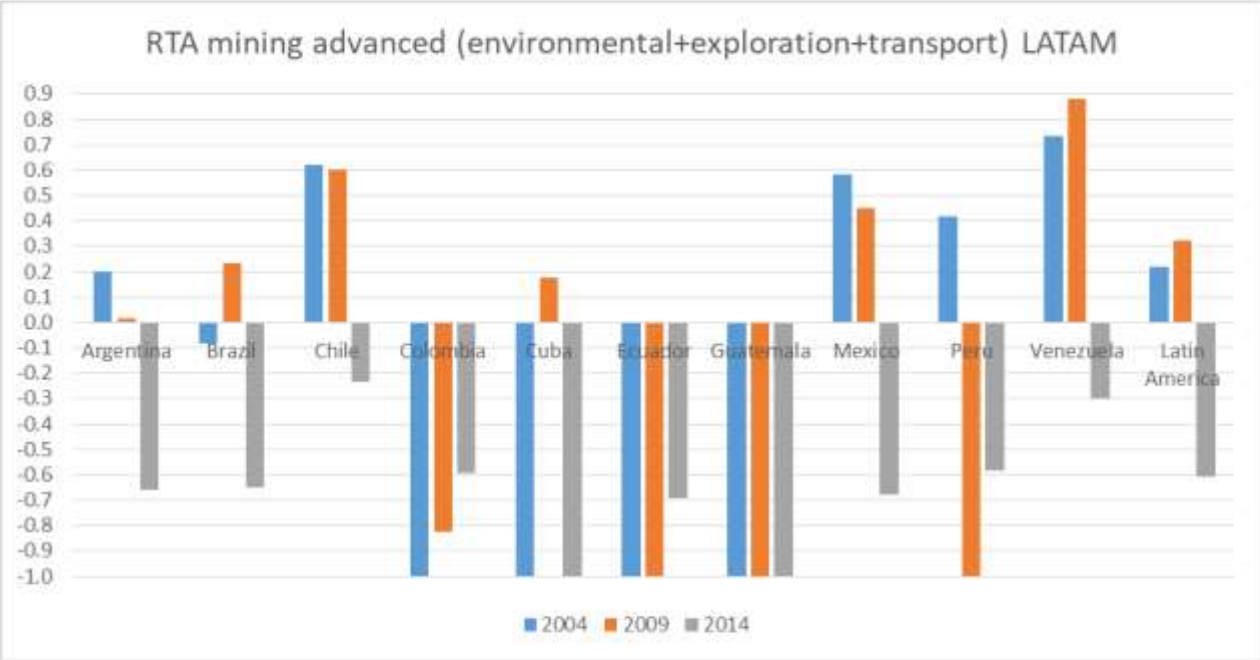
(Hirschmann, 1977) between mining companies and third parties such as suppliers to mining firms (Molina, Olivari and Pietrobelli, 2016).

Issues of transport technology are important in the context of Latin America. Mining activities are performed at high altitudes and in narrow veins in several areas of Latin America (e.g. Peru and Chile). The La Rinaconda mine, in Puno, at 5100 m above sea level, is the highest in the world (Molina, Olivari and Pietrobelli, 2016) and similar conditions prevail in Chile. Existing equipment and solutions underperform, and there is a need to adapt them or develop new ones. Similarly, in Brazil most of the activity has been moved to deeper mines, where the treatment of the mineral is more complex (Figueiredo and Piana, 2016). These conditions pose remarkable demands for innovation, especially in transport technologies also aimed at removing geographical barriers (Calzada Olvera, 2021; Pietrobelli, Marin and Olivari, 2018).

Given the importance of these three technological fields, we examine whether Latin America has been able to develop an RTA in these technologies, with the results reported in Figure 10. The figure reveals that Latin America as a whole had an RTA in key mining technologies in 2004 and 2009, but that this advantage disappeared by 2014. Such results are consistent with those for innovation in the mining sector more generally (see Figure 8). Considering individual Latin American countries, Colombia, Ecuador and Guatemala are not specialized in key mining innovations in the whole period under study. Argentina, Chile, Mexico, Peru and Venezuela had a RTA in these key technologies in the earlier periods, but as for Latin America as a whole, this advantage disappeared by 2014, such that none of the Latin American countries had a positive RTA in the latter period. In addition to what comes out in Figure 8, Figure 10 also reveals a worsening trend of the cutting-edge (key) technologies[19] in the Latin American mining industry.

Figure 10 – RTA in key mining technologies (environmental + exploration + transport patents) in terms of origin* in Latin America, 2004-2014

[19] In this context, it is worth remembering that cutting-edge technologies are capturing innovation quality, which is a different measure of quality from that of patent value indicators in Section 3.4.2.



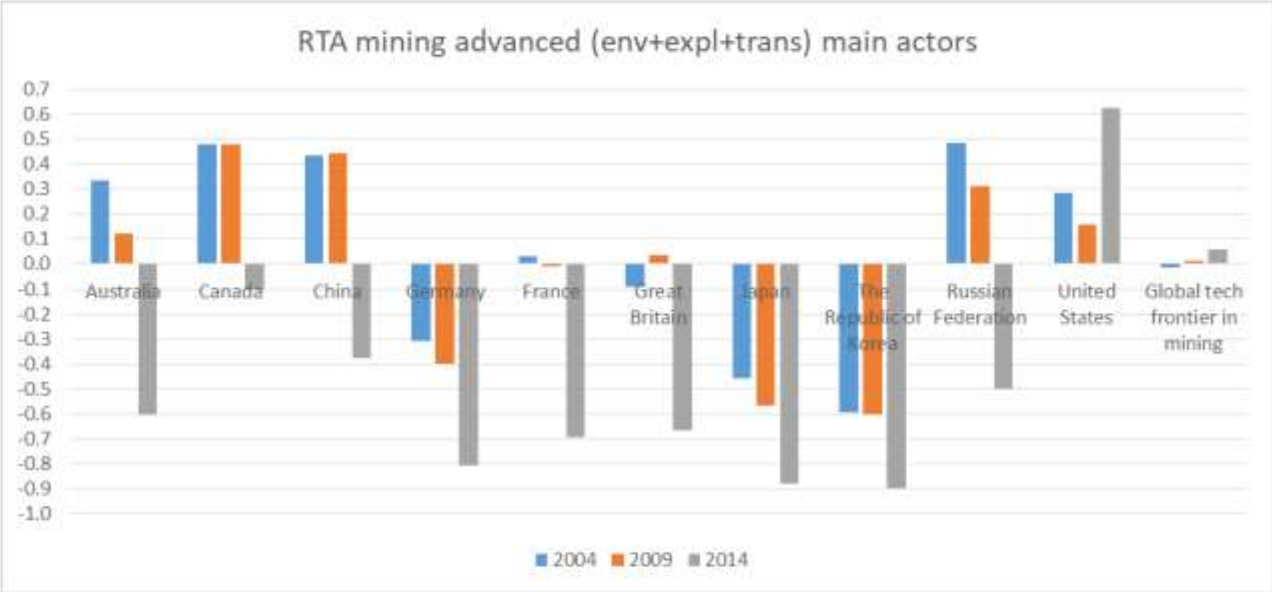
*"origin" is the country of residence of the applicant.

