Innovation and Competitiveness in Mining Value Chains in Latin America

Institutions for Development Sector

Competitiveness, Technology, and Innovation Division

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DISCUSSION PAPER Nº IDB-DP-902

December 2021

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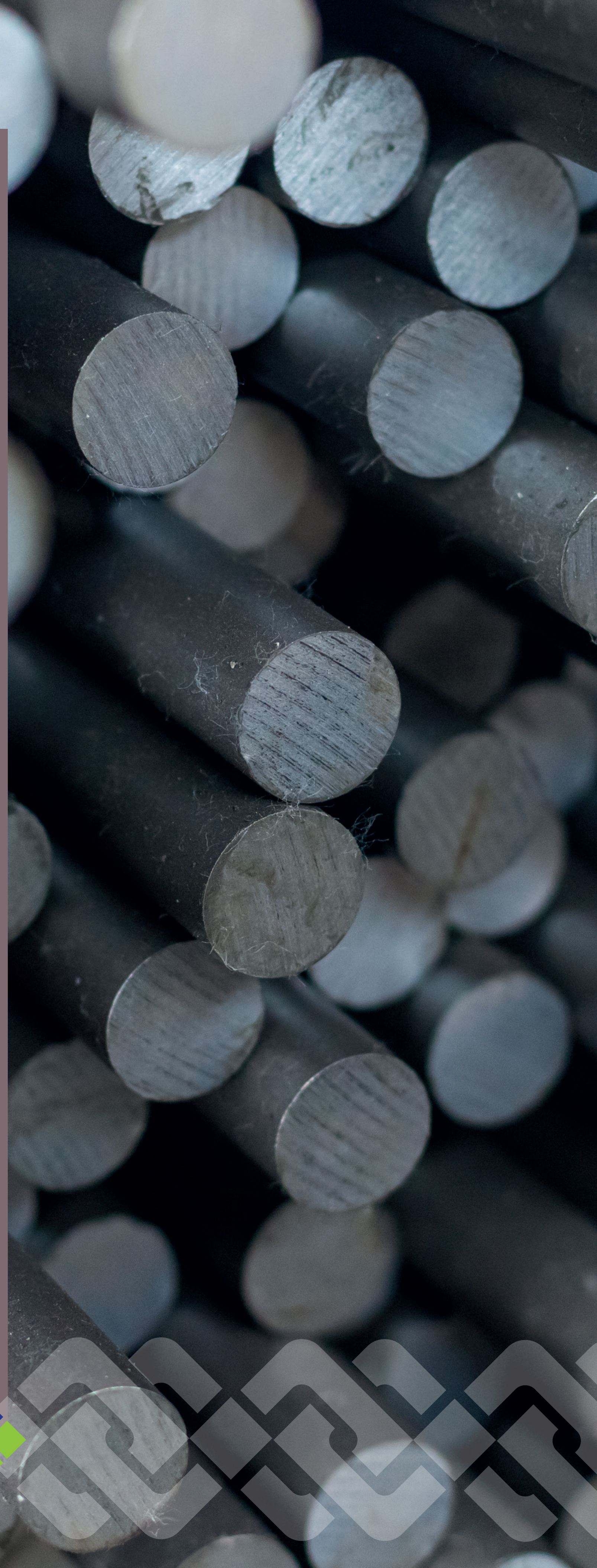

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ABSTRACT

This paper provides an international overview of the mining global value chain (GVC) and its most recent transformations and trends, focusing on Argentina, Brazil, and Peru. The study uses international trade data and patent and scientific publications data. By using trade in value added, we first investigate the role of those countries in the international mining trade, and their specialization, participation, and position in the mining GVC for the period 2005–15. The analysis is carried out for both mining products and mining-related services, and also looks at the contribution of services to mining exports. Second, we analyze the evolution of innovative activity and the direction of technological change in the mining sector over the past 40 years by looking at patent applications, both internationally and with attention to the three target countries. We also provide an overview of, and some insights on, knowledge flow in the mining sector based on scientific production.

JEL Codes: F10, Q37, O13, O31, O54, L72
Keywords: mining, global value chains, trade, input-output methodology, patents, innovation, scientific publications data.

INTRODUCTION

The objective of this paper is to provide an international overview of the mining global value chain (GVC) and its most recent transformations and trends, focusing on Argentina, Brazil, and Peru, by using both international trade data and patent and scientific publications data.

Part I analyzes the trade dimension of the mining GVC. First, we present a macro comparative view of patterns of trade in mining products and their recent growth. Specifically, we look at trade value, trends, and the composition of exports of mining products for the world's largest exporters. Those top exporters are considered potential competitors but also benchmarks for Latin American countries. This comparative view is obtained using standard trade flows. Second, we compare Argentina, Brazil, and Peru with reference countries, providing a detailed, comprehensive picture of the role of these countries in the international mining trade and their specialization, participation, and position in the mining GVC during 2005–15. This analysis includes both mining products and mining-related services and looks at the contribution of services to mining exports. The analysis is constructed mainly using value added trade data to examine the mining sector from a value chain perspective, providing a fresh, detailed view of direct and indirect, domestic and foreign links in the sector.

Part II investigates the innovation dimension of the mining value chain. Specifically, it analyzes the evolution of innovative activity in the mining sector over the past 40 years, focusing on Argentina, Brazil, and Peru and other reference Latin American countries. This analysis is based on both patent data and scientific publications. To gather information about the direction of technological change, patent applications related to the mining sector were identified using the World Intellectual Property Office (WIPO) database integrated with the EPO PATSTAT database. An overview of, and some insights on, the knowledge flows in the mining sector based on scientific production is also provided by using data on publications and related information extracted from the Web of Science Core Collection platform.

The analysis of trade and innovation provides a rich macro-picture of the effective depth and complexity of the mining value chains of some leading Latin American economies.

PART I: INTERNATIONAL TRADE DATA

International Trade in Mining

International trade in raw materials and intermediate inputs has been a prominent feature of world trade flows since ancient times (World Bank, 2020). However, increasing trade integration in the past three decades has brought an unprecedented disintegration of the production process (the so-called great unbundling; Baldwin 2013), fostering growth in intermediate trade. The production of a finished product now involves the participation of many economies, with countries specializing in different fragments of the vertical production chain.

The notion of global value chains is now often associated with either international trade in raw materials, intermediate inputs, or tasks. This phenomenon has been studied quite extensively by trade economists (Arndt, 1997; Balassa, 1967; Deardorff, 1998; Dixit and Grossman, 1982; Feenstra, 1998; Feenstra and Hanson, 1996, 1997; Findlay, 1978; Jones and Kierzkowski, 1997; Krugman, 1995; among others). The common wisdom is that, thanks to production fragmentation, even small countries with limited capacities or resources now have a chance to participate in GVCs and benefit from global trade. Thanks to GVCs, firms in developing countries can enter foreign markets at lower costs, benefit from specialization in niche tasks, and gain access to larger markets. They can also access cheaper and better inputs, productivity-enhancing technologies, and improved management practices with positive effects in terms of growth, competitiveness, trade, and development (Cattaneo, Gereffi, Miroudot, et al., 2013; Minten, Randrianarison, and Swinnen, 2009; Montalbano, Nenci, and Pietrobelli, 2018; Montalbano and Nenci, 2020; Swinnen, 2016; Swinnen and Vandeplas, 2014; World Bank, 2020). Because of these implications, GVCs are becoming attractive to policymakers in developing countries.

The mining sector is by its very nature connected to GVCs because mining products are primary inputs for resource-intensive industries. Thus, the sector is characterized by a high share of GVC integration and by a growing share of world trade following the large price surge over the past three decades. In 2018, the value of mining product exports increased for all major exporters. Fuels and mining products recorded the highest growth, at 23 percent. However, worldwide exports of fuels and mining products are only 91 percent of their 2008 value, owing to a combination of weaker demand and increased supply leading to a decline in fuel prices (World Trade Organization, 2019).

Patterns of Trade in Mining Products: Key Features

Trade in mining products has some notable features. First, the endowment of mineral resources is a necessary but not sufficient condition for a country to have a comparative advantage in mining products. Literature in the field underlines that complementary inputs—such as a modicum of capital and skilled labor, a supportive legislative framework, access to social license to extract, and an adequate transportation infrastructure—are needed to allow a country to export mining products (Tilton, 1983, 1992).

Second, trade patterns in mining products are not static. Changes in specialization are possible due to changes in resources, terms of trade, or policy (David and Wright, 1997; Wright and Czelusta, 2004).

Third, location-specific geological and technical knowledge can be important in gaining comparative advantages in mining. The case of Latin America confirms this. The rise of Latin America as a mining product exporter occurred only when the endowments—which were always there—became available for exploitation. This change was a result of a policy change that focused more clearly on developing the mining sector (Wright and Czelusta, 2007).

Finally, mining product exporters naturally move up the development ladder as capital and skilled labor accumulate over time (Davis and Vásquez Cordano, 2013). Governments tend to implement protectionist trade policies to speed up this progression. This tendency is a result of several concerns about the resource curse (the paradox of plenty) and about the risk that exporting mining products exposes an economy to declining terms of trade and export revenue volatility.

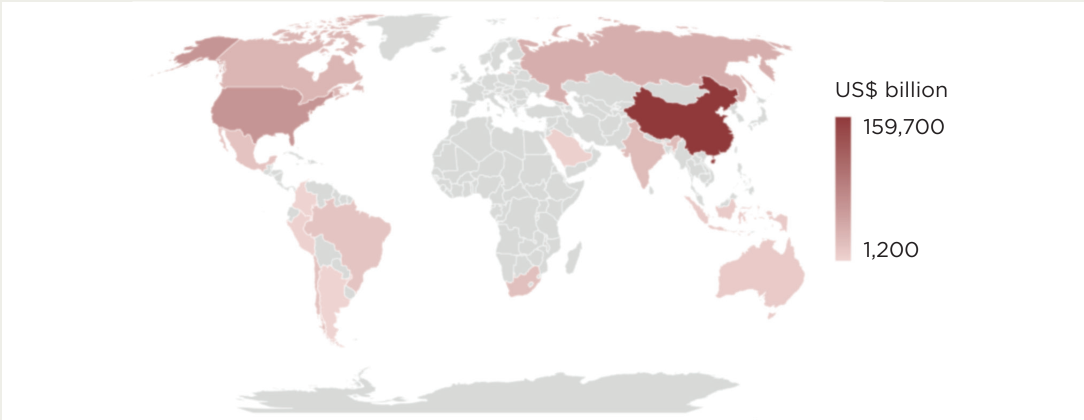
It has long been held that developing countries tend to export mining products and import manufactured goods. The evidence for this is mixed. Figure 1 shows that the current top mining product exporters are the United States, Canada, and Australia (Comtrade data, 2019).[1] In contrast, this primacy is shared with several developing countries—namely China, the Russian Federation, India, South Africa, Saudi Arabia, Indonesia, and some Latin American countries (Figure 1).

During the 2010s, the United States, the Russian Federation, Canada, and particularly China significantly increased their importance as global mining exporters. This general trend partially reversed after the 2009 financial crisis, with the relevant exception of China, whose exports gained momentum after 2010 (Figure 2).

Because of Asia's massive appetite for mining products, a large number of exports were sent to Asia in the 2010s, specifically to China, Japan, South Korea, and India. In 2017, China imported almost the same value of mining products as the United States and Germany combined (Comtrade; Figure 3).

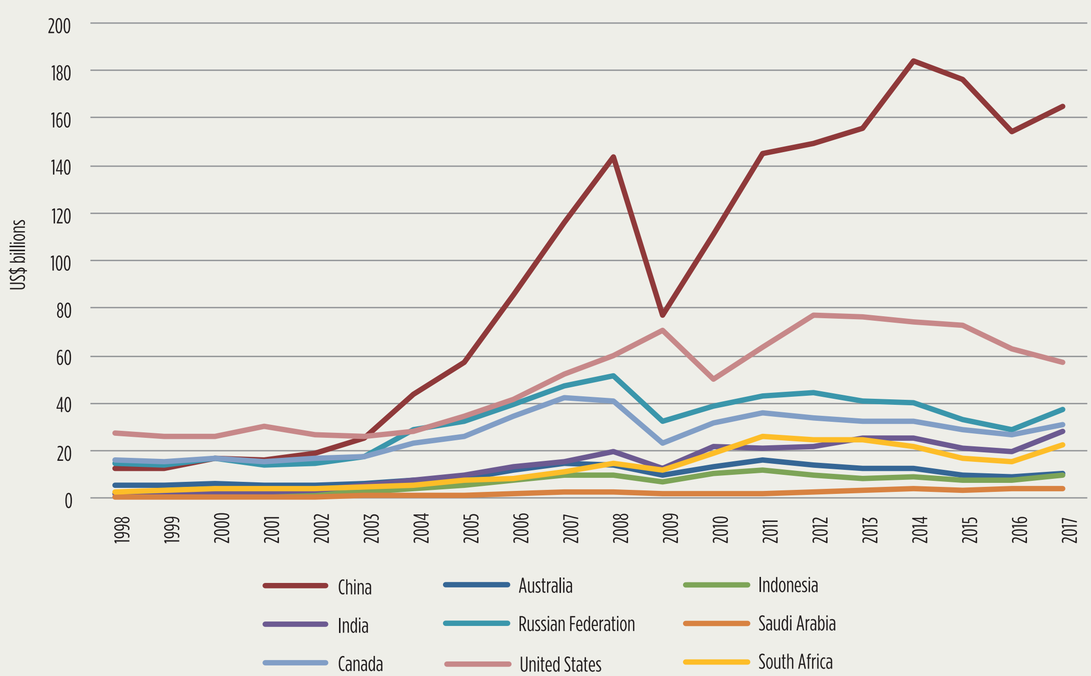
1 https://comtrade.un.org/

Figure 1. The World's Largest Exporters of Mining Products, 2016–18



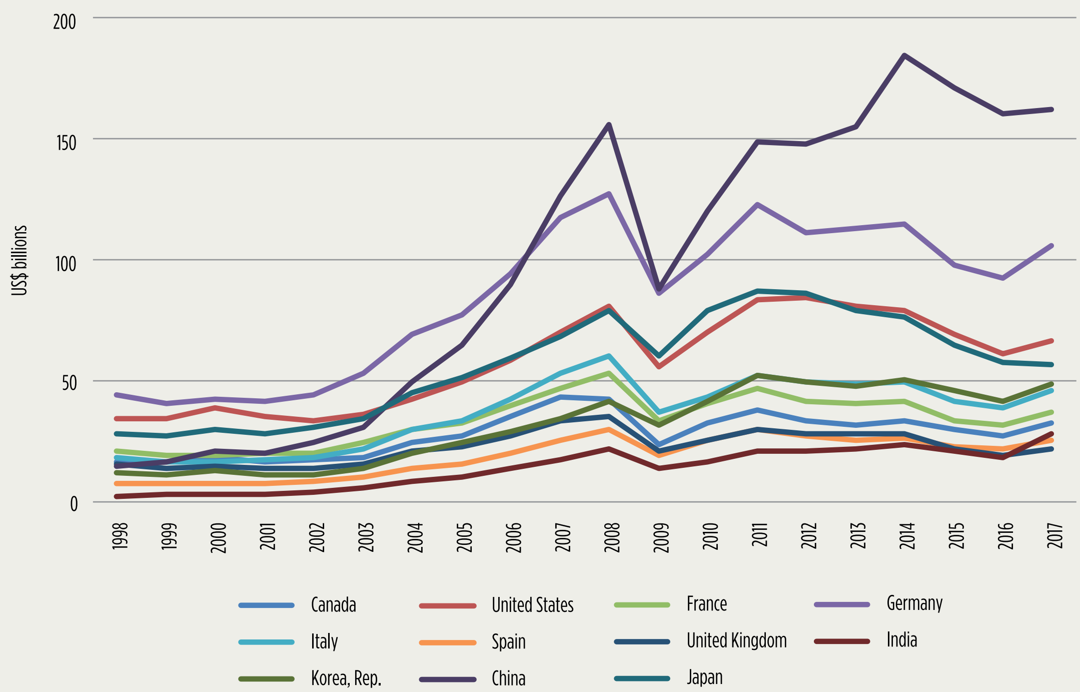
Source: Authors' elaboration based on Comtrade data.
Notes: Mining products are defined as base metals and articles of base metal (Internation Trade Administration Harmonized System Codes [HS], section XV). Comtrade data reports trade value in current U.S. dollars, free on board (FOB) for exports and cost, insurance, and freight (CIF) for imports.

Figure 2. Export Trend for Mining Products, 1998–2017



Source: Authors' elaboration based on Comtrade data.
Note: Mining products are defined as base metals and articles of base metal (HS, section XV).