Note: consistent with Figures 8 and 9, we transform the RTA variable based on patents such that it lies between -1 and +1, with values greater than zero indicating RTA.

Source: Own elaboration based on WIPO Mining Database and WIPO IP Statistics Data Center for data regarding patents in all sectors worldwide (https://www3.wipo.int/ipstats/index.htm?tab=patent).

For purposes of comparison, Figure 11 displays information on RTAs in key mining technologies for countries that are generally considered to be on the global mining technological frontier. The figure indicates that this set of countries as a whole did not have an RTA in key mining technologies in 2004, although they became specialized in innovation in these technological fields by 2009, an advantage that they increased slightly between 2009 and 2014. The positive developments over time tend to be due to increases in RTA for a relatively small set of countries, with the slight rise between 2009 and 2014 being largely driven by the increase in the RTA for the US. It is also the case that many of the countries that are considered on the technological frontier do not have an RTA in key mining technologies, revealing that these countries are not involved in medium-high quality mining innovation. Comparing the results for the frontier with those from Latin America (Figure 10) suggests both a converging and a diverging specialization pattern, with convergence taking place in the earlier period (i.e. Latin America's RTA declining and that of the frontier rising) but diverging in the latter period (i.e. Latin America losing RTA in key mining technologies and the frontier increasing its specialization).

Figure 11 – RTA in key mining technologies (environmental + exploration + transport patents) in terms of origin* for countries on the global technological frontier in mining, 2004-2014



*"origin" is the country of residence of the applicant.

Note: consistent with Figure 10, we transform the RTA variable based on patents such that it lies between -1 and +1, with values greater than zero indicating RTA.

Source: Own elaboration based on WIPO Mining Database and WIPO IP Statistics Data Center for data regarding patents in all sectors worldwide (https://www3.wipo.int/ipstats/index.htm?tab=patent).

3.4.2 The quality of the Latin American mining patents

The previous section indicated that while Latin America had a technological advantage in mining technologies in the earlier period, this advantage has diminished over time. Beyond considering the specialization pattern, however, it is also important to understand whether the knowledge being developed in the context of Latin American mining is of high quality. We further address this question in this section using information on patent families and patent citations.

For economists, a high-quality patent is generally one that fulfils the key objectives of the patent system, i.e. to reward and incentivize innovation while enabling diffusion and further technological developments (see Guellec and van Pottelsberghe de la Potterie, 2007, for a discussion). Squicciarini, Dernis and Criscuolo (2013) argue that low patent quality is widely perceived to generate uncertainty, to lower incentives to innovate, to stifle technology development and to trigger a number of market failures that ultimately harm innovation, entrepreneurship, employment and growth, as well as consumers' welfare (Hall et al., 2003).

In our analysis, we calculate two patent value indicators for Latin America, further using information on countries at the global mining technological frontier for purposes of comparison. These two indicators of patent quality are an index of patent family size and an indicator based on forward citations (OECD, 2009).

The set of patents filed in several countries which are related to each other by one or several common priority filings is generally known as a patent family. (OECD, 2009; Squicciarini, Dernis and Criscuolo, 2013). In this context, the size of patent families is proxied by the number of patent offices at which a given invention has been protected. Martinez (2010) states that it is now widely recognized that patent families can be used for many purposes, such as to analyse patenting strategies of applicants and countries, monitor the globalization of inventions and study the inventive performance of technological knowledge of different countries.

Patent family data have been used to set an economic threshold, with the aim to capture only the most valuable ones. Since filing patent applications abroad is associated with higher costs for the applicant, in terms of patent office fees, patent attorneys bills and transaction costs, the intuition goes that applicants would only follow the path if the time, effort and cost associated with it, is worth it. Applicants would only seek international patent protection for their most valuable patents, as they would only be willing to do it if the expected commercial value of their invention is high enough. Thus, the higher the size of a patent family to which a patent belongs to, the higher the quality of that patent.

An alternative quality indicator relies on so-called forward patent citations. If a patent[20] is granted, a public document is created containing extensive information about the inventor, his/her employer, and the technological antecedents of the invention, all of which can be accessed in computerized form. Among this information are "references" or "citations". It is the patent examiner who determines which citations a patent must include. The citations serve the legal function of delimiting the scope of the property right conveyed by the patent. The granting of the patent is a legal statement that the idea embodied in the patent represents a novel and useful contribution over and above the previous state of knowledge, as represented by the citations. Thus, in principle, a citation of patent X by patent Y means that X represents a piece of previously existing knowledge upon which Y builds (Jaffe, 1993).

The prior art of the invention (patent) cited in patent documents provides useful information about the diffusion of technologies. Jaffe and Rassenfosse (2017) stress that the citations received by a patent from subsequent patents (forward citations) inform us about the technological descendants of the patented invention. A patent that is never cited was a technological dead end. A patent with many or technologically diverse forward citations correspond to an invention that was followed by many or technologically diverse descendants. The number of citations a patent application receives in subsequent patent applications (forward citations) has been found to be strongly associated with the economic value of patents (Harhoff, Narin, Scherer and Vopel, 1999) and the social value of inventions (Trajtenberg, 1990). The number of forward citations is one of the most frequently used value indicators and can be an important proxy for the quality of an innovation (OECD, 2009).

Table 1 reports information on the patent family size for Latin American mining patents. This is also compared to the countries that are on the global technological frontier in mining. Precisely, in the second column of Table 1, we report the maximum patent family size in Latin America and the countries on the global frontier. Furthermore, the third column of Table 1 reports the percentage of mining patents, invented in Latin America and in other countries, grouped in families with a size of less than 5 patents (i.e. a very small size)[21].

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[20] A patent is a property right in the commercial use of a device. For a patent to be granted, the invention must be nontrivial, meaning that it would not appear obvious to a skilled practitioner of the relevant technology, and it must be useful, meaning that it has potential commercial value.

[21] The higher the share of mining patents in a region or a country with family size smaller than 5, the lower the quality of those patents.

The results indicate that Latin America has one of the smallest sizes of patent families in comparison to the countries on the global technological frontier in mining[22]. The table further indicates that Latin America has a relatively large share of mining patents that are in families of less than five patents. Only the Russian Federation, the Republic of Korea and China perform worse than Latin America in terms of the indicator concerning family size, with the Russian Federation and the Republic of Korea having a smaller maximum family size than Latin America and China having very few patents in family sizes greater than 5. These results provide some initial evidence suggesting that the average quality of Latin American patents may not be that high, albeit relative to the leading countries.