Figure 3. The World's Largest Importers of Mining Products, 1998–2017



Source: Authors' elaboration based on Comtrade data.
Note: Mining products are defined as base metals and articles of base metal (HS, section XV).

At the same time, China was the world leader in exporting some mining products (data for 2017):

- iron and steel (US$43 billion) and articles made from iron or steel (US$57 billion);
- aluminum and aluminum articles (US$23 billion);
- miscellaneous articles made from base metals (US$17 billion), and tools, implements, and cutlery or parts made from base metals (US$15 billion).

All these export flows registered dramatic growth in the 2010s (Figure 4). In general, all emerging exporting countries, except the Russian Federation, showed increasing trade specialization in mining products compared with the end of the 1990s. Conversely, industrialized countries showed higher product diversification, strengthening their role as global competitors (Figure 4).

Figure 4. Mining Product Exports: Disaggregation for the World's Largest Exporters, 1998 and 2017

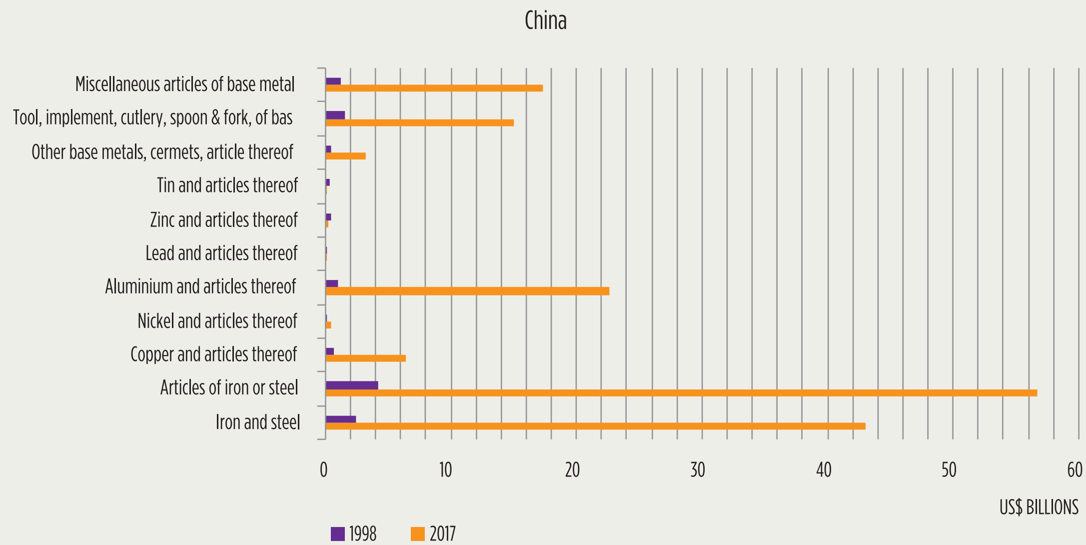
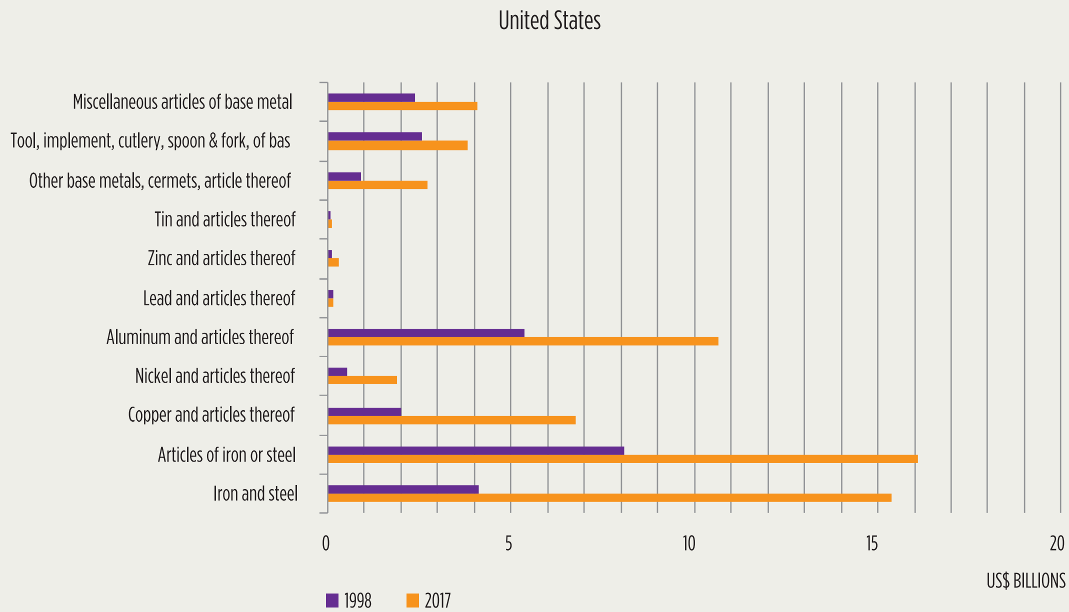


Figure 4. Mining Product Exports: Disaggregation for the World's Largest Exporters, 1998 and 2017 *(continued)*



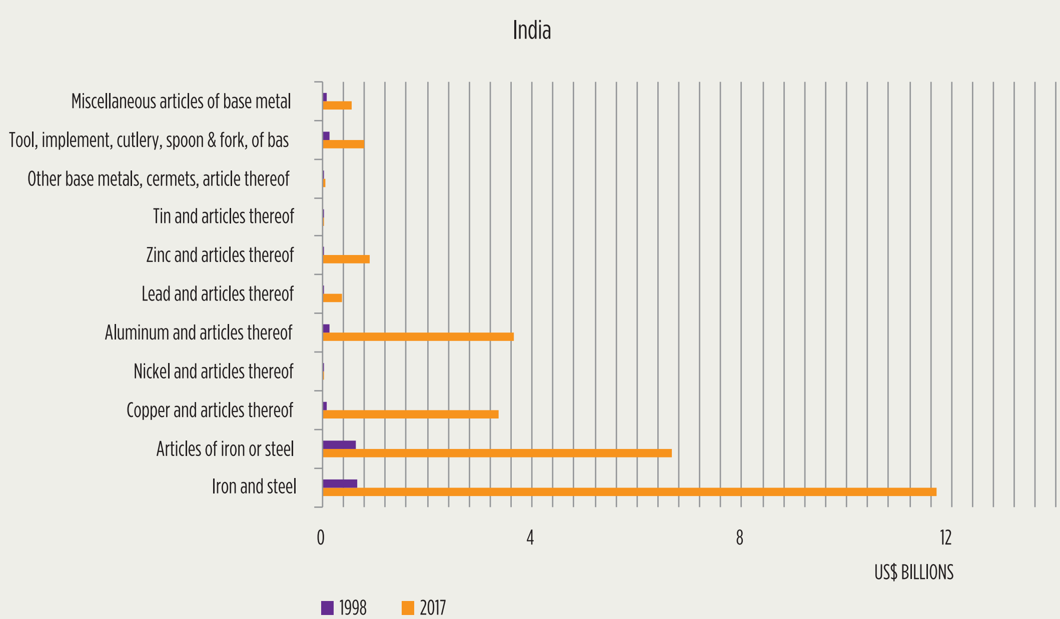
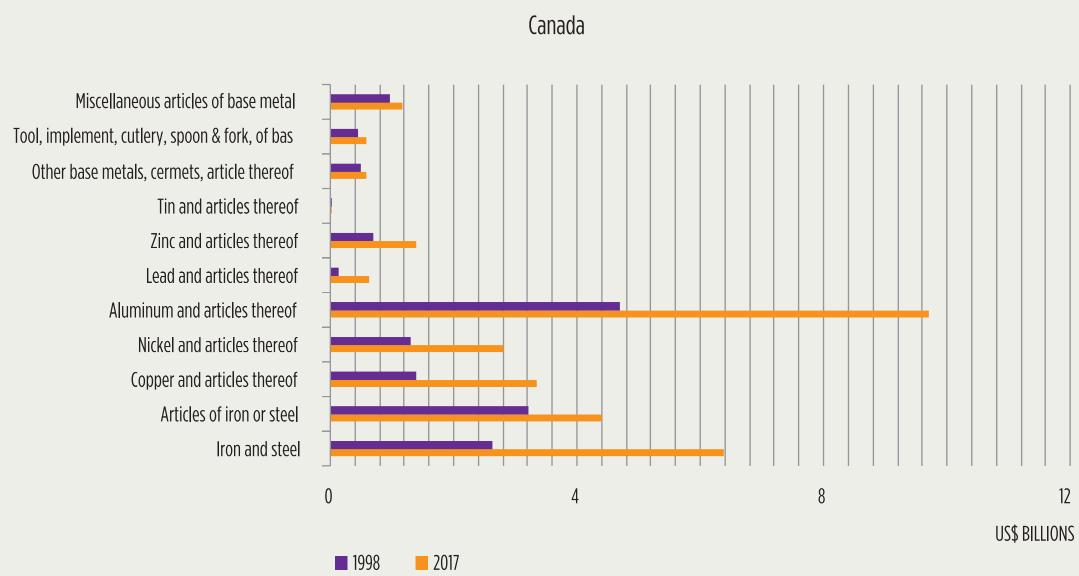


Figure 4. Mining Product Exports: Disaggregation for the World's Largest Exporters, 1998 and 2017 *(continued)*



Source: Authors' elaboration based on Comtrade data.
Note: Mining products are defined as base metals and articles of base metal (HS, section XV).

Trade in Mining Products for Argentina, Brazil, and Peru

Many Latin American countries have significant resources in raw materials, especially in mining. This sector represents significant economic activity for Peru, Chile, and Brazil (Pietrobelli, Marin, and Olivari, 2018). Although mainly known for oil, Argentina is also becoming an important mining country, even with only a small part of its geological potential developed. Mining does not currently account for a substantial share of employment (since it does not create many direct jobs), but the mining sector uses inputs from other sectors that may be more labor-intensive and require different skill levels. Thanks to these linkages, mining may be an important indirect source of employment in related sectors, which may represent an opportunity for some mineral-rich countries, such as those in Latin American (Korinek, 2020).

Several Latin American countries—mainly South American economies—are important exporters of mining products globally. Exports are heavily concentrated in iron and steel and items made from iron or steel, copper and copper articles, and aluminum and aluminum products. The concentration has changed slightly in the past decade, with a significant reduction in the weight of aluminum products.

Focusing on the three target economies, it is worth noting a large increase in export value registered by Brazil in the past two decades (although it has suffered a setback since 2011). Brazil is also the only economy of the three to clearly diversify mining product exports (Figure 5). A positive trend is seen for articles made of iron or steel, copper and copper articles, aluminum and aluminum products, and miscellaneous articles made from base metals. Iron and steel is the prominent sector of Brazilian mining exports (valued at about US$11 million in 2017).

Conversely, Peru shows a clear concentration in copper exports, and an emerging positive trend in zinc and articles made from zinc and tin and articles made from tin. As noted, Argentina is still quite new in terms of mining exports. The most relevant products are aluminum and articles made of aluminum and iron and steel products (Figure 5).

Figure 5. Mining Product Exports: Disaggregation for the Main Latin American Exporters, 1998 and 2017

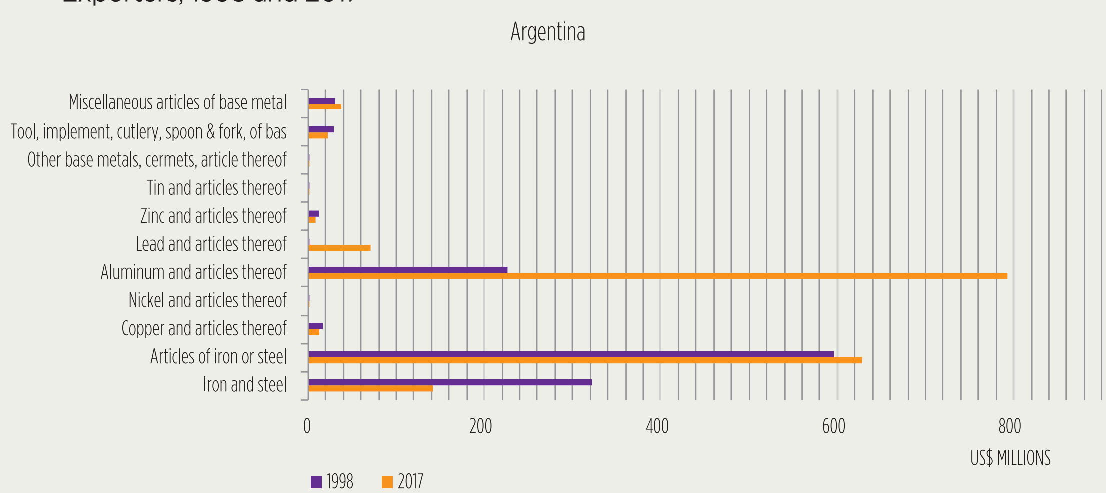
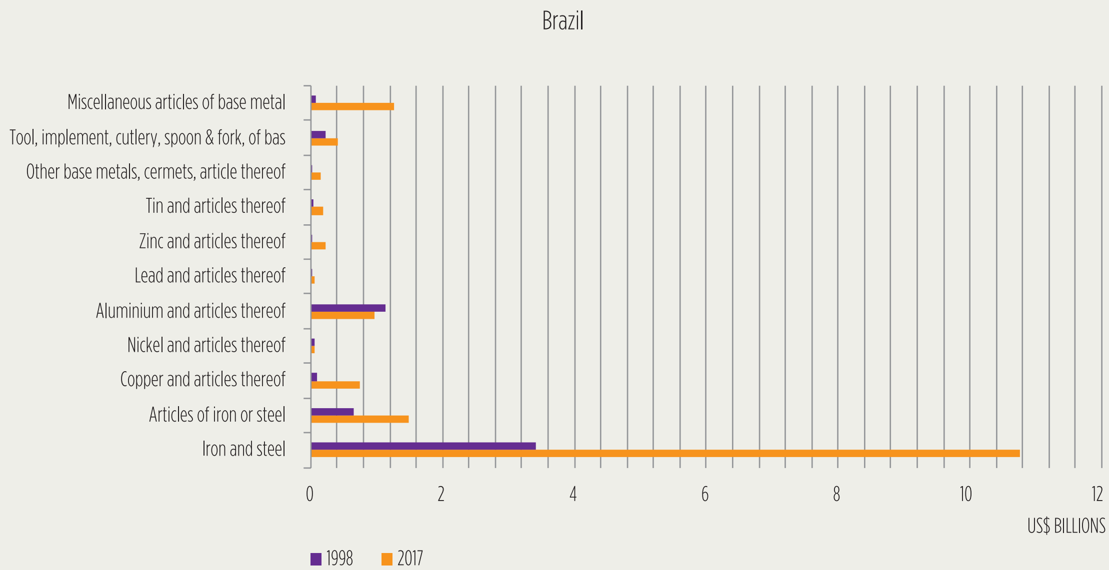
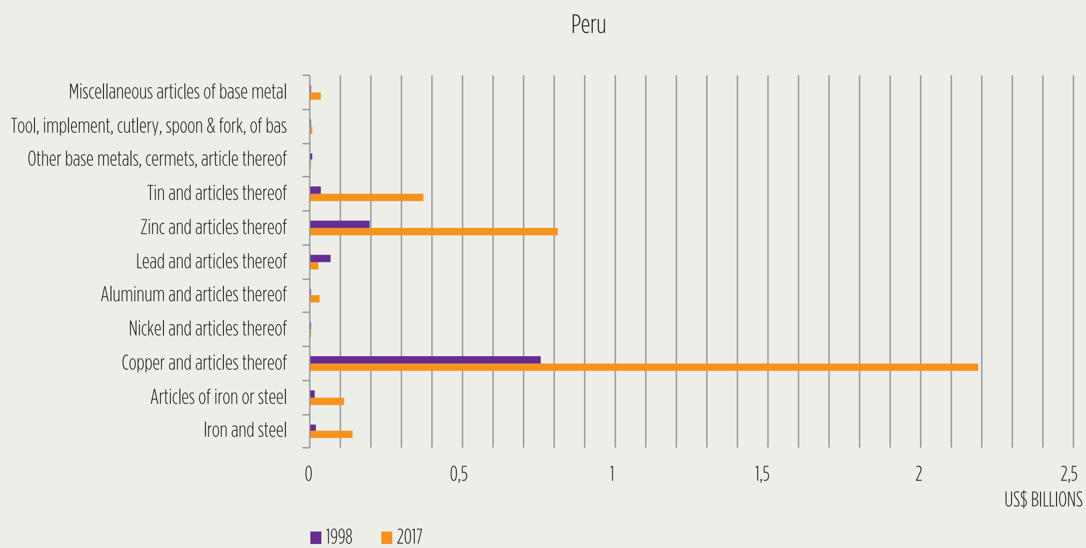


Figure 5. Mining Product Exports: Disaggregation for the Main Latin American Exporters, 1998 and 2017 *(continued)*





Source: Authors' elaboration based on Comtrade data.
Note: Mining products are defined as base metals and articles of base metal (HS, section XV).

In terms of weighted value (i.e., the value of exports as a share of the country's gross domestic product [GDP]), although the value of Argentina's mining product exports started to grow at the end of the 1990s, on average, weighted exports showed a decreasing trend over the 2002–15 period, especially for iron and steel products, aluminum and aluminum products, and iron and steel. The total value of these categories was US$3 billion in 2017 (Comtrade).

The weighted value of mining exports is particularly important for the Brazilian economy, with the average export value excluding the three main products being US$1 billion. However, Brazilian exports also showed a general decline as a percentage of GDP in the 2010s. Starting from 2006, a negative trend also affected Peru's exports of copper and copper products.

Trade and Global Value Chains

An important question raised in the GVC empirical literature is to what extent individual countries and sectors are involved in international production networks. This is a key issue since the involvement in GVCs appears to be linked to economic growth. The use of higher-quality, more sophisticated imports of intermediate inputs and technologies through GVCs increases the quality of final products and the efficiency of firms' processes and access to know-how, which can potentially spill over to the rest of the economy. GVCs can also provide opportunities to move into higher-value activities. Beyond the productivity increases from specialization in tasks and economies of scale, GVCs provide opportunities to increase the value added over time through upgrading processes characterized by organizational changes or improved production techniques. The latter may be driven by the use of foreign intermediate inputs that come from GVC participation or through GVC-related creation of economies of scale or scope.

It is commonly considered that once countries have successfully entered GVCs, they should move into activities with higher value-added products on a unit value basis: metals rather than unprocessed minerals and ores, food production rather than agriculture, etc. Among raw materials producers, there has been a push to move production downstream to sectors with higher unit values to capture a greater share of the value added in-country. However, some research suggests that it is not only the share of value added that matters, but also the volume of trade (Kowalski, Lopez Gonzalez, Ragoussis, et al., 2015). Moreover, it may not always be the case that downstream activities generate greater domestic value added.

Measuring global value chains through trade in value added

In the past, simple indicators (e.g., market share, the geographical composition of imports and exports, bilateral trade balances, and sectoral indices of specialization) could provide a satisfactory picture of a country's role in international markets and the evolution of that role over time. With the increasing complexity and sophistication of cross-border production-sharing activities, the use of only official trade data has not revealed the significance and nature of changes in the global business cycle, and these indicators have become inadequate. When production is organized in sequential processing stages in different countries, intermediate goods and services cross borders several times along the chain, often passing through many countries more than once. This process leads to a significant amount of "double counting" in global trade. Consequently, the country where the final producer is located appears to capture most of the value of goods and services traded, whereas the role of countries providing inputs upstream is overlooked.

The relevance of this issue is confirmed by the many initiatives and efforts that try to address the measurement of trade flows in the context of GVCs and to estimate the so-called trade in value added (see Hummels, Ishii, and Yi, 2001; Johnson and Noguera, 2012; OECD and WTO, 2012; Timmer et al., 2015; among others). The latter effort reflects the value that is added by industries in producing goods and services, and it is equivalent to the difference between industry output and the sum of its intermediate inputs.

The recent availability of multi-region input-output (MRIO) tables, combined with bilateral trade statistics, allowed us to trace where value is created in the global production chain and hence, which countries and sectors contributed value to it. With this aim, in this paper we refer to Borin and Mancini's (2016, 2019) methodology and calculate the following value-added components of gross exports at the country and mining sector level:

- The **domestic value added** (DVA) is value added exported in final or intermediate goods or services. This is a measure of GDP in gross exports. At the sector level, DVA contains the exporter's value added from mining that goes to the direct importer for one or more stages of production before it is absorbed by direct importers or in third countries (or eventually returns home).
- The **foreign value added** (FVA) is value added contained in intermediate goods or services imported from abroad and exported in the form of final or intermediate inputs. It measures the import content of a country's exports.
- The **returned value added** or reflection (REF) is domestic value added in intermediate goods or services exported, re-imported, and absorbed into the domestic economy.

The difference between DVA and REF gives the value added absorbed in foreign countries, called VAX (Johnson and Noguera, 2012). VAX captures the contribution of the domestic country (or sector) to the exports of other countries.

Some of these components are used in the next sections to measure GVC participation.

Trade in value added in mining products in Argentina, Brazil, and Peru

Looking at trade in value added in mining exports, we trace what is domestically produced in the three target countries (i.e., the DVA component), what is produced abroad (the FVA component), and what is exported, re-imported, and absorbed into the domestic economies (the REF component).

Korinek (2020) carried out a preliminary analysis of trade in value added in mining. This work established some facts, mostly at the international and regional levels. One was that most of the value added in mining products is domestic—the DVA component accounts for more than 80 percent of gross exports in all countries. This proportion is a result of the inherent value of the minerals extracted, plus the value addition of labor and capital expenditures in the sector. This situation is in line with the characteristics of the sector: as with most natural resource sectors, mining is upstream in its value chain and exports are used in many further stages of intermediate and final goods production.

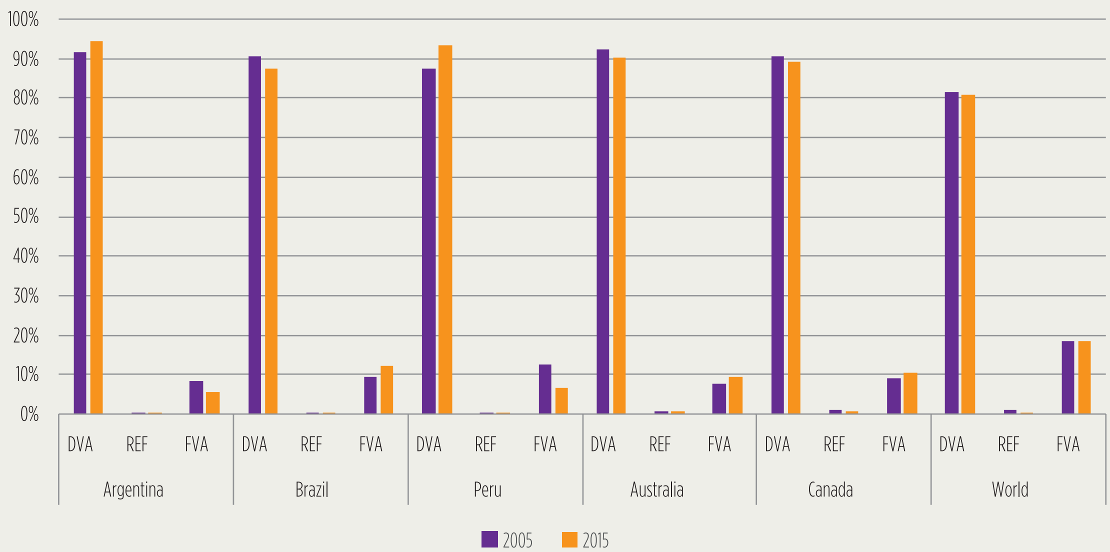
This paper provides a fresh analysis, focusing mainly on the three target Latin American countries (Argentina, Brazil, and Peru). To give a relative and realistic view of the role of these countries, this section compares them at the world level[2] and with reference to two countries known to participate heavily in high-value-adding activities: Australia and Canada.

The DVA component (a measure of GDP in exports) showed an increasing trend for both Argentina and Peru, in 2015, reaching 95 percent and 93 percent of exports, respectively, containing

2 World average is calculated by considering all 65 countries included in the 2018 version of the TiVA dataset.

value added produced domestically (Figure 6). Brazil showed a decreasing trend, with the DVA shrinking two percentage points (from 90 to 88 percent). The two reference countries, Australia and Canada, also showed declines, although their DVA share was higher than Brazil's. At the world level, the DVA component is lower, around 80 percent. The value added produced abroad, the FVA component, is small for all countries. Brazil again showed the same trend as Australia and Canada with an increasing FVA share. Finally, the REF—the subcomponent of the DVA embedded in gross exports that is finally absorbed by the exporting country itself—is very small or nonexistent for all countries and the world. This means that in the mining exports, virtually no value added in the intermediate stages returns via intermediate imports (Figure 6).

Figure 6. Value-Added Components of Gross Exports: International Comparison, 2005 and 2015



Source: OECD, Trade in Value Added data (2018).

Global value chain participation and positioning in mining products for Argentina, Brazil, and Peru

Using trade in value added, it is possible to measure both the participation and the positioning of countries and sectors in GVCs.

Participation in GVCs provides producers with access to new markets and potentially higher returns and can affect both the volume and value of goods and services they produce. Participation in GVCs takes two main forms: (i) importing foreign inputs for exports or *backward participation,* and (ii) producing inputs used in third countries' exports, or *forward participation*. Participation in GVCs is generally assessed through a participation index by looking at its two forms as a share of a country's exports.

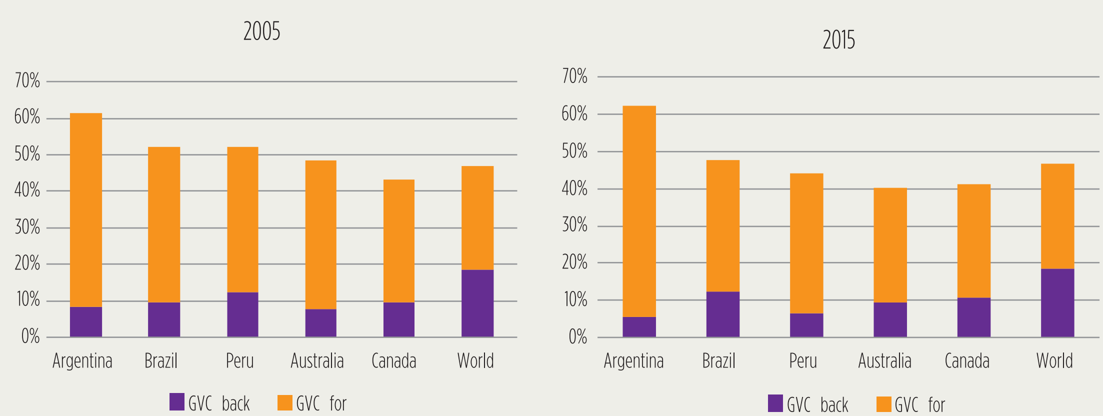
In this report, in line with the above breakdown of gross exports, we followed Borin and Mancini's (2019) methodology and calculated their measure of *overall GVC participation*. This is given by the sum of the *backward* component—that is, the use of imported inputs to produce goods (or services) that are exported—and the *forward* component—the value of intermediate exports sent indirectly through third countries to final destinations. The higher (or lower) the value of the GVC participation index, the larger (or smaller) the participation of a country (or sector) in global supply chains.

In the case of mining, owing to the sector's characteristics and the use of mining products in the production of final goods, we expect higher GVC *forward* participation compared to GVC *backward* participation.

Looking at the GVC participation in mining exports of the three target countries, it is worth noting that it is indeed relevant (Figure 7). The high GVC participation for these countries reflects extensive forward integration because mining is the most upstream sector. Argentina's mining sector emerges as the most integrated into the GVC, with an increasing share (over 60 percent in 2015). This high GVC participation means that, although in absolute terms the added value of mining exports is lower than in the other two Latin American countries, it presents a relatively higher level of participation (i.e., the value of intermediate exports sent indirectly through third countries to final destinations as a share of gross exports is larger than that of its regional partners).

The share of GVC participation is lower for Brazil and Peru and also shows a decreasing trend (Figure 7). However, these two countries show a different composition of the GVC participation indicator. Although both register a decline in the indicator, Brazil's backward component increased (i.e., the value added from using foreign inputs in its exports), while both components declined for Peru. Brazil shares those trends with Australia and Canada. At the world level, the GVC participation index is stable at less than 50 percent.

Figure 7. Global Value Chain Participation in the Mining Sector: International Comparison, 2005 and 2015



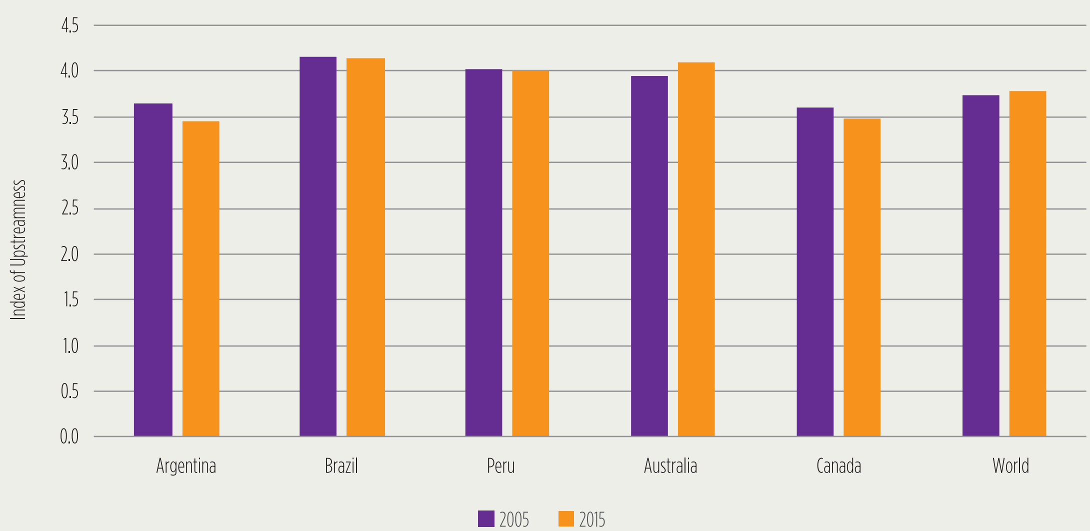
Source: Authors' calculations based on Trade in Value Added data (OECD, 2018).
Note: Mining and quarrying of non-energy producing products.

A country's position in a given value chain largely depends on its comparative advantages and, therefore, the mix of skills and resource endowments it brings to international production. Recently, a strand of the international trade literature has developed measures of the positioning of countries and industries in GVCs (see Alfaro et al., 2019; Antràs et al., 2012; Antràs and Chor, 2013; Fally, 2012; Fally and Hillberry, 2015; Miller and Temurshoev, 2017; Wang et al., 2017). Countries can be located upstream at the beginning of the value chain, in activities such as producing raw materials like mining products (or research and design), or downstream at the end of the value chain, in activities such as assembling manufactured products, logistics, and customer services.

In this report, we computed the indicator developed independently by Fally (2012) and Antràs and Chor (2013), and consolidated in Antràs et al. (2012) by using the Eora data.[3] This indicator describes the distance upstream, or the "upstreamness," of a production sector from final demand. Starting from one industry in a given country, the index measures how many stages of production remain before the goods or services produced by this industry reach final consumers. An increase in upstreamness means the economies are more specialized in producing inputs at the beginning of the value chain; a decrease reveals lower specialization, a shorter distance from final demand, or both.

As expected, because of the intrinsic characteristics of the mining sector, the three countries are upstream in the mining value chain. The average distance to final demand is high (more than 3.5 stages of production) and has decreased perceptibly only for Argentina (Figure 8), which reached the same level as Canada. Conversely, Australia has been moving farther upstream relative to final demand in the mining sector. This could be due to the fact that chains have lengthened as production has become more fragmented.[4]

Figure 8. Global Value Chain Positioning of the Mining Sector (Mining and Quarrying): International Comparison, 2005 and 2015



Source: Authors' calculations based on Eora data.

3 The Eora global supply chain database (https://worldmrio.com/) is useful for providing a wider international comparison of GVC linkages because it covers 190 countries for 1990–2015 and 26 harmonized sectors (International Standard Industrial Classification of Economic Activities [ISIC] Rev. 3). In Eora, mining is included in the "Mining and quarrying" sector (sector 3), which corresponds to industries 10, 11, 12, 13, and 14 in ISIC (Rev. 3).

4 When the production of some inputs is outsourced, their value added is moved backward to the industries supplying intermediate inputs and the distance to final demand increases (Backer and Miroudot, 2013).

produces in the mining sector. Doing so helps to pin down the links between the country and the sector where the value of production originates and the market where it is absorbed in final demand.