Table 1 – Patent family size regarding the mining patents originating in Latin America and the countries on the global mining technological frontier, 1970-2015

Country of residence of the applicant (origin)	Max family size per each country in mining technologies, 1970-2015	Percentage of mining patents grouped in families with Size < 5
Russian Federation	20	96.7
The Republic of Korea	34	86.6
Latin America	50	53.1
Germany	80	49.9
Australia	107	37.8
China	111	98.9
France	120	32.3
Great Britain	191	35.8
Canada	200	45.9
Japan	212	80.9
United States	493	58.5

Source: Own elaboration based on WIPO Mining Database.

Turning to forward citations, Table 2 reports information on the share of total forward citations received by overall mining patents worldwide[23] (second column) and the average number of citations per mining patent (third column) for the frontier set of countries[24], for Latin America as a whole, and for the rest of the world. The results indicate that China, Japan and the US receive the highest share of forward citations worldwide in regards to their mining patents. Latin American mining patents only account for 0.36% of total forward citations worldwide between 1970 and 2015. They receive the lowest share of forward citations according to the second column of Table 2. The average number of citations of each mining

[22] In this context, we compare a region (i.e. Latin America) with individual countries on the frontier. It is important to point out that our results are not subject to any kind of geographical aggregation bias because we examine patent quality, which is independent of the quantity of patents a country or a region owns.

[23] Defined as the ratio of forward citations received by the mining patents originating from the applicant country over total forward citations received by overall mining patents at the global level from 1970 to 2015.

[24] The same set of countries that lay on the global mining technological frontier used as a benchmark in the previous sections.

patent is also one of the lowest, in comparison to both the countries on the global technological frontier in mining and the global trend more generally.

In Table 3, we focus on individual Latin America countries. Examining the second column of Table 3, the countries whose total mining patents received the highest share of forward citations within the Latin American region are Brazil (32.9%), Mexico (23.8%), Panama (14.9%), Chile (12.3%) and Venezuela (9.5%), with the Latin American countries with the highest average number of forward citations per mining patent being Bolivia, Dominican Republic, Panama and Venezuela. Nevertheless, the positive results concerning Bolivia and the Dominican Republic are biased by the fact that there is a very small number of mining patents (i.e. a handful of patents) invented locally from 1970 to 2015. Thus, comparing the third column of Tables 2 and 3, it turns out that only Panama and Venezuela have an average share of forward citations for each mining patent higher than the global average (0.25). Summarising, the results in this section suggest that the quality of innovation being undertaken in Latin America lags behind that in the frontier countries.

Table 2 – Indicator of forward citations of mining patents in terms of origin*, 1970-2015

ORIGIN	**% TOTAL FORWARD CITATIONS**	**AVERAGE NUMBER OF CITATIONS PER EACH PATENT**
Australia	0.92	0.24
Canada	2.22	0.31
China	29.88	0.31
Germany	5.34	0.28
France	2.37	0.23
Great Britain	2.34	0.28
Japan	19.29	0.37
The Republic of Korea	1.70	0.25
Russian Federation	2.11	0.06
United States	23.18	0.21
Latin America	**0.36**	**0.15**
Rest of the world	10.65	0.25
World (total)	100.00	0.25

*origin = country of origin of the applicant.

Source: Own elaboration based on WIPO Mining Database and EPO-PATSTAT dataset.

Table 3 – Indicator of forward citations of mining patents in terms of origin* in individual Latin American countries, 1970-2015

ORIGIN	% TOTAL FORWARD CITATIONS within LATAM	AVERAGE NUMBER OF CITATIONS PER EACH PATENT
Argentina	4.85	0.15
Bolivia	0.05	0.40
Brazil	32.93	0.10
Chile	12.26	0.14
Colombia	0.30	0.05
Cuba	1.17	0.09
Dominican Republic	0.05	0.33
Ecuador	0.02	0.01
Mexico	23.77	0.19
Panama	14.94	0.42
Peru	0.09	0.01
Uruguay	0.09	0.21
Venezuela	9.48	0.28
Total Latin America	100.00	

*origin = country of origin of the applicant.

Source: Own elaboration based on WIPO Mining Database and EPO-PATSTAT dataset.

4 Discussion

The results presented above indicate the Latin America has a strong specialization in the extraction and export of mining products, with inward FDI being a major activity that is both driving and being driven by this specialization pattern. At the same time, the results further show that Latin America has not been able to develop a specialization in other activities within the mining sector, notably mining equipment production and mining innovation, with the innovation taking place in the mining sector being of a low quality in comparison to frontier countries. In this section, we discuss some of the potential reasons for these results, focussing on the role of mining suppliers.

According to the Pavitt taxonomy (Pavitt, 1984), the mining sector is considered to share many characteristics of supplier-dominated innovation. This type of innovation is found in firms from predominantly traditional manufacturing industries such as textiles as well as agriculture, for example. Supplier dominated innovation firms rely on sources of innovation external to the firm, such as suppliers. Users of their products are price sensitive and the goal of innovation is cost cutting. Furthermore, the knowledge used in this type of firm has a low level of appropriability (Calzada Olvera and Iizuka, 2020).

Besides technological learning processes, knowledge-intensive suppliers have been key for turning natural resource industries into knowledge-based industries with high innovation capabilities. Knowledge-intensive suppliers, from equipment to engineering services, have also been fundamental for the competitiveness of the industry itself, and the emergence of knowledge intensive clusters (Urzua, 2013).