In terms of production of value added (i.e., the GDP), the country currently producing the highest value added in the mining sector in the world is China at 18.2 percent, followed by the United States (7.7 percent), Australia (6.9 percent), Chile (3.9 percent), and Canada (3.4 percent) (2015; Table 1). The shares of the three Latin American countries—1.7 percent (Argentina), 2.3 percent (Brazil), and 2.7 percent (Peru)—are higher than the world average (1.5 percent) (OECD-TiVA data).

Table 1. Value Added Produce by the Mining Sector, by Country, 2015

Exporter	US$ millions	% of World Value Added	Exporter	US$ millions	% of World Value Added
China	98589.6	18.21	Italy	381.1	0.07
Mexico	11052.7	2.04	Japan	1536.5	0.28
Argentina	**8915.9**	**1.65**	Kazakhstan	4446.6	0.82
Australia	**37497.5**	**6.93**	Cambodia	31.9	0.01
Austria	548.4	0.10	Korea	1655.0	0.31
Belgium	215.1	0.04	Lithuania	78.9	0.01
Bulgaria	646.7	0.12	Luxembourg	18.6	0.00
Brazil	**12180.0**	**2.25**	Latvia	59.6	0.01
Brunei Darussalam	660.0	0.12	Morocco	2691.5	0.50
Canada	**18585.9**	**3.43**	Malta	8.2	0.00
Switzerland	577.4	0.11	Malaysia	4665.3	0.86
Chile	21362.7	3.95	Netherlands	418.2	0.08
Colombia	2142.9	0.40	Norway	751.2	0.14
Costa Rica	103.9	0.02	New Zealand	365.9	0.07
Cyprus	24.2	0.00	**Peru**	**14378.0**	**2.66**
Czech Republic	330.4	0.06	Philippines	4043.6	0.75
Germany	3905.7	0.72	Poland	2843.2	0.53
Denmark	97.3	0.02	Portugal	490.7	0.09
Spain	2243.3	0.41	Romania	154.0	0.03
Estonia	118.8	0.02	Russian Federation	11004.1	2.03
Finland	805.9	0.15	Saudi Arabia	2035.6	0.38
France	2060.9	0.38	Singapore	0.0	0.00
United Kingdom	4784.5	0.88	Slovak Republic	202.4	0.04
Greece	794.6	0.15	Slovenia	107.0	0.02

Exporter	US$ millions	% of World Value Added	Exporter	US$ millions	% of World Value Added
Hong Kong	149.1	0.03	Sweden	1894.5	0.35
Croatia	42.7	0.01	Thailand	771.0	0.14
Hungary	107.0	0.02	Tunisia	331.0	0.06
Indonesia	15729.3	2.90	Turkey	5088.4	0.94
India	8050.5	1.49	Chinese Taipei	645.3	0.12
Ireland	628.4	0.12	United States	41519.1	7.67
Iceland	18.6	0.00	Vietnam	2188.2	0.40
Israel	435.8	0.08	South Africa	16667.3	3.08
ROW	*166594.8*	*30.77*			

Source: Authors' calculations based on Trade in Value Added data (OECD, 2018).
Note: Mining and quarrying of non-energy producing products.

In terms of absorption of value added (i.e., destination of the value added via exports), most of the value added originating in the mining sector in Brazil (73.5 percent) and Peru (71.9 percent) is absorbed by foreign countries' final demand (Table 2). Brazil's and Peru's mining products are used in production in foreign countries and purchased by foreign consumers. Although the numbers for the two countries were similar in 2015, Brazil's share of value added absorbed domestically decreased, whereas Peru's share increased. The trend for Brazil reveals growing value added in mining product exports directly consumed by the direct importer (i.e., that the importer uses in the production of goods consumed domestically).

The Brazilian trend is in line with that shown by both Australia and Canada: the two economies present a very high share (over 80 percent) of value added originating in their mining sectors absorbed by foreign countries' final demand. This trend is evidence of the deep integration of their mining sector at the world level. Conversely, Argentina registers a growing percentage of value added in the mining sector being directly absorbed within the country (80 percent in 2015 versus 55 percent in 2005). This means Argentine mining inputs are mainly used to produce goods consumed domestically.

Table 2. Value Added in the Mining Sector Absorbed by Domestic and Foreign Final Demand, by Country, 2005 and 2015

Value Added	2005		2015	
	US$ millions	% of Total	US$ millions	% of Total
ARGENTINA				
Absorbed by domestic final demand	1105.5	55.0	7140.9	80.1
Absorbed by foreign countries' final demand	905.2	45.0	1775.0	19.9

Value Added	2005		2015	
	US$ millions	% of Total	US$ millions	% of Total
BRAZIL				
Absorbed by domestic final demand	2478.6	33.7	3231.0	26.5
Absorbed by foreign countries' final demand	4879.9	66.3	8949.0	73.5
PERU				
Absorbed by domestic final demand	789.2	16.4	4044.7	28.1
Absorbed by foreign countries' final demand	4020.4	83.6	10333.2	71.9
AUSTRALIA				
Absorbed by domestic final demand	8601.1	38.0	6453.6	17.2
Absorbed by foreign countries' final demand	14049.8	62.0	31043.9	82.8
CANADA				
Absorbed by domestic final demand	2016.6	17.0	3501.2	18.8
Absorbed by foreign countries' final demand	9839.7	83.0	15084.7	81.2

Source: Authors' calculations based on Trade in Value Added data (OECD, 2018).
Note: Mining and quarrying of non-energy producing products.

Looking at the markets that absorb the value added produced in the domestic mining sector (other than the country itself), for Argentina, the foreign markets that absorb value added are essentially the regional ones (Latin American countries plus the United States and Canada), plus China. In the case of Brazil, a polarization emerges: more than half of the Brazilian value added in the sector is absorbed equally by the domestic and the Chinese markets. The rest is spread out at the international level (Table 3). Quite similar is the case of Peru, where about 28 percent of value added is absorbed by the domestic market and about 24 percent by China. Absorption by the U.S. market is significant as well (11 percent).

This distribution means that for Brazil and Peru a significant share of value added coming from their domestic mining sector is absorbed—via exports—by selected foreign countries. This polarization is even more evident for Australia, where more than 40 percent of the value added produced in the domestic mining sector is absorbed by the Chinese market, a percentage higher than that absorbed by the domestic market (17.2 percent). Canada absorbs 18.8 percent of its mining value added domestically and has two main foreign partners that absorb its value added produced in the mining sector: China (13.4 percent) and the United States (25.9 percent) (Table 3).

Table 3. Absorption of Value Added Produced in Domestic Mining Sectors, by Country, 2015

Importer	Exporter					Importer	Exporter				
	Argentina	Brazil	Peru	Australia	Canada		Argentina	Brazil	Peru	Australia	Canada
	% of Total						% of Total				
China	1.5	26.0	23.7	42.2	13.36	Italy	0.3	1.3	1.2	0.4	0.81
Mexico	0.4	0.7	0.9	0.7	1.58	Japan	1.1	5.1	3.5	6.8	4.32
Argentina	80.1	2.0	0.4	0.2	0.23	Kazakhstan	0.0	0.1	0.1	0.1	0.07
Australia	0.2	0.6	0.5	17.2	1.08	Cambodia	0.0	0.0	0.0	0.0	0.04
Austria	0.1	0.2	0.2	0.1	0.2	Korea	0.3	1.6	1.7	2.8	1.56
Belgium	0.1	0.3	0.3	0.2	0.96	Lithuania	0.0	0.0	0.0	0.0	0.02
Bulgaria	0.0	0.0	0.0	0.0	0.03	Luxembourg	0.0	0.0	0.0	0.0	0.02
Brazil	2.8	26.5	2.1	0.5	0.59	Latvia	0.0	0.0	0.0	0.0	0.01
Brunei Darussalam	0.0	0.0	0.0	0.0	0.01	Morocco	0.1	0.1	0.1	0.0	0.07
Canada	1.3	0.9	3.5	0.7	18.84	Malta	0.0	0.0	0.0	0.0	0.01
Switzerland	0.1	0.3	0.4	0.2	0.27	Malaysia	0.1	0.6	0.3	0.7	0.2
Chile	0.6	0.3	0.6	0.2	0.4	Netherlands	0.1	0.3	0.2	0.2	0.33
Colombia	0.2	0.3	0.8	0.2	0.18	Norway	0.1	0.2	0.2	0.2	0.32
Costa Rica	0.0	0.0	0.0	0.0	0.03	New Zealand	0.0	0.1	0.1	0.3	0.21
Cyprus	0.0	0.0	0.0	0.0	0.01	Peru	0.2	0.2	28.1	0.1	0.11
Czech Republic	0.0	0.2	0.1	0.1	0.12	Philippines	0.0	0.3	0.2	0.3	0.2
Germany	1.0	2.4	1.6	0.9	2.02	Poland	0.1	0.9	0.3	0.3	0.34
Denmark	0.1	0.1	0.1	0.1	0.11	Portugal	0.0	0.1	0.1	0.0	0.08
Spain	0.5	0.8	1.2	0.4	0.74	Romania	0.0	0.2	0.1	0.1	0.08
Estonia	0.0	0.0	0.0	0.0	0.01	Russian Federation	0.2	0.5	0.4	0.4	0.4
Finland	0.1	0.2	0.2	0.1	0.26	Saudi Arabia	0.2	1.1	0.6	0.8	0.7
France	0.3	1.2	0.9	0.6	1.29	Singapore	0.0	0.2	0.1	0.2	0.14
United Kingdom	0.3	1.3	0.9	1.0	4.43	Slovak Republic	0.0	0.1	0.1	0.1	0.06
Greece	0.0	0.1	0.1	0.1	0.07	Slovenia	0.0	0.0	0.0	0.0	0.02
Hong Kong	0.1	0.4	0.4	1.6	1.17	Sweden	0.1	0.6	0.3	0.1	0.35
Croatia	0.0	0.0	0.0	0.0	0.02	Thailand	0.1	0.4	0.4	0.9	0.38
Hungary	0.0	0.1	0.1	0.1	0.09	Tunisia	0.0	0.0	0.0	0.0	0.02
Indonesia	0.2	0.8	0.4	1.1	0.41	Turkey	0.2	1.2	0.6	0.5	0.66
India	0.5	2.8	4.9	3.5	5.88	Chinese Taipei	0.1	0.7	0.5	1.0	0.51
Ireland	0.0	0.1	0.1	0.1	0.13	United States	3.2	7.5	11.0	6.5	25.91
Iceland	0.0	0.0	0.0	0.0	0.01	Vietnam	0.2	0.4	0.3	0.6	0.69
Israel	0.0	0.1	0.1	0.1	0.15	South Africa	0.1	0.3	0.2	0.2	0.15
ROW	*2.5*	*7.2*	*5.2*	*4.6*	*6.55*						

Source: Authors' calculations based on Trade in Value Added data (OECD, 2018).
Note: Mining and quarrying of non-energy producing products

Next, for each country, we analyzed how much value added in mining exports is absorbed directly by the largest importer and how much by the markets for that importer's exports. On average—for all three target countries—over 60 percent of the value added is absorbed directly by the largest importer, whereas not less than 25 percent is absorbed by tertiary markets—that is, the destination markets of the main importer's (processing or final) goods (OECD-TiVA data, 2018).

Services in Mining and Trade in Mining-Related Services

Services represent an essential element of GVCs, including in the mining sector. Services are required for the main stages of mining cycle (prospecting and exploration, feasibility assessment, exploitation, and closure and remediation). Each stage requires specialized mining services, such as geological services; engineering services; construction services; drilling services; blasting and other uses of explosives; provision of energy and water; environmental services; communications services; leasing of machinery and equipment; maintenance and repair of machinery and equipment; infrastructure for transport; food, accommodation, and uniform services at mining camps; business and other professional services, such as accounting, legal, managerial, and human resources; and financial services (Korinek, 2020).

This section analyzes the importance of services for mining value added. This analysis highlights which countries use services the most and which perform better in producing value through services. Comparisons with both the world average and the average of the most successful emerging mining service exporter, Australia, are also provided.

A second analysis focuses on trade in mining-related services. Unfortunately, data on trade in services are not as developed as data for goods, and the available disaggregation does not allow tracing of this flow of services. However, the OECD's Trade in Value Added (TiVA) tables provide information on international trade in mining-related services (the D09 sector in the International Standard Industrial Classification of All Economic Activities [ISIC] Rev. 4), both in terms of gross trade flows and flows in value added. Consequently, TiVA data are used to trace export trends and GVC trade of mining support services activities.

The importance of services for mining value added

At the aggregate level, the work of Korinek (2020) emphasizes that embodied services in mining exports represent an important economic industry at the global level (valued at over US$40 billion), doubling over the 2005–15 period. This growth highlights the intensification of the importance of services in the mining sector as a result of both greater use of services and growth in outsourcing of services.

Outside of the mining sector itself (which accounts for 59 percent of value added), services are the main input for mining activities, representing 23 percent of the value added of mining exports, on average.[5]

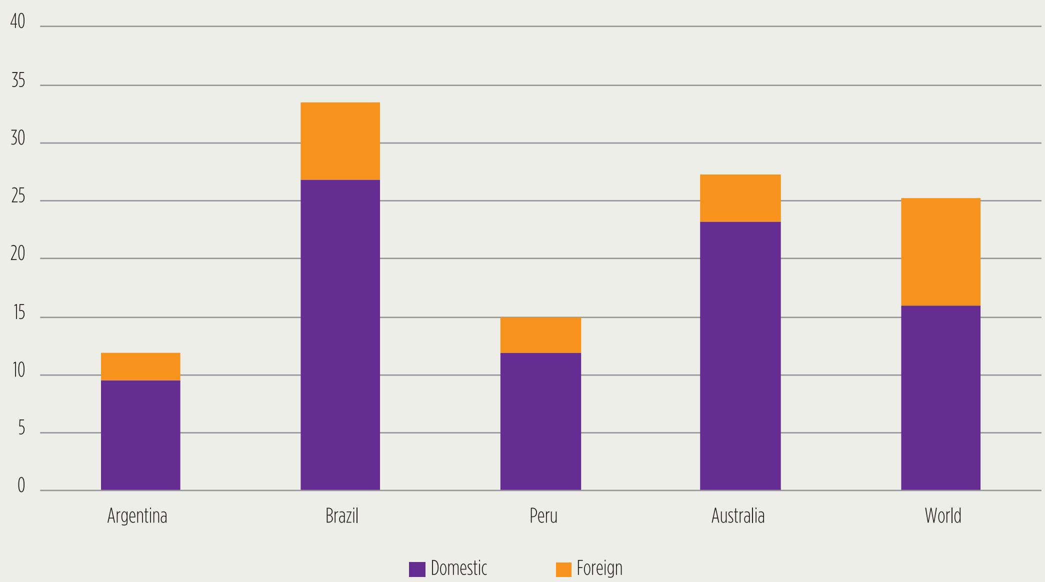
5 Inputs from manufacturing represent a very small share of the value added in mining: 4 percent (domestic manufacturing inputs) and 3 percent (foreign manufacturing). Energy and water represent 7 percent of the value added in mining.

There is some heterogeneity by country, however. Considering the largest mining producers in value added terms (according to TiVA data), Australia shows that services account for 26 percent of the value added of its mining sector. In Chile—the second most important mining country—services account for 21 percent of value added. Other important mining countries in terms of value added are Canada (where services account for 18 percent of value), South Africa (20 percent), the United States (20 percent), the Russian Federation (23 percent), and Indonesia (13 percent) (Korinek, 2020).

In most of these countries, a large majority of services to the mining sector are provided domestically (on average, accounting for 18 percent of the value added of mining exports). It is not a surprising result. In general, services are less traded than goods. This suggests that the mining sector may provide economically important opportunities for job creation in supporting services in mineral-rich countries.

Focusing on the three target economies, Figure 9 compares their service shares of value added in gross exports with Australia's service share and the world average, distinguishing between domestic and foreign services.

Figure 9. Domestic and Foreign Services Share of Value Added in Gross Exports (Percent), 2015



Source: Authors' calculations based on Trade in Value Added data (OECD, 2018).

The share of services used in countries' mining sectors varies greatly. Brazil shows the highest services share, accounting for 33 percent of mining value added, higher than the Australian share and the world average. In Peru, services account for 15 percent of the value added of the sector, whereas Argentina shows the lowest share, 12 percent. Possible reasons are that, in some countries, mining services suppliers are small firms that do not generally do much trade. Some mining services are also quite specific and specialized; as a result, there may be a reduced market for that kind of service. Moreover, some services—such as legal, financial, insurance, and transport services—have been subject to tariffs.

Most of these services are sourced domestically (Figure 9), although some countries import services that are productivity-enhancing or that require skills or technologies that are not available in-country.