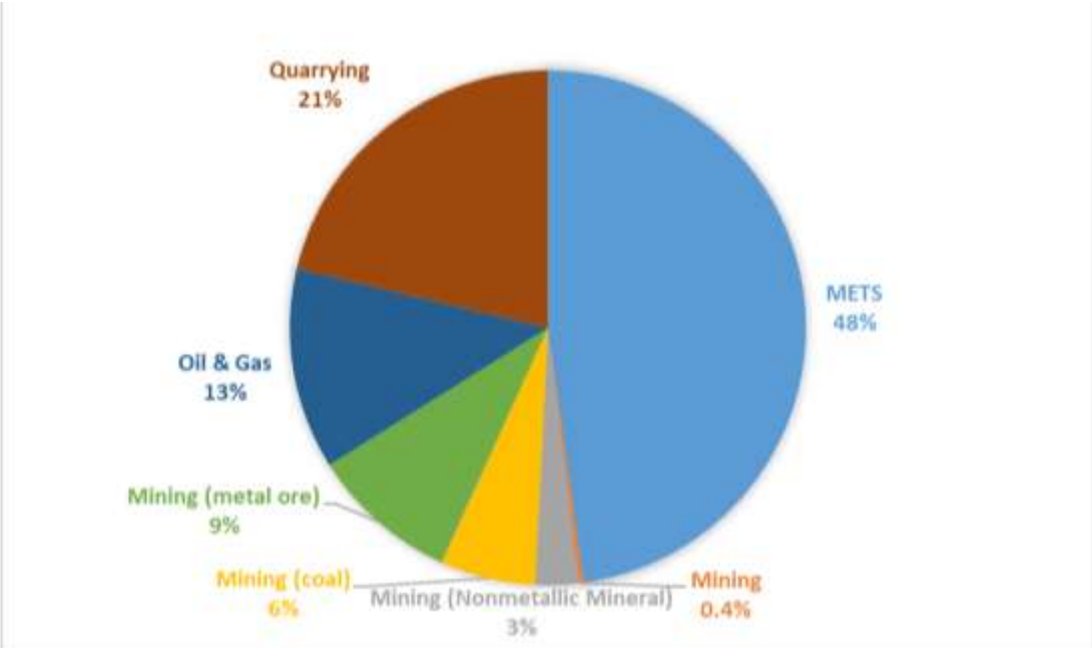
The relevance of suppliers of mining firms, i.e. METS[25] firms in mining innovation at the global level has been confirmed by several studies (Bartos, 2007; Calzada Olvera, 2021; Daly, Valacchi and Raffo, 2019; Francis, 2015; Iizuka, Pietrobelli and Vargas, 2019; Scott-Kemmis, 2013; Urzua, 2003).

The results described above suggest that this has not happened in the case of Latin America, with Latin America showing a declining comparative disadvantage in exporting (producing) mining equipment. Given such results, we examine whether and to what extent local METS carry out innovative activities in Latin America in comparison to the global trend.

In the mining sector, firms account for around three quarters of the applications that carry out patenting activities both at the global level and in Latin America (see Appendix C on this). Investigating the type of firms that undertake inventive activity in mining technologies, Figure 12 describes the particular types of firms (using information on their economic sector from the ORBIS dataset) that undertake mining-related patenting activities, both for the world as a whole and for Latin America.

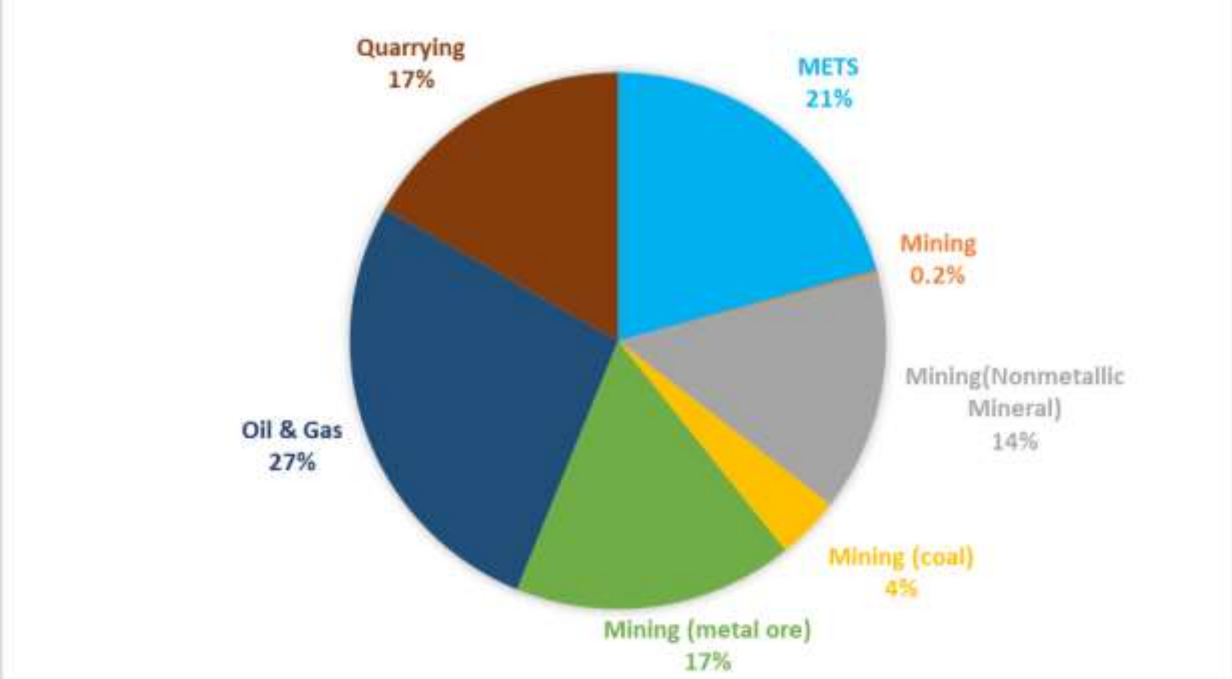
Figure 12 – Share of mining patents divided in terms of firm economic sector, 1970-2015 (average)

a) World



[25] Scott-Kemmis (2013) states that the METS include, among others: core engineering design & project management (EPCM), general support services, information technology equipment & related services, consulting services, specialized technology, core mining & processing equipment, general equipment and components and other services.

b) Latin America



Source: Own elaboration based on WIPO Mining Database and BVD ORBIS.

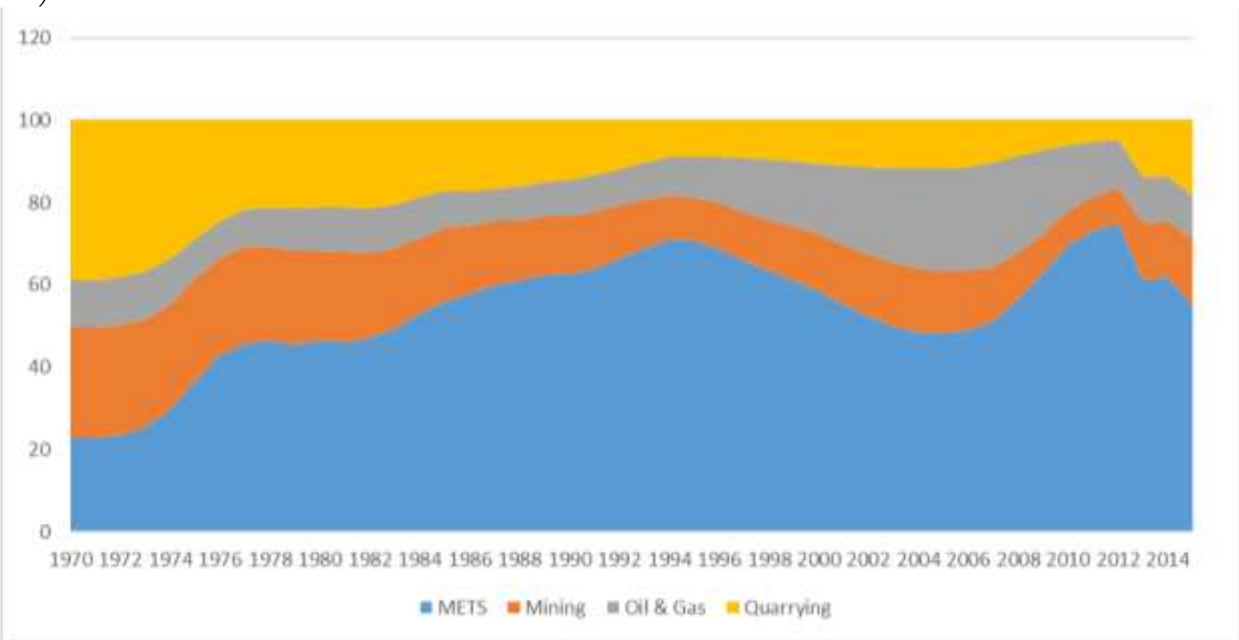
Figure 12a indicates that around half of patent applications in the mining sector globally are taken out by METS firms (48%), followed by quarrying firms (21%), mining firms (18%) and oil and gas companies (13%). This confirms the fact that innovation in the mining industry is supplier-dominated. In Latin America, there is a higher percentage of firms that innovate in mining technologies that belong to the oil & gas (27%) and the mining sector (35%), in comparison to the global average (13% and 18.4% respectively). Nevertheless, the most relevant difference between Figures 12a and 12b is that Latin America has, on average, a much lower share of mining patents applied for by METS firms (21%) in comparison to the global share. Such a difference may be a key explanation for why Latin America performs relatively poorly in mining innovation. This result on the relative lack of involvement of METS in patent applications in Latin American countries is further confirmed when comparing individual Latin American countries to countries on the global mining frontier[26] (see Appendix D).

Results depicted in Figure 12 are averages over the period 1970-2015. To examine whether the outcomes depicted in Figure 12 show variation over time, Figure 13 reports information on the share of different types of firm in mining innovation (i.e. patent applications) by year, again for both the world as a whole and for Latin America.

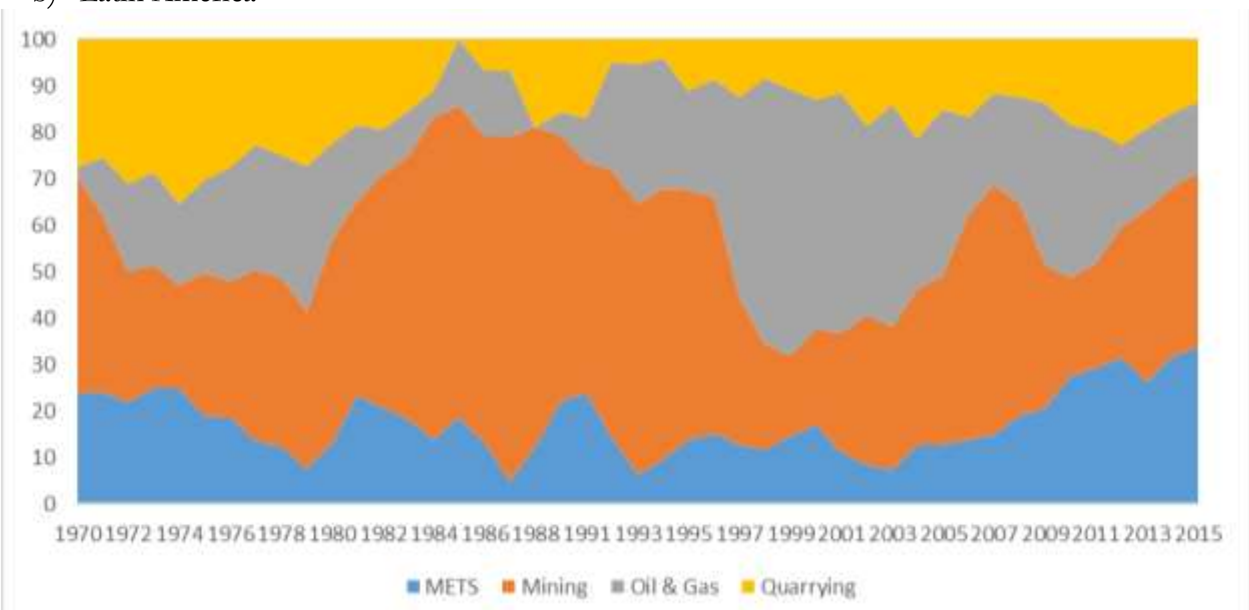
[26] One of the reasons why the countries on the global mining technological frontier are better at mining innovation than Latin American countries may relate to the fact that their innovation systems host innovative stakeholders from different industries that are likely to develop mining innovation. Hence, stronger linkages between mining companies and third parties are created (Bartos, 2007).

Figure 13 - Share of mining patents divided in terms of firm economic sector over time, 1970-2015

a) World



b) Latin America



Source: Own elaboration based on WIPO Mining Database and BVD ORBIS.

Figure 13a indicates that the share of METS in patent applications increased over time from just over 20% in 1970, accounting for more than half of all applications from the 1980s onwards. Most recently, the share of METS has decreased, though it still remains above 50%. In contrast, the results in Figure 13b show that mining firms have played a dominant role in Latin America in mining patenting activity for much of the period considered, and especially from the beginning of the 1980s to the end of the 1990s. Mining firms' patenting activity diminished, mainly in favour of oil & gas companies, between the end of the 1990s and the first half of 2000s. METS companies have played a generally minor role in patenting activity in Latin America, accounting for less than 25% of all patent applications for much of the period. Since the early 2000s however, the share of METS has increased significantly from below 10% in 2003 to above 30% in 2015. The extent to which this increase is broad-based, however, remains a concern with Calzada Olvera (2021; p. 2) arguing that while in recent years some suppliers in Latin America have made important contributions to increasing innovation in the mining industry, most suppliers have not been able to do so.

In considering the reasons for the lack of broad-based innovative activity by METS firms in Latin America, several barriers to local suppliers' innovative performance in Latin America have been identified. Calzada Olvera (2021), for example, highlights a number of barriers including a lack of testing spaces for prototypes to broader issues, conservative business attitudes, hierarchical governance of the value chain and limited communication channels between mining companies and suppliers. A further major barrier often faced by suppliers is the risk-aversion to work with local suppliers. When there are high transaction costs, complexity of information and asset specificity, mining companies prefer long-standing suppliers, which in only few instances are local. As Stubrin (2017) points out, mining firms' operators are loyal to international suppliers, they trust their technologies and they have been trained in using them[27]. Thus, such preferences reinforce the technological lock-in. Moreover, since interactions between suppliers and mining firms are more of a transactional nature rather than collaborative, with a hierarchical governance of the value chain often prevailing (Pietrobelli, Marin and Olivari, 2018), innovation risks end up being absorbed almost entirely by the supply firm (Figuereido and Piana, 2017).