The largest providers of traded services to the mining sector are mainly developed economies. The United States holds first position, followed by China, Germany, the United Kingdom, Japan, France, and the Netherlands (Korinek, 2020). None of the top global providers of mining services are Latin American countries.

Table 4 reports the main mining service providers for the target countries. Together with Australia, Peru presents the highest diversification in terms of service suppliers. The largest providers are essentially those already identified at the world level: the United States, the Netherlands, China, and Japan.

Table 4. Main Sources of Imported Services for Mining, by Country

Argentina	US$ millions	%
China	1.5	0.2
Brazil	2.8	0.4
Germany	0.9	0.1
France	0.6	0.1
United Kingdom	0.4	0.1
Japan	0.5	0.1
United States	4.0	0.6
Rest of the World	1.7	0.2
Total	*12.3*	

Brazil	US$ millions	%
India	16.9	0.1
Ireland	13.1	0.1
Italy	28.2	0.2
Japan	31.2	0.2
Korea	10.8	0.1
Netherlands	210.1	1.3
Norway	30.0	0.2
Russian Federation	9.6	0.1
Singapore	7.3	0.1
Sweden	15.9	0.1
United States	309.4	1.9
Rest of the World	46.3	0.3
Total	*728.7*	

Peru	US$ millions	%
China	45.4	0.4
Mexico	9.4	0.1
Brazil	15.9	0.1
Canada	6.9	0.1
Chile	15.7	0.1
Colombia	11.0	0.1
Germany	20.1	0.2
Spain	21.8	0.2
France	8.6	0.1
United Kingdom	10.0	0.1
India	9.5	0.1
Italy	7.8	0.1
Japan	21.0	0.2
Korea	11.0	0.1
Netherlands	6.0	0.1
United States	100.4	0.8
Rest of the World	20.4	0.1
Total	*340.6*	

Table 4. Main Sources of Imported Services for Mining, by Country *(continued)*

Australia	US$ millions	%
China	262.5	0.6
Germany	72.0	0.2
France	39.9	0.1
United Kingdom	95.6	0.2
Hong Kong	27.3	0.1
Indonesia	32.0	0.1
India	46.4	0.1
Italy	37.2	0.1
Japan	157.4	0.4
Korea	56.5	0.1
Netherlands	33.2	0.1
New Zealand	42.0	0.1
Singapore	91.8	0.2
Thailand	39.4	0.1
Chinese Taipei	23.9	0.1
United States	339.0	0.8
Rest of the World	151.4	0.4
Total	*1547.4*	

Source: Authors' calculations based on Trade in Value Added data (OECD, 2018).

The major importers for services for the mining industry are countries characterized by large mining industries, such as Australia, Chile, Brazil, Canada, South Africa, and Peru.

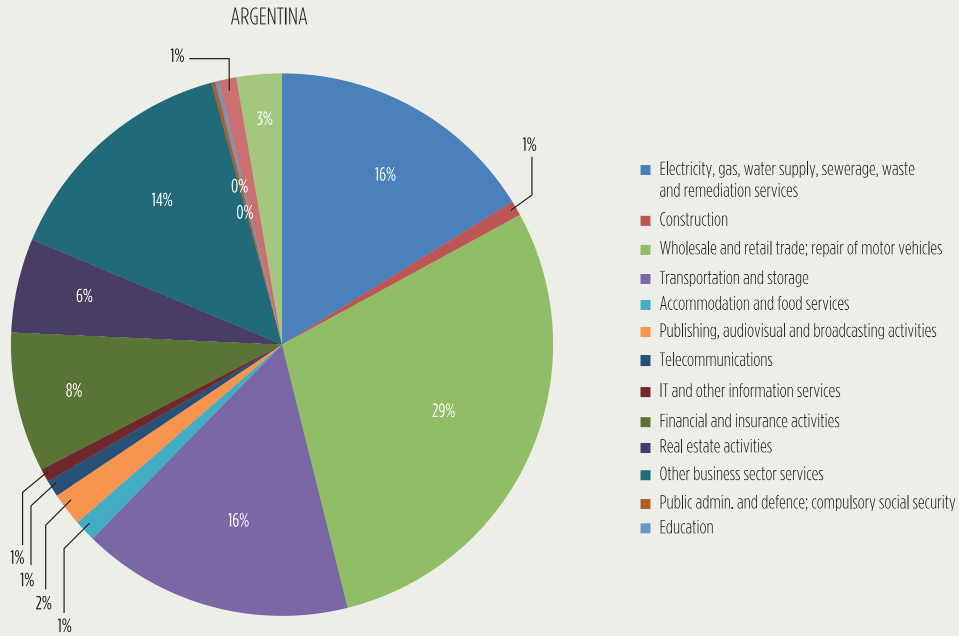
Figure 10 shows the details for the target countries. For Argentina, the wholesale and retail trade and repairs category accounts for 29 percent; transportation and storage for 16 percent; and electricity, gas, water supply, sewerage, waste, and remediation services for 16 percent.

In Brazil, the largest services subsector is "other business services" (representing 29 percent), which includes research and development services; professional and management consulting services (e.g., legal, accounting, management consulting, managerial, public relations, advertising, market research, and public opinion polling); and technical, trade-related, and other business services (e.g., architectural, engineering, and other technical services; waste treatment and depollution, agricultural, and mining services; operating leasing services; and trade-related services). This subsector is followed by wholesale and retail trade and repairs (25 percent) and financial and insurance activities (12 percent).

Wholesale and retail trade and repairs is also the leading subsector in Peru, representing 33 percent of the value added of mining exports, followed by transportation and storage (13 percent), other business services (12 percent), and financial and insurance activities (11 percent).

Comparing this evidence with the Australian case (Figure 10), it emerges that services used in Australia for mining exports are more diversified. Although the standard subsectors are important, other sectors appear to be relevant, such as electricity, gas, water supply, sewerage, waste, and remediation services (12 percent); construction (10 percent); and arts, entertainment, recreation, and other service activities (7 percent).

Figure 10. Services Value Added Embodied in Mining Exports, 2015



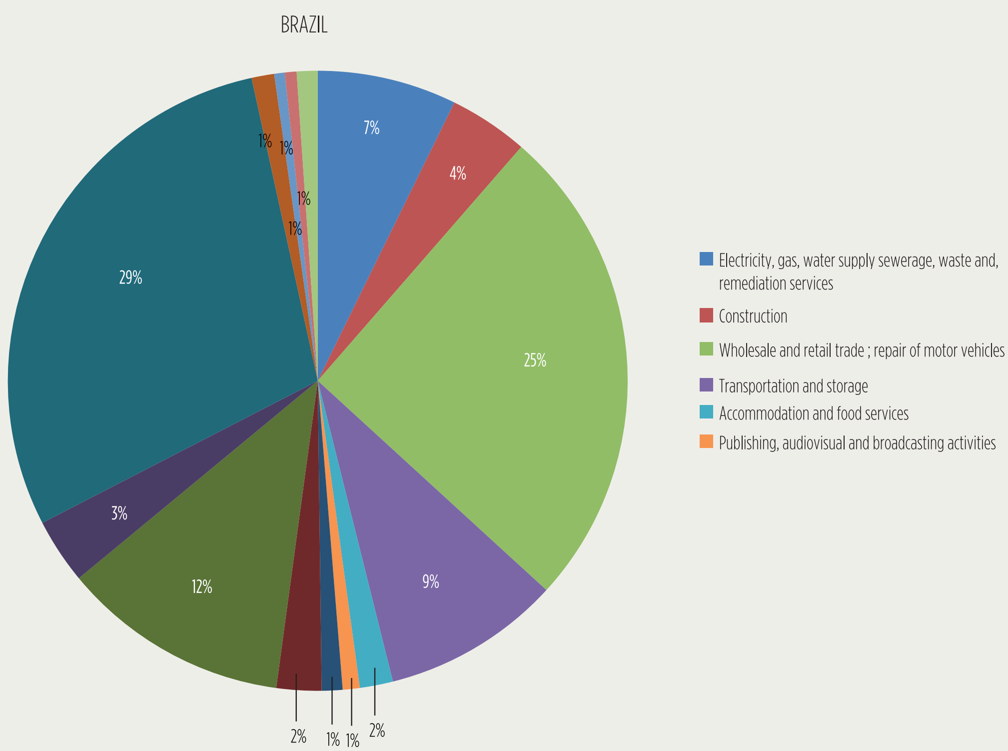
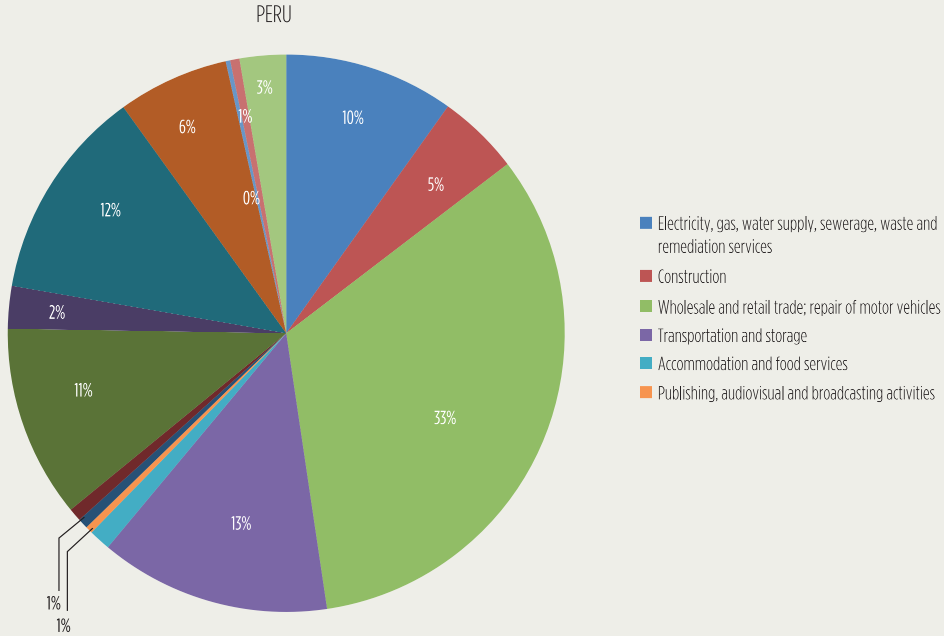
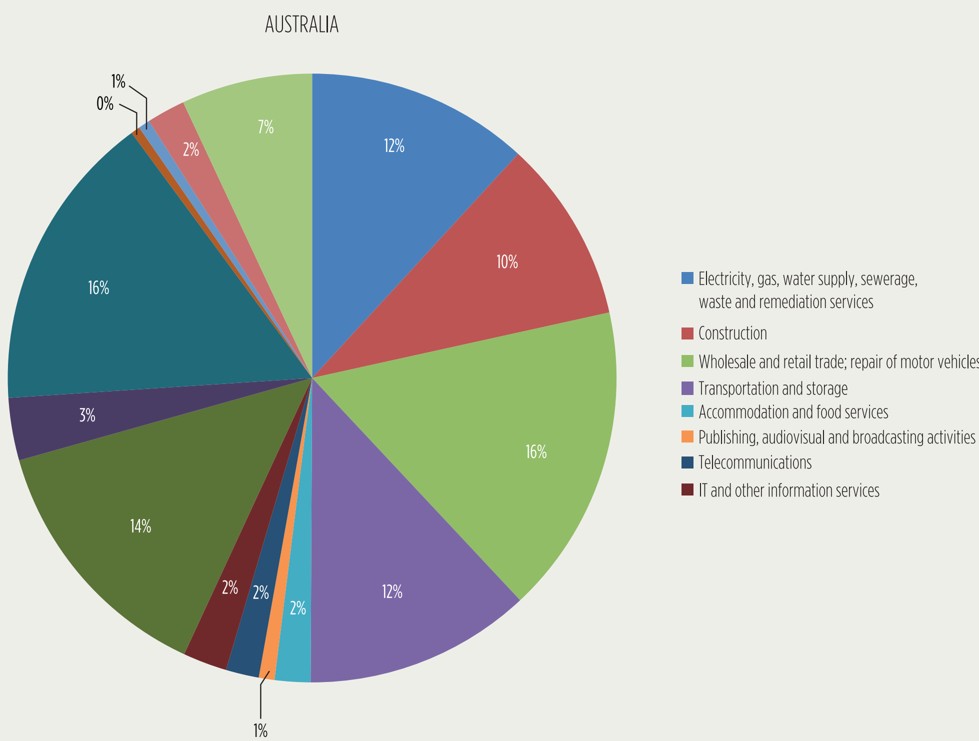


Figure 10. Services Value Added Embodied in Mining Exports, 2015 *(continued)*





Source: Authors' calculations based on Trade in Value Added data (OECD, 2018).

Global value chain trade in mining-related services

TiVA data is used to trace gross export and import trends and GVC trade of mining support service activities.

The top exporters of mining-related services in the world are the United States, Norway, and the Russian Federation, followed by the United Kingdom, Germany, and Australia. Among them, Australia can be considered a successful case: the value of services it provided increased from US$4 million in 2005 to US$215 million in 2015. The target countries hold a marginal position, Peru in particular.

Many of the top service exporters (except the United Kingdom) are also the top importers of mining-related services, together with France. Again, the three Latin American target countries are not among the leading importers.

Looking at trade in value added in mining service exports, we trace what is domestically produced (DVA) in each economy, what was produced abroad (FVA), and what is exported, re-imported, and absorbed into domestic economies (REF) by comparing the three target countries with Australia and the world average.

About 90 percent of the value added in mining service exports of the three Latin American countries is domestic (Figure 11), a share similar to Australia's but higher than the world average (80 percent). This trend has strengthened in recent years for both Argentina and Peru, whereas Brazil shows a decreasing trend, with its DVA shrinking about five percentage points (from 92 to 87 percent).

The value added in import services produced abroad—the FVA component—is quite small for all countries examined. Only Brazil shows an increasing FVA share (above 12 percent).

Finally, the REF—the subcomponent of the DVA embedded in gross exports that is finally absorbed by the exporting country itself—is close to zero for all the countries (an expected result for this kind of services); so is the world average.

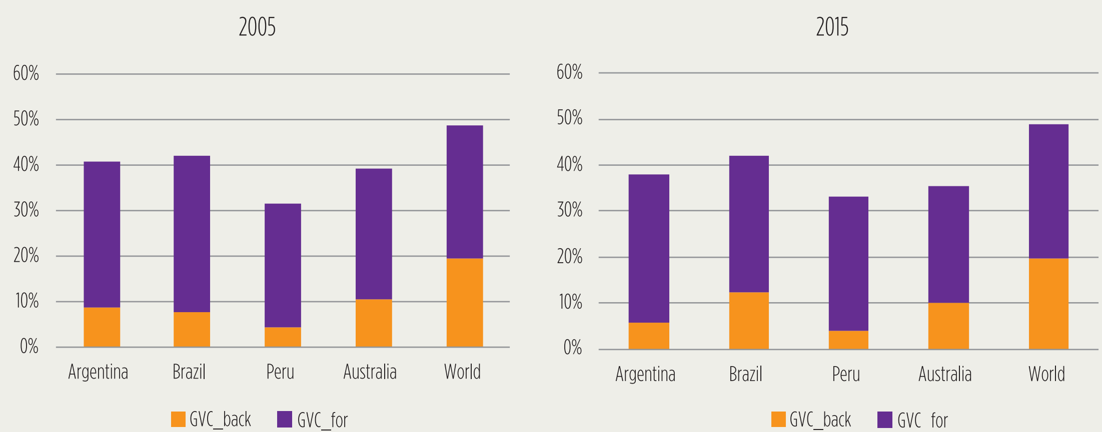
Figure 11. Comparison of Value-Added Components of Gross Service Exports, 2005 and 2015

Source: Authors' elaboration based on Trade in Value Added data (OECD, 2018).
Note: DVA: domestic value added; REF: returned value added; FVA: foreign value added.

The GVC participation in mining service exports of the three target countries plus Australia (and the world average) shows a certain level of heterogeneity over the reference period: it appears quite stable in Brazil (42 percent), it has decreased for Argentina and Australia (less than 40 percent), and it has increased in Peru (around 32 percent) (Figure 12). All countries register GVC participation lower than the world average, which is around 50 percent.

It is worth noting the prevailing share of the GVC *forward* component (value added embedded in exports of services used by other countries) compared to the *backward* component, not surprising given the characteristics of the sector. However, although the GVC *backward* component for all these countries is lower than the world average, it is growing in Brazil, where it is now higher than in Australia.

Figure 12. Comparison of Global Value Chain Participation for Mining Service Exports, 2005 and 2015



Source: Authors' elaboration based on Trade in Value Added data (OECD, 2018).