5 Conclusion

In this paper, we have shown that Latin America has developed a strong specialization in the extraction and export of mining products. However, we have highlighted a remarkable heterogeneity in specialisation patterns both across countries and across sub-sectors of the mining industry. Using data on exports as well as inward FDIs, we find that Latin America has not been able to develop specialization in higher value-added activities within the mining value chain, such as the production and export of mining equipment and the production of mining technology, especially in those key technologies that are driving mining technology. Indeed, Latin America has seen a declining specialization in mining innovation in recent years. Moreover, the innovation that is taking place in Latin America is not of a high quality. The results thus suggest that Latin America relies on foreign technology and equipment for the mining sector (i.e., it is a technology user) rather than being a developer of new technology and equipment. This pattern appears to be reinforced in recent years, with an increasing specialization in mining production, but a decreasing specialization in mining equipment production and mining innovation. This reveals the presence of diverging specialization patterns over time, i.e. the specializations in mining production (of mineral commodities) and in mining innovation/technology are moving away from each other in recent years.

Production specialisation without innovation specialisation may lead to a lack of long-run development (Dosi and Tranchero, 2021). In fact, Cimoli et al. (2011) argue that a country having comparative

[27] This is in line with the findings in Section 3.2, referring to the specialization of Latin America in importing (using) mining equipment from foreign equipment manufacturers, i.e. suppliers.

advantage in exporting natural resources commodities (e.g. mining), only relying on the static rents provided by natural resources, will certainly have troubles in achieving natural resource-based development if it does not manage to use these exports as a basis for learning, linkage effects, technological learning. In other words, more important than having or not having natural resources production specialisation is to effectively use natural resources as a basis for learning, innovation and structural upgrading.

One potential explanation for the poor innovative performance of Latin America in mining is that local METS firms, which are supposed to be key innovators for the mining industry, are much less active in mining innovation than at the global level. While at the global level, 48% of global mining patents are invented by METS companies, in the case of Latin America just 21% of mining patents are invented by METS. Such a conclusion is reinforced by the fact that Latin America is not specialized in exporting mining equipment, suggesting weaknesses of local equipment suppliers. Conversely, Latin America is specialized in importing foreign technology embodied in mining equipment, relying on foreign suppliers. Relatedly, Dosi, Riccio and Virgillito (2021) found that countries stuck into supplier-dominated sectors seem to have missed major opportunities of catching-up. Support for technological upgrading will be required to allow local suppliers of goods and services to the mining industry enhance their technological capacities. Optimal policy requires that industrial and technology policy are accordingly aligned and complementary (Kaplan 2012). In fact, natural resource-based economic development is not the result of the mere extraction of mineral commodities itself but rather of the development of productive linkages (Kaplinsky, 2011), especially with medium and high knowledge intensity sectors (Calzada Olvera and Foster-McGregor, 2018).

It is often considered that the accumulation of technological capabilities is an important tool to avoid the resource curse and to involve more local mining suppliers in mining activities (Cimoli and Porcile, 2011). The fact that Latin America appears to have not been able to upgrade in the mining sector suggests a structural weakness that may place limitations on the growth of the mining sector, and on the role that the mining sector can play as a development escalator. The widening of the technology gap in the Latin American region in the last decades may well reflect a state of hysteresis, which may require a thorough redefinition of industrial and technology policies to overcome.

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Appendix A Product categories related to mining equipment

Table A1 – Surface and underground mining equipment

HS-Code	Description	Value Chain Segment
842911	Bulldozers and angledozers :-- Track laying	Final Equipment
842919	Bulldozers and angledozers :-- Other	Final Equipment
842920	Graders and levellers	Final Equipment
842930	Scrapers	Final Equipment
842940	Tamping machines and road rollers	Final Equipment
842951	Mechanical shovels, excavators and shovel loaders :- Front-end shovel loaders	Final Equipment
842952	Mechanical shovels, excavators and shovel loaders :-- Machinery with a 360(revolving superstructure	Final Equipment
842959	Mechanical shovels, excavators and shovel loaders :-- Other	Final Equipment
843010	Pile-drivers and pile-extractors	Final Equipment
843031	Coal or rock cutters and tunnelling machinery :-- Self-propelled	Final Equipment
843039	Coal or rock cutters and tunnelling machinery :- Other	Final Equipment
843041	Other boring or sinking machinery :-- Self-propelled	Final Equipment
843049	Other boring or sinking machinery :-- Other	Final Equipment
843050	Other machinery, self-propelled	Final Equipment
843061	Other machinery, not self-propelled :-- Tamping or compacting machinery	Final Equipment
843062	Other machinery, not self-propelled :- Scrapers	Final Equipment
843069	Other machinery, not self-propelled :- Other	Final Equipment
820713	Rock drilling or earth boring tools :-- With working part of cermets	Final Equipment
870130	Track-laying tractors	Final Equipment
870410	Dump trucks designed for off-highway use	Final Equipment
820712	Parts of rock drilling or earth boring tools except carbide	Intermediates
843141	Buckets, shovels, grabs etc for excavating machinery	Intermediates
843142	Bulldozer and angledozer blades	Intermediates
843143	Parts of boring or sinking machinery	Intermediates
843149	Parts of cranes, work-trucks, shovels, constr machine	Intermediates

Source: Bamber, Fernandez-Stark and Gereffi (2016; pp. 52-54).

Table A2 – Mineral processing equipment

HS-Code	Description	Value Chain Segment
845510	Tube mills	Final Equipment
845521	Other rolling mills :-- Hot or combination hot and cold	Final Equipment
845522	Other rolling mills :-- Cold	Final Equipment
847410	Sorting, screening, separating or washing machines	Final Equipment
847420	Crushing or grinding machines	Final Equipment
847439	Mixing or kneading machines :-- Other	Final Equipment
847480	Machines to agglomerate, shape, mould minerals or fuel	Final Equipment
841370	Centrifugal pumps nes	Final Equipment
841710	Furnaces and ovens for the roasting, melting or other heat-treatment of ores, pyrites or of metals	Final Equipment
847982	Other machines and mechanical appliances :-- Mixing, kneading, crushing, grinding, screening, sifting, homogenising, emulsifying or stirring machines	Final Equipment
845530	Rolls for rolling mills	Intermediates
845590	Other parts for rolling mills	Intermediates
841790	Parts for Furnaces and ovens for the roasting, melting or other heat-treatment of ores, pyrites or of metals	Intermediates
847490	Parts	Intermediates
732591*	Balls, iron or steel, cast, for grinding mills	Intermediates

Source: Bamber, Fernandez-Stark and Gereffi (2016; pp. 52-54).