Most of the value added originating in the mining service sector in both Argentina (about 90 percent) and Brazil (more than 70 percent) is absorbed by domestic final demand (Table 5). This means that mining services in these countries are used mainly by domestic consumers. However, the two countries registered an opposite path over the reference period: Argentina significantly increased the share of value added absorbed domestically in 2015 compared to 2005, whereas Brazil reduced its share, showing a growing internationalization of the services it uses.

Peru registered the highest share of value added absorbed by foreign countries' final demand in the mining service sector, although that share shrank significantly in the last year for which data are available (Table 5). In 2015, about half of mining services used in Peru were absorbed by foreign consumers.

Table 5. Value Added in the Mining Services Sector Absorbed by Domestic and Foreign Final Demand, by Country

Value Added	2005		2015	
	US$ millions	% of Total	US$ millions	% of Total
ARGENTINA				
Absorbed by domestic final demand	353.0	59.3	2309.6	89.5
Absorbed by foreign final demand	242.3	40.7	271.2	10.5
BRAZIL				
Absorbed by domestic final demand	487.3	76.4	1586.6	70.7
Absorbed by foreign final demand	150.4	23.6	656.5	29.2
PERU				
Absorbed by domestic final demand	182.6	32.9	366.0	54.1
Absorbed by foreign final demand	372.8	67.1	310.4	45.9

Source: Authors' elaboration based on Trade in Value Added data (OECD, 2018).

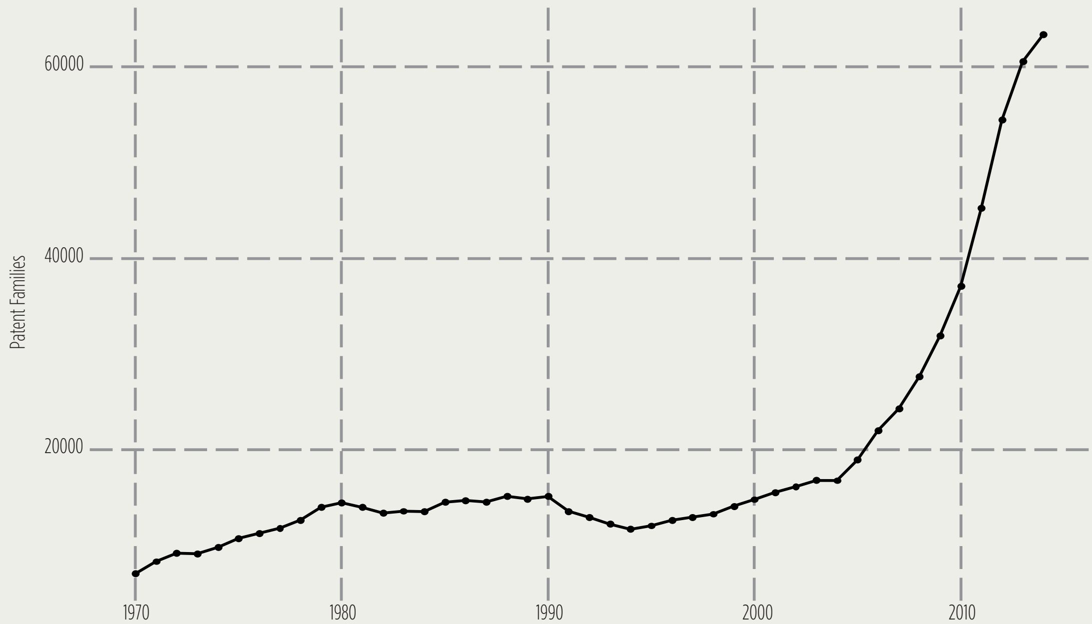
PART II: PATENT DATA AND SCIENTIFIC PUBLICATIONS

Evolution of Mining Technologies

The following is an analysis of the evolution of innovative activity in the mining sector over the past 40 years using patent data. Patent applications related to the mining sector were identified by the World Intellectual Property Office (WIPO), which classifies mining patents by examining the technological classes indicated in patent documents. The WIPO dataset is the primary source of data for this section. The dataset consists of about 900,000 mining-related patent families for the period 1970–2014. (A patent family is a set of related patent applications for the same innovation.)

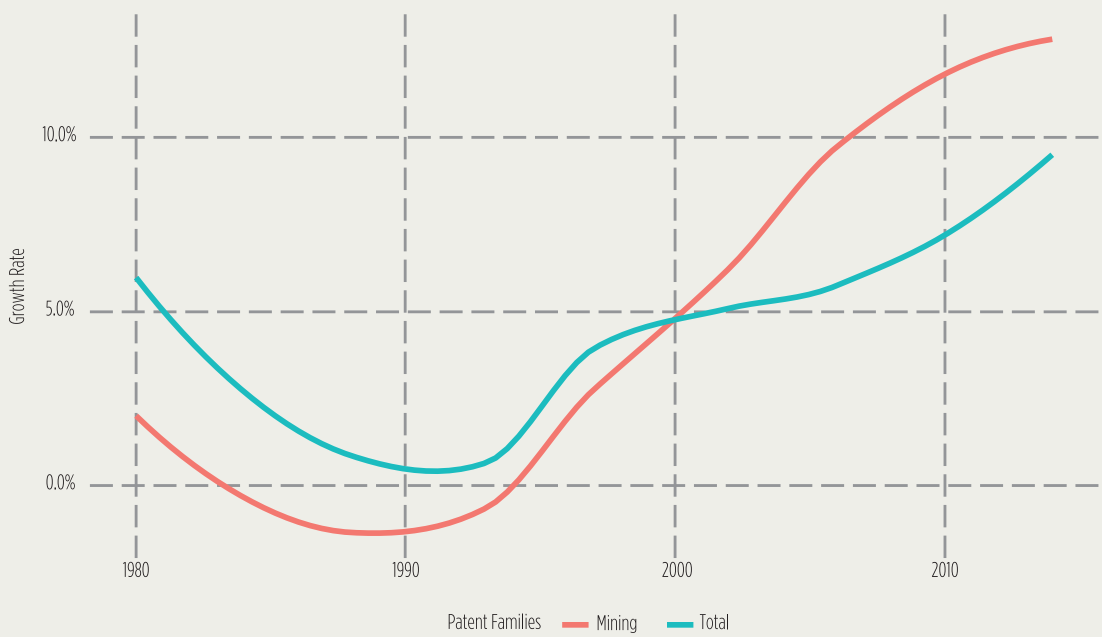
Figure 13 plots the yearly number of patent families related to mining technologies from 1970 to 2014 in the world. The figure shows that mining patent families increased enormously over time, from fewer than 10,000 families in 1970 to over 60,000 of 2014. While the increase was less evident during the first 30 years of the period, from the end of the 1990s, sustained and very rapid (after 2005) growth in mining patent families is clear. This outstanding growth may be due, in part, to the overall increase in the number of patents during the past 20 years. However, as shown in Figure 14, mining patent families grew at much higher rate than overall patent families starting in 2000 (the year in which the growth rate of mining patent families, represented by the red line in Figure 14, overtakes that of total patents families). Such rapid growth also led to a substantial increase in the importance of mining patent families compared to global patent production. Indeed, the share of patent families related to mining technologies out of total patent families moved from its minimum level of about 1.7 percent during the late 1990s to its maximum level in recent years (Figure 15). For example, in 2013, mining patent families accounted for around 2.8 percent of overall patent families.

Figure 13. World Growth of Mining Technologies, 1970–2014



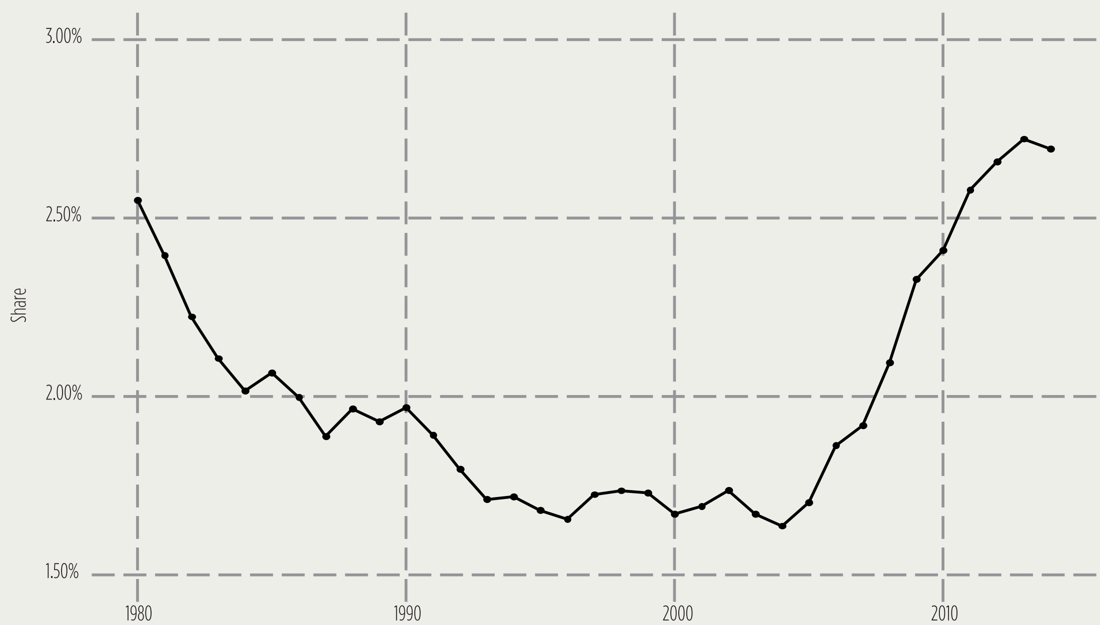
Source: Authors' elaboration based on PATSTAT database.

Figure 14. Worldwide Annual Growth Rate of Mining Patent Families and Total Patent Families, 1980–2014



Source: Authors' elaboration based on PATSTAT database.

Figure 15. World Mining Share of Total Patent Families, 1980–2014

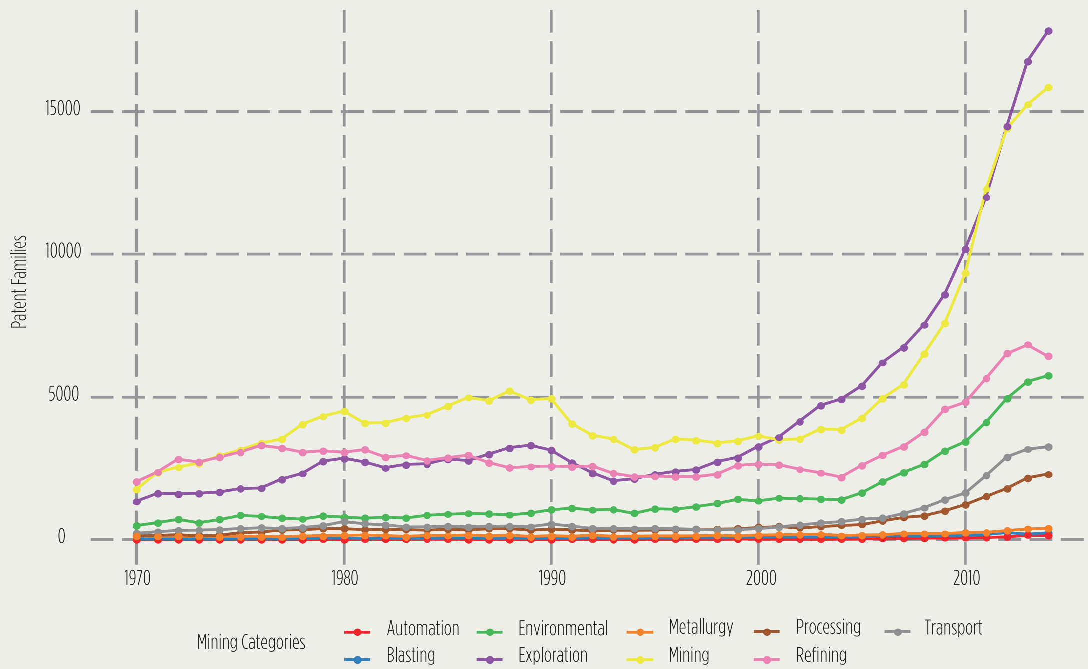


Source: Authors' elaboration based on PATSTAT database.

WIPO classifies mining patents in nine subcategories of mining technologies. The growth of mining patent families by subcategory is presented in Figure 16. Over the period under study, the overall pattern seems to resemble global growth of mining patents. The highest share of patents belongs to pure mining-related technologies (yellow line), followed by exploration (purple line) and refining (pink line) technologies. Interestingly, pure mining- and exploration-related technologies show the highest rate of growth.

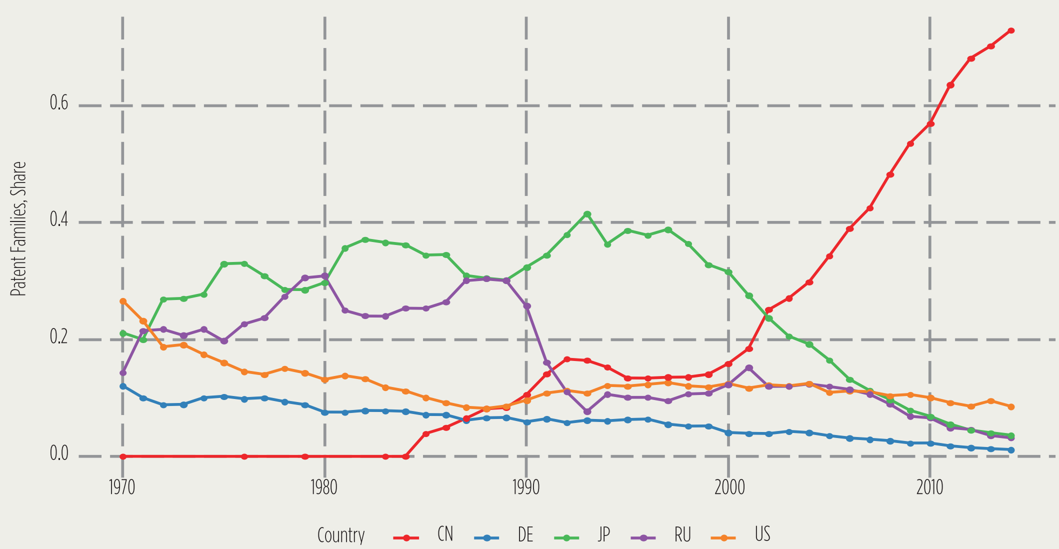
Another useful finding from the WIPO database relates to country of origin of patent families in mining technologies. Using this data, we can identify the patenting patterns of countries globally and the relative positioning of the three Latin America focus countries (Argentina, Brazil, and Peru). Figure 17 reports the shares of the five most innovative countries in mining technologies: China, Japan, Germany, Russia, and the United States. Japan and Russia retain the highest share of patents in mining until the mid-1990s, when they experience a big drop in their relative positions. Figure 17 also reveals that from 2000 onward, China became the top innovative country in mining.

Figure 16. World Growth of Mining Technology Patents, by Subcategory, 1970–2015



Source: Authors' elaboration based on PATSTAT database.

Figure 17. Mining Technologies: Top Five Countries of Origin, 1970–2014



Source: Authors' elaboration based on PATSTAT database.
Note: CN: China; DE: Germany; JP: Japan; RU: Russia; US: United States.

Figures 18 to 24 explore the evolution of mining-related technologies in Latin America and the relative positioning of the three focus countries. Figure 18 compares the growth of mining patent families in Latin America with that of the rest of the world. Though it fluctuates somewhat, the pattern of mining patenting in Latin America is well in line with the worldwide pattern. Latin America seems to have slightly anticipated the increase in mining technologies that started around the mid-1990s and continued growing until the end of the period.

As shown in Figure 19, the relative importance of mining technologies to overall innovation in Latin America also substantially increased from the late 1990s onward, peaking at 5 percent in 2008 and almost doubling the relative share observed for the global patenting dynamics shown in Figure 15.

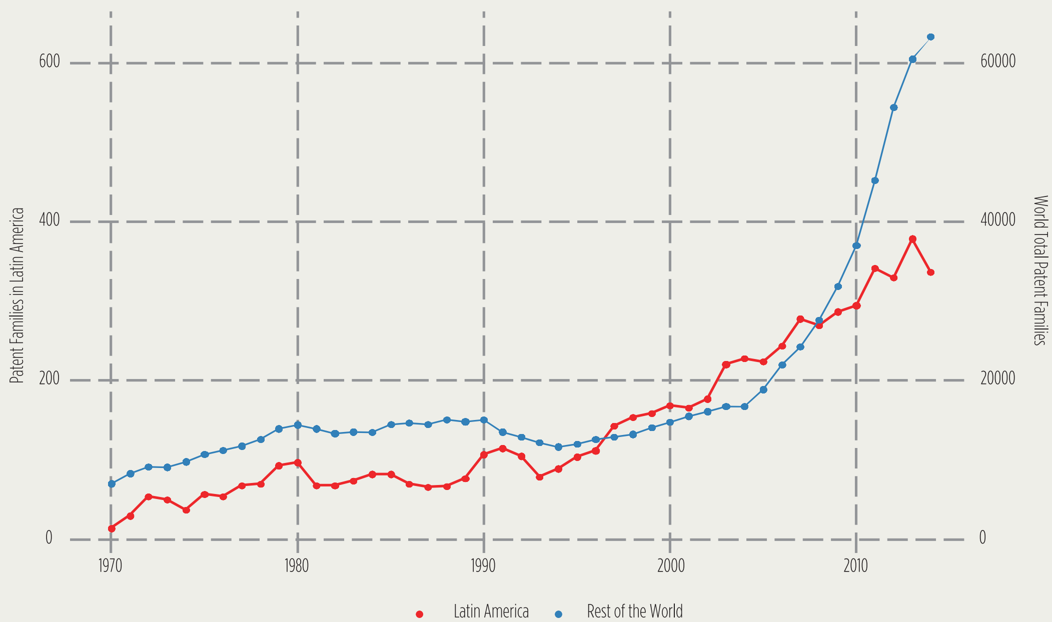
Looking at the growth of Latin American mining patent families by technological subcategory (Figure 20), technologies related to pure mining (yellow line), exploration (purple line), and refining (pink line) are still the best-represented categories.

Among the five most innovative countries in mining technology in Latin America (Figure 21), Brazil is by far the most active in relative terms, even if patent counts are observed to gradually fall starting from mid-2000s. Starting from 1980, Brazil has accounted for about 60 percent of total mining patent families in Latin America throughout the entire period under scrutiny, with Mexico (18 percent) second and Argentina (15 percent) third. For most of the observed years (up to 2008), the two least innovative countries, with shares below 10 percent, were Chile and Peru.

Figure 22 shows the growth in mining patents in Brazil, Argentina, and Peru from 1970 to 2014, compared with the overall trend in Latin America. Brazil greatly outperformed Argentina and Peru, experiencing fast growth in the number of patent families starting from the end of the 1990s, which drove the overall increase of mining patent families in Latin America, which was in line with the overall trends in global mining patenting. The shares of mining patent families of Brazil, Argentina, and Peru are also in line with the global trend. Mining-related technology in these three countries accounts for 1 to 3 percent of their total invention activity, with a clearly increasing trend throughout the period (Figure 23).

Finally, Figure 24 plots the number of mining patent families in each technological subcategory for each of Argentina, Brazil, and Peru. For Latin America, pure mining, exploration, and refining are the best-represented subcategories in Brazilian mining patent production. Exploration and pure mining technologies also dominate in Argentina, while Peru tends to be more oriented toward pure mining (though the total number of patent families is very low).

Figure 18. Mining Technologies, Latin America and Rest of the World, 1970–2015

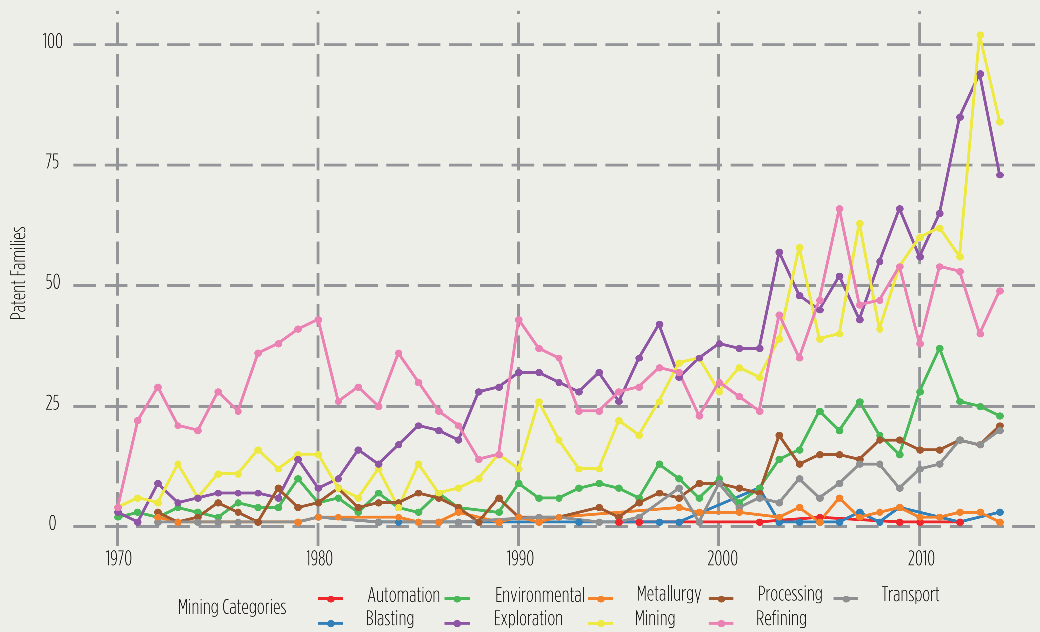


Source: Authors' elaboration based on PATSTAT database.

Figure 19. Mining Share of Total Patent Families, Latin America, 1970–2014

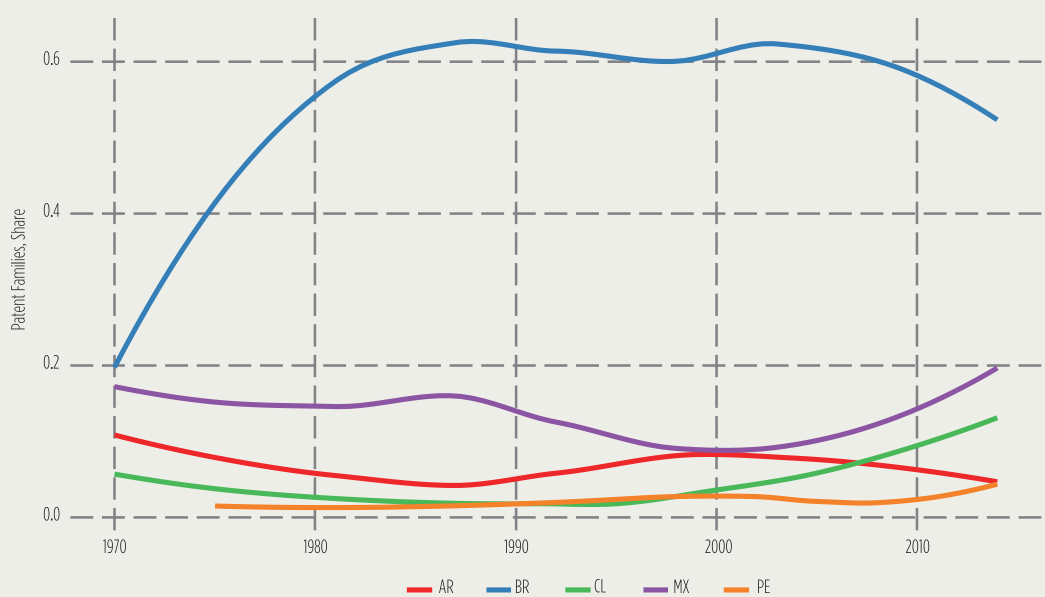
Source: Authors' elaboration based on PATSTAT database.

Figure 20. Growth of Mining Technologies in Latin America, by Subcategory, 1970–2015



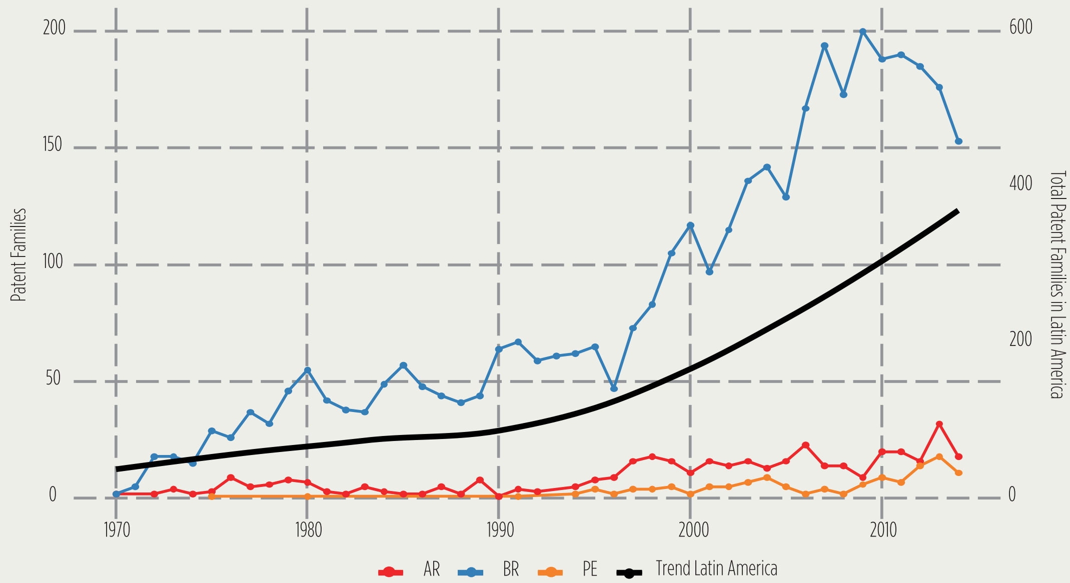
Source: Authors' elaboration based on PATSTAT database.

Figure 21. Mining Technologies: Top Five Latin American Countries of Origin, 1970–2015



Source: Authors' elaboration based on PATSTAT database.
Note: AR: Argentina; BR: Brazil; CL: Chile; MX: Mexico; PE: Peru.

Figure 22. Growth in Mining Technology Patent Families: Brazil, Argentina, Peru, and Latin America, 1970–2014

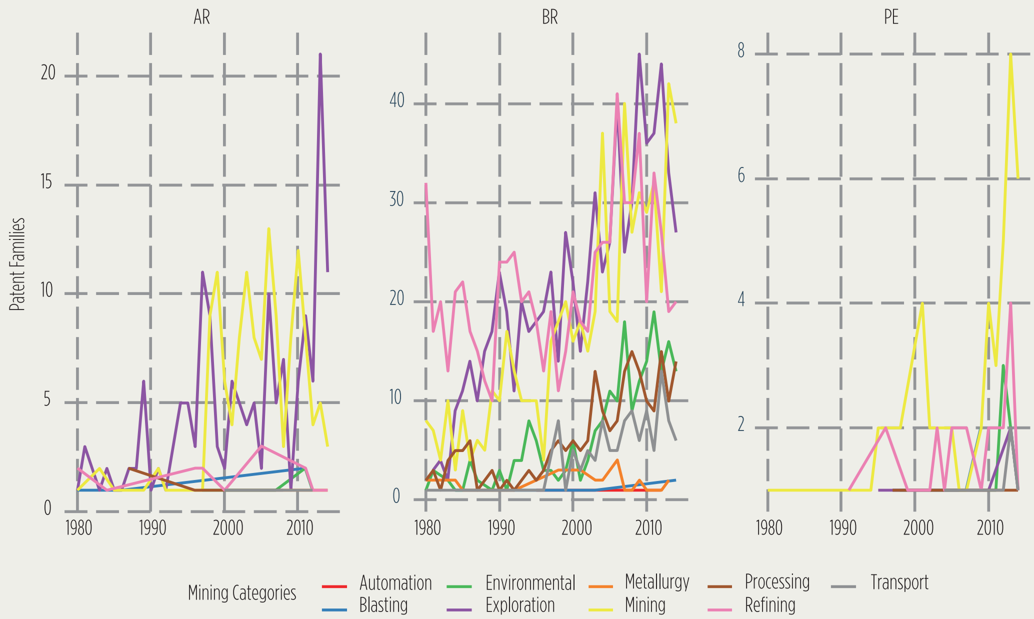


Source: Authors' elaboration based on PATSTAT database.
Note: AR: Argentina; BR: Brazil; PE: Peru.

Figure 23. Mining Share of Total Patent Families in Brazil, Argentina, and Peru Combined, 1970–2014

Source: Authors' elaboration based on PATSTAT database.

Figure 24. Growth of Mining Technologies, by Subcategory, Argentina, Brazil, and Peru, 1980–2014



Source: Authors' elaboration based on PATSTAT database.
Note: AR: Argentina; BR: Brazil; PE: Peru.

The simple counting of patent families in mining technologies provides a reliable instrument to quantify the efforts made by countries on technological advancements in the mining sector and their historical evolution. To obtain a clearer representation of the intensity of knowledge development in the mining sector, we constructed an indicator that complements patent counting with National Accounts.

First, we collected data from the United Nations' *National Accounts Statistics: Main Aggregates and Detailed Tables* database,[6] which provides the sectoral breakdown of GDP (according to the ISIC Rev. 3.1 industrial classifications) for all countries, at constant 2010 U.S. dollars. Second, we selected the gross value added in the mining and utilities sector (ISIC C and E),[7] expressed in constant millions of dollars, for each country from 1970 to 2014. Then, we used the production in mining series to weight the number of mining-related technologies.

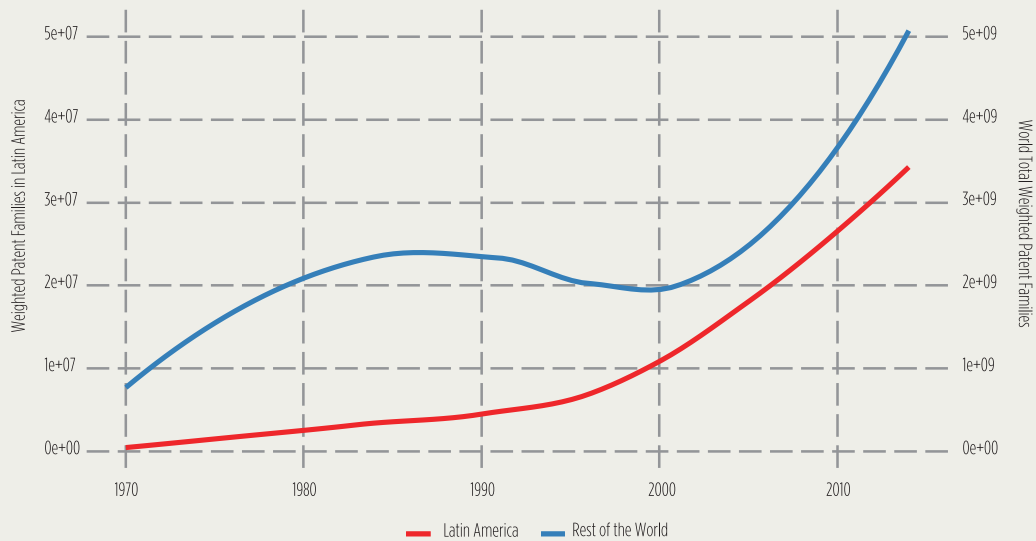
Figure 25 plots the growth in weighted patent families in Latin American countries compared with the rest of the world. The figure shows that with production-weighted patents, the patterns evident in Figure 18 are possibly more pronounced. In contrast, while the overall trend is increasing, the rest of the world (blue line) experienced a decline during the early 1990s, followed by a steep increase from the 2000s onward. Knowledge in the mining sector in Latin America grew at an almost

6 Available at https://unstats.un.org.

7 To be precise, the UN database provides a series for manufacturing (ISIC D) and one for mining, manufacturing, and utilities (ISIC C-E). Our series on mining and utilities is therefore obtained by subtraction.

exponential rate throughout the study period, with strong acceleration from the mid-1990s until 2015, thus anticipating world growth. This evidence suggests that the worldwide upturn observed in the 1990s was driven by innovation efforts in Latin America.