Table A3 – Materials handling equipment

HS-Code	Description	Value Chain Segment
842831	Mine conveyors/elevators, continuous action Other continuous-action elevators and conveyors, for goods or materials :-- Specially designed for underground use	Final Equipment
842850	Mine wagon pushers, locomotive or wagon traversers, wagon tippers and similar railway wagon handling equipment	Final Equipment
842890	Other lifting handling or loading machinery	Final Equipment
843131	Parts of lifts, skip hoist or escalators	Intermediates
843139	Parts of lifting/handling machinery nes	Intermediates
843110	Parts of hoists and winches	Intermediates

Source: Bamber, Fernandez-Stark and Gereffi (2016; pp. 52-54).

Table A4 – Wear parts

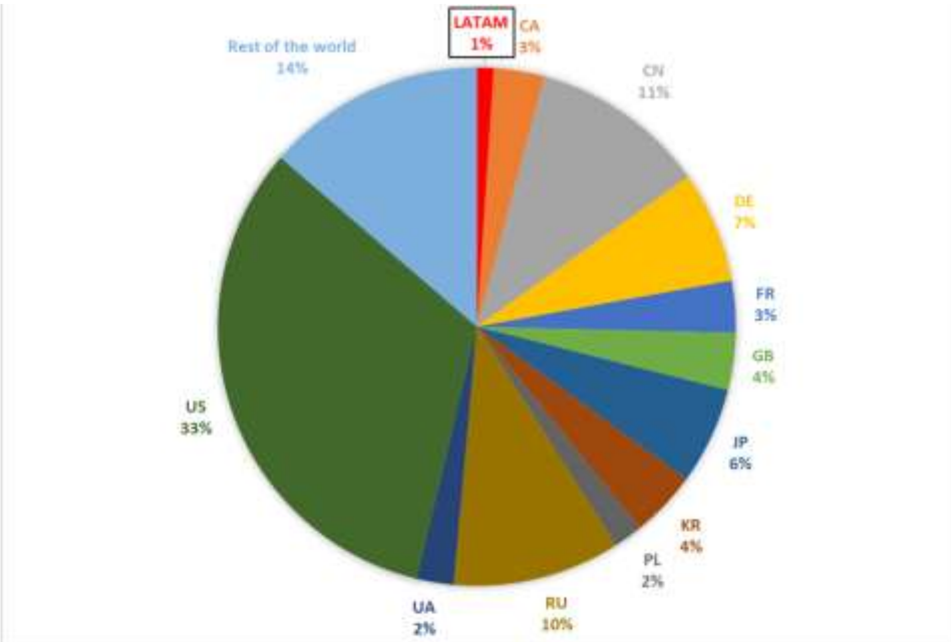
HS-Code	Description	Value Chain Segment
732591	Balls, iron or steel, cast, for grinding mills	Intermediates
841790	Parts for Furnaces and ovens for the roasting, melting or other heat-treatment of ores, pyrites or of metals	Intermediates
843141	Buckets, shovels, grabs etc for excavating machinery	Intermediates
843142	Bulldozer and angledozer blades	Intermediates
843143	Parts of boring or sinking machinery	Intermediates
843149	Parts of cranes, work-trucks, shovels, constr machine	Intermediates
845530	Rolls for rolling mills	Intermediates
845590	Other parts for rolling mills	Intermediates
843139	Parts of lifting/handling machinery nes	Intermediates

Note: Wear parts are included with original equipment at delivery and thus are considered intermediates for each type of mining equipment. However, these are pieces that must be replaced regularly during use and thus represent an interesting market as this has constant turn over, thus we examine these as a separate group as well.

Source: Bamber, Fernandez-Stark and Gereffi (2016; pp. 52-54).

Appendix B Share of mining patents in terms of inventors' country of residence

Figure B1 – Share of mining patents in terms of inventor's country of residence worldwide, 1970-2015



Note:

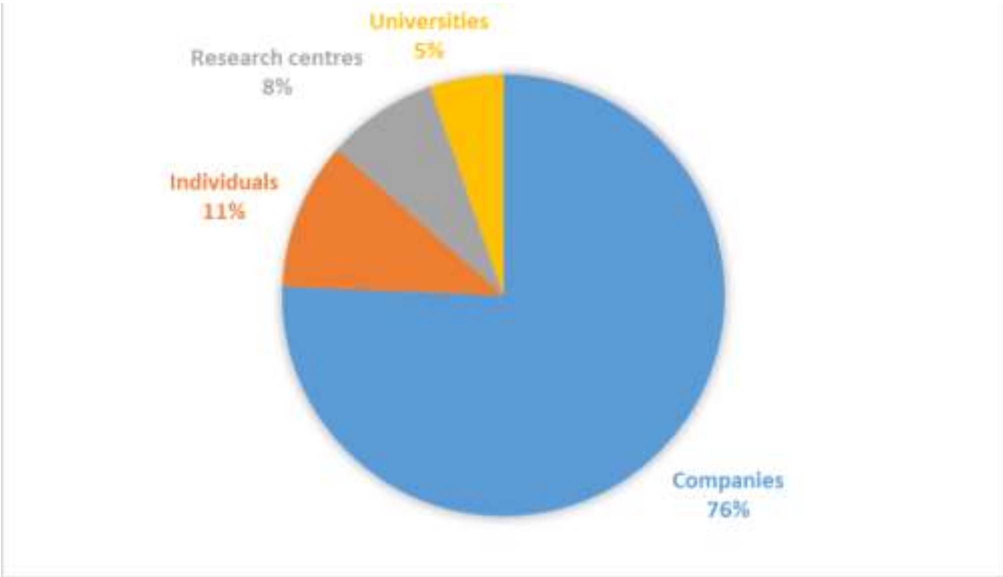
- LATAM does not include Haiti, Paraguay, Guadeloupe, Martinique (MQ), Saint Martin and Saint Barthèlemy because they have no mining patents in terms of applicant country.
- "Rest of the world" represents all the other countries, that are not labelled in the chart, with less than 1 percent each.
- We use counts of patent applications to make these statistics.

Source: own elaboration based on WIPO Mining Database.

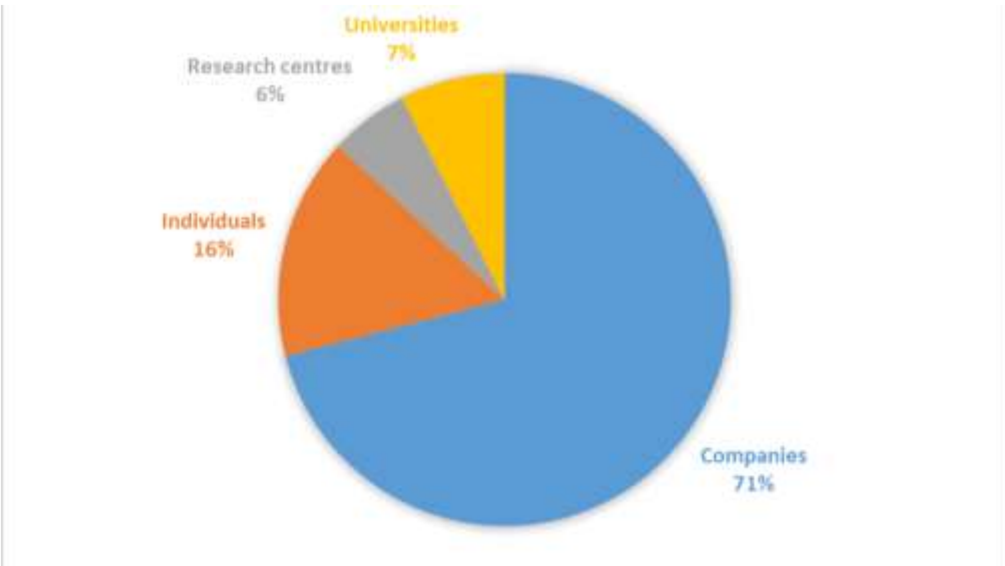
Appendix C Share of mining patents per type of applicant

Figure C1 – Share of mining patents per type of applicant, 1970-2015

1) World



2) Latin America

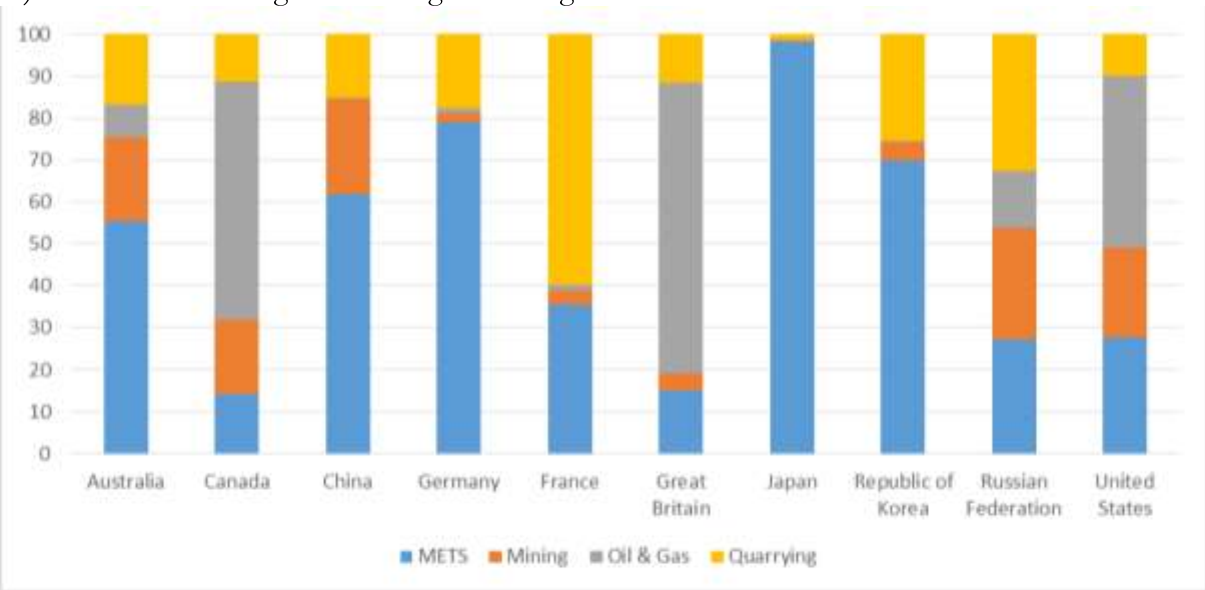


Source: Own elaboration based on WIPO Mining Database and BVD Orbis.

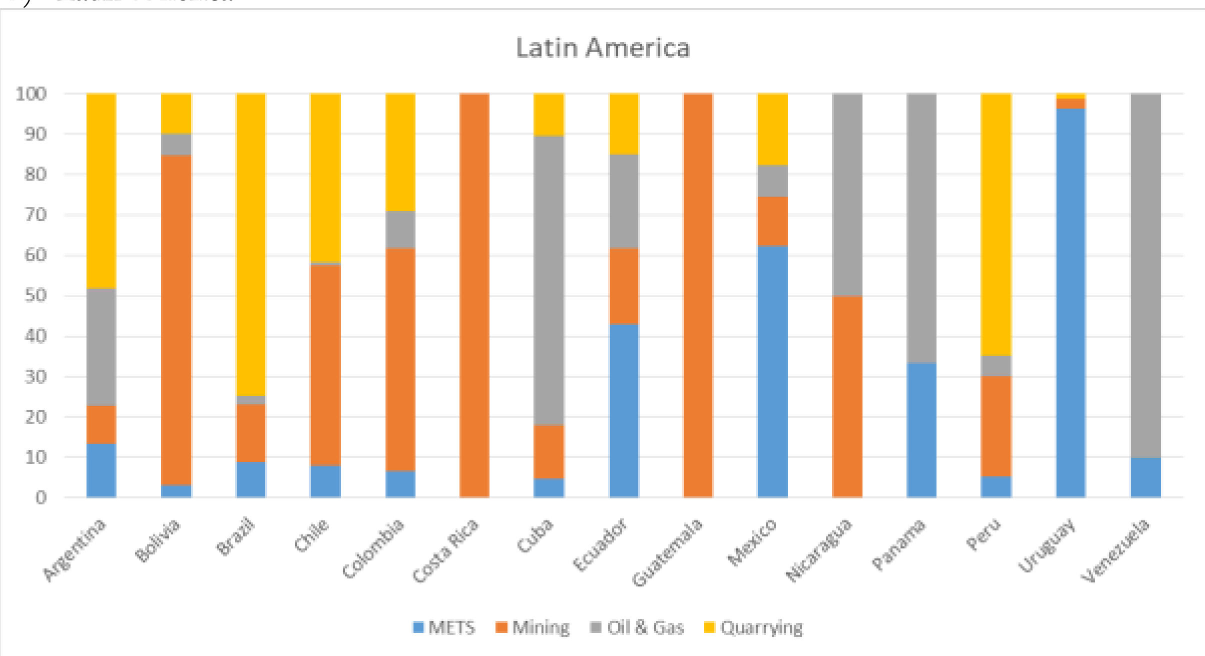
Appendix D Share of mining patents distributed in terms of applicant firm (economic sector) per each country

Figure D1 - Share of mining patents (origin*) distributed in terms of applicant firm (economic sector) per each country, 1970-2015

1) Countries on the global mining technological frontier



2) Latin America



*origin = country of origin of the applicant firm.

Source: Own elaboration based on WIPO Mining Database and BVD ORBIS.