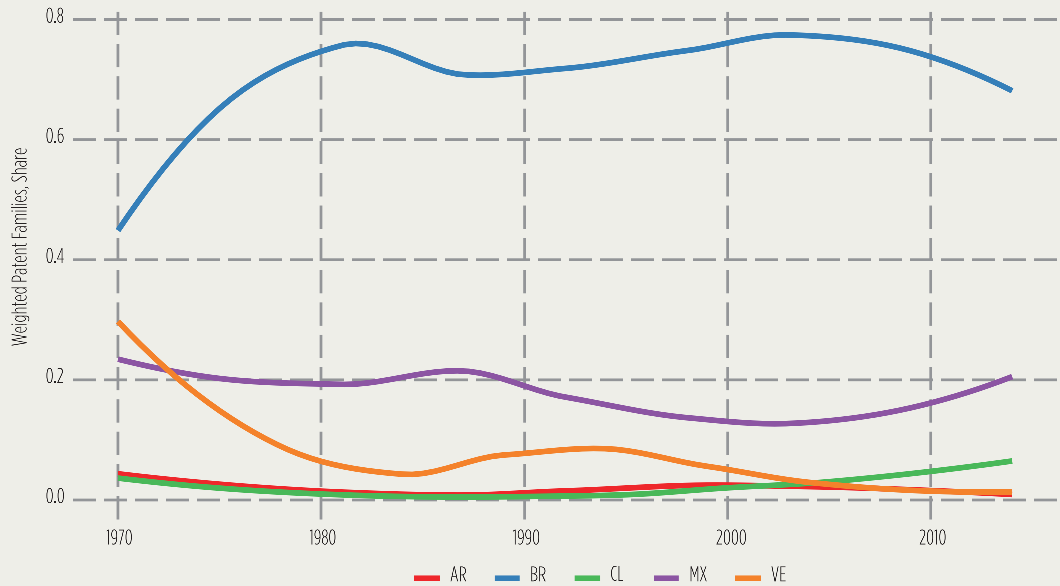
Figure 25. Mining-Related Patent Families Weighted by Millions of Dollars of Production, Mining and Utilities Sector, Latin America and Rest of the World, 1970–2015



Source: Authors' elaboration based on PATSTAT database.

Exploiting the weighted indicator, we also look more closely at Latin America by focusing on its top five countries in terms of mining knowledge concentration. The share of production-weighted patent families of these countries is reported in Figure 26. The figure confirms the predominant role played by Brazil (blue line). Together with Brazil, Mexico, Argentina, and Chile, Venezuela is among the top Latin America countries (orange line). Interestingly, Venezuela accounted for a significant share of Latin American mining innovation until the mid-1990s, when it started experiencing a very sharp decline.

Figure 26. Mining-Related Patent Families Weighted by Millions of Dollars of Production, Mining and Utilities Sector, Top Five Latin America Countries of Origin, 1970–2015



Source: Authors' elaboration based on PATSTAT database.
Note: AR: Argentina; BR: Brazil; CL: Chile; MX: Mexico; VE: Venezuela.

Mapping the Knowledge Base in Mining Technologies

The WIPO database is highly useful in that it allows the establishment of a link between technological and industrial classification. Patents related to the mining sector can be identified based on this source, but the information provided in this dataset is limited to the country of the applicant, identification of the applicant and the inventors, and the date of application. These variables are useful to gain insights into the rate of technological change in the mining sector, as shown by Daly, Valacchi, and Raffo (2019) and by the analysis in the previous section. However, this evidence does not allow us to formulate hypotheses about the direction of technological change, which can instead be understood by looking at the evolutionary patterns of the sector's knowledge base over the period under study (Krafft, Quatraro, and Saviotti, 2011, 2014).

To determine the sector's knowledge base, we needed to rely on data about citations and the technological classes of patents. We used the European Patent Office's PATSTAT database[8] because it enables matching with the WIPO mining patents database and provides all information contained in patent documents. By exploiting the technological classification in patent documents, a large stream of literature on geography and innovation provided several empirical measures of the relationship between technologies. Recently, such measures have also been used to develop global maps of the knowledge base, which can provide valuable information about promising re-

8 See https://www.epo.org/searching-for-patents/business/patstat.html for more information.

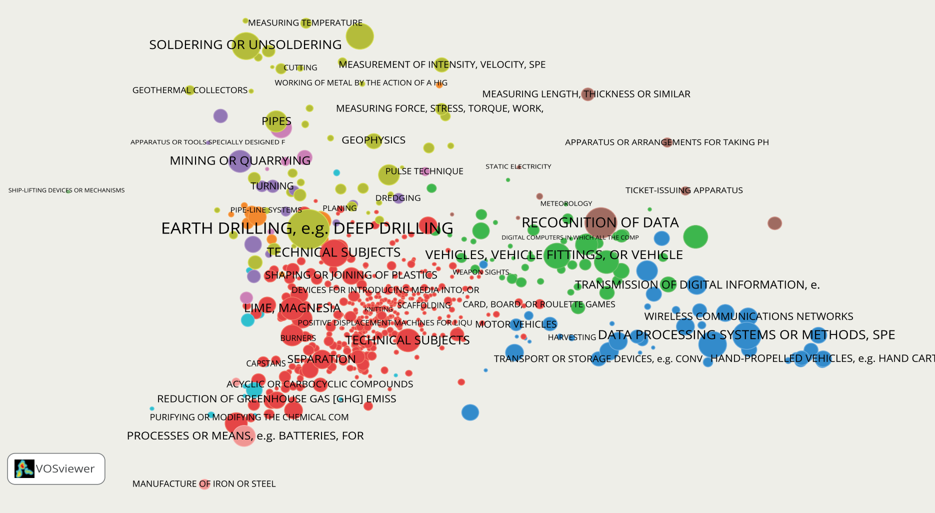
search areas and the positioning of specific units of analysis, like firms, regions, or countries. Visual evidence is presented in Figures 27 to 30 of the evolutionary patterns in the structure of the mining knowledge base and the relationship between knowledge and geography.

Technological proximity can be measured in several ways, each reflecting slightly different views of how technologies are related. This report uses technology classes as revealed by the patents' backward citations. Given that backward citations reveal prior art, this proximity measure is based on the concept that if two classes are often cited together in patent documents, they possess some degree of relatedness. As a first step, we matched mining patent families identified by WIPO data to those applications' corresponding record in the PATSTAT global database (spring 2019 edition). We were able to extrapolate all the citations made by the focal (mining) patents and the corresponding technology classes to which cited patents are assigned. We then obtained our co-citation-based proximity measure by counting the number of times two technology classes appeared together in the backward citation of mining patents from 1970 to 2014.

The resulting symmetric matrix of proximities among technologies can be seen as a network adjacency matrix where technologies represent the nodes and their proximities measure the strength of their links. In this way, the matrix can be plotted using network analysis techniques, providing a visual representation of a knowledge base.

Figure 27 shows the global map of the knowledge base behind mining patent families from 1970 to 2014. The size of the nodes is proportional to the overall number of citations received by the technology class. Node color identifies membership of technologies in empirically derived technology clusters. In Figure 27, eight clusters are identifiable. The two most central clusters, representing the core of the mining knowledge base, are identified by red and yellow nodes and are related mainly to earth drilling, physical process, and product technologies (e.g., pipes). It is worth noting that mining knowledge relies heavily on data recognition, data processing, and measurement technologies (the blue, brown, and green clusters), though these clusters are slightly farther away from the core.

Figure 27. Global Mining Knowledge Base, 1970–2014



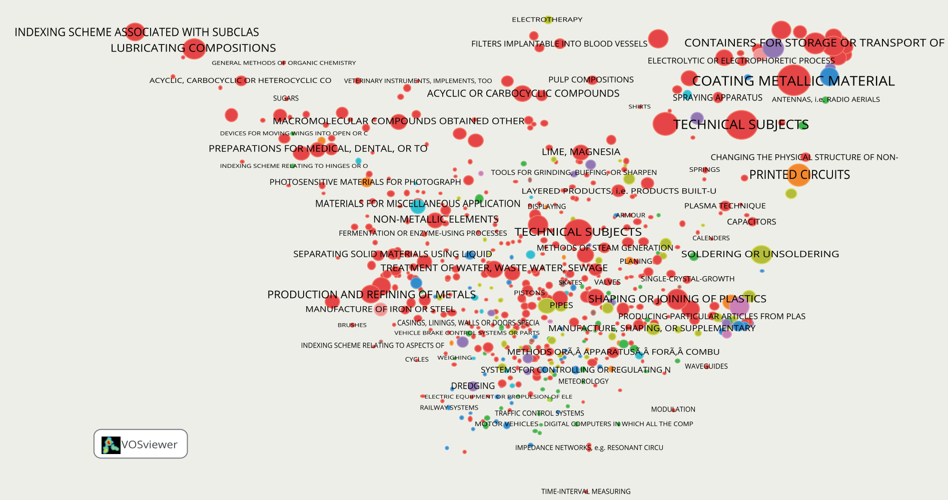
Source: Authors' elaboration based on PATSTAT database.

The global map of the mining knowledge base over the past 40 years provides a useful representation of the key sources of knowledge for innovation in the mining sector. To identify potential emerging technological domains and map the evolutionary patterns of the structure of the mining knowledge base, we calculated the technological proximity behind mining technologies at three points in time: (i) at the beginning of our sample, from 1970 to 1975 (Figure 28), (ii) from 1990 to 1995 (Figure 29), and (iii) from 2009 to 2014 (Figure 30). As in Figure 27, node size is proportional to the number of citations received by the technology class, and nodes are colored on the basis of technology clusters identified in the global map. For clarity, in Table 6 we report the most central technologies (in terms of link strength) for each cluster, according to cluster color.

The mining knowledge base from 1970 to 1975 (Figure 28) relied heavily on physical and chemical processes, as well as on materials. During 1990–95, the mining knowledge base was notably sparse, with the appearance of large clusters related to data recognition, vehicles, and transmission technologies (brown and green) and to semiconductors (orange in Figure 29). The most recent map of the mining knowledge base (2009–14; Figure 30) somewhat resembles the global map while being relatively sparse. It is characterized by the presence of two large clusters of data recognition and processes and materials related technologies, together with integrated climate change mitigation technologies related to energy.

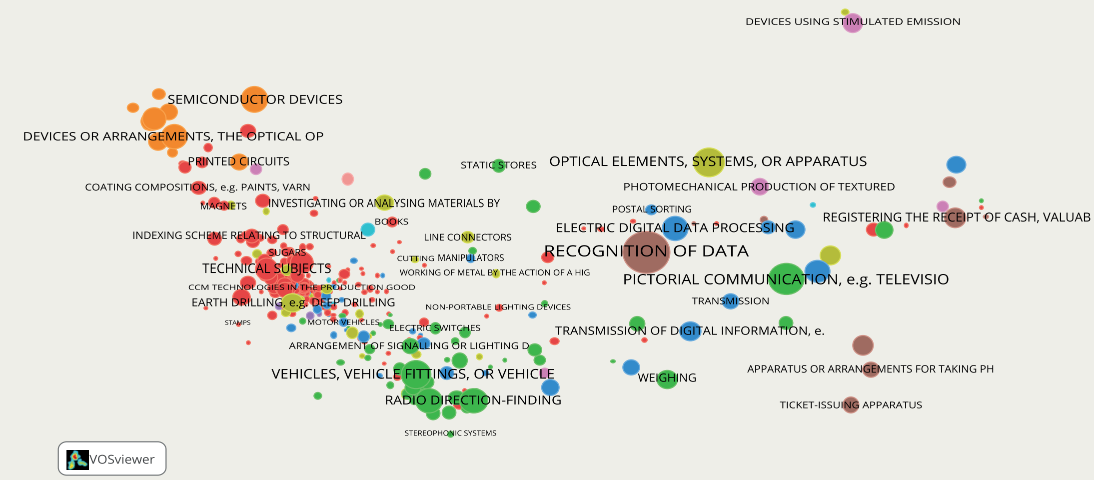
This evidence reflects recent ongoing, and to some extent interlinked, trends in innovation efforts in the mining sector. This reflects, on one hand, the so-called digital transformation of mining activities, and, on the other hand, the increasing attention to mining's environmental impact. Digital transformation, and the related gains in terms of increased efficiency and optimal exploitation of production resources, emerged as a response to changed economic conditions, particularly the decrease of commodity prices. Valacchi et al. (2019) showed that this trend is associated with an increase in innovation efforts in the mining sectors. The evidence provided here suggests that Schumpeterian dynamics of creative response (Schumpeter, 1947) are directed toward the expansion of the sectoral knowledge base, aiming at hybridizing mature and advanced (digital) technologies.

Figure 28. Global Mining Knowledge Base, 1970–75



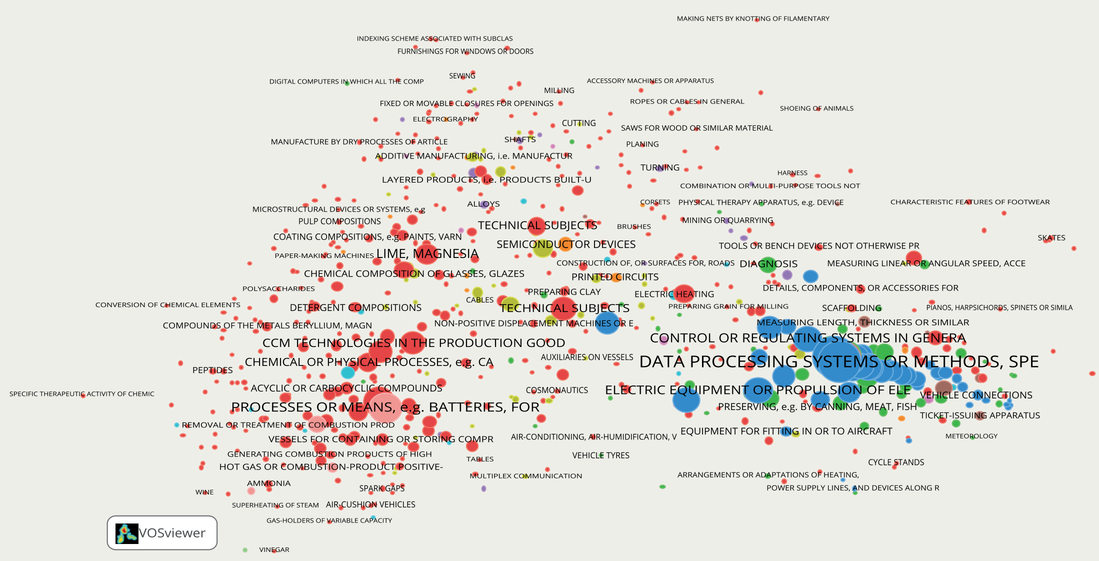
Source: Authors' elaboration based on PATSTAT database.

Figure 29. Global Mining Knowledge Base, 1990–95



Source: Authors' elaboration based on PATSTAT database.

Figure 30. Global Mining Knowledge Base, 2009–14



Source: Authors' elaboration based on PATSTAT database.

Table 6. Top Technologies in Global Mining Knowledge Base, by Cluster

Cluster Color	Technology	Cluster Color	Technology
Red	Technical subjects	Purple	Tools for grinding, buffing, or sharpening
Red	Lime, magnesia	Purple	Shafts
Red	Climate Change Mitigation technologies in the production of goods	Purple	Other metalworking
Red	Chemical or physical processes, e.g. catalysis or colloid chemistry	Light blue	Cracking hydrocarbon oils
Red	Nonmetallic elements	Light blue	Electric heating
Red	Materials for miscellaneous applications not provided for elsewhere	Light blue	Reclamation of contaminated soil
Red	Separation	Light blue	Modifying the physical structure of ferrous metals
Red	Reduction of greenhouse gas emissions	Light blue	Nuclear reactors
Green	Vehicles, vehicle fittings, or vehicle parts	Light blue	Launching, hauling-out, or dry-docking of vessels
Green	Radio direction-finding	Light blue	Capstans
Green	Pictorial communication, e.g. television	Light blue	Systems for regulating electric or magnetic variables
Green	Seats specially adapted for vehicles	Orange	Semiconductor devices
Green	Diagnosis	Orange	Devices or arrangements, the optical operation of which is modified by changing the optical properties
Green	Traffic control systems	Orange	Arrangements or circuits for control of indicating devices
Green	Signaling or calling systems	Orange	Printed circuits
Green	Time or attendance registers	Orange	Displaying
Blue	Data processing systems or methods	Orange	Electrography
Blue	Systems for controlling or regulating nonelectric variables	Orange	Organic dyes or closely related compounds for producing dyes
Blue	Electric digital data processing	Orange	Measurement of nuclear or x-radiation
Blue	Transmission of digital information, e.g. telegraphic communication	Brown	Recognition of data
Blue	Electric equipment or propulsion of electrically propelled vehicles	Brown	Registering the receipt of cash, valuables, or tokens
Blue	Wireless communications networks	Brown	Measuring length, thickness, or similar linear dimensions
Blue	Climate Change Mitigation technologies related to transportation	Brown	Apparatus or arrangements for taking photographs or for projecting or viewing them
Blue	Image data processing or generation, in general	Brown	Ticket-issuing apparatus
Yellow	Earth drilling, e.g. deep drilling	Brown	Static electricity
Yellow	Soldering or unsoldering	Brown	Saddles
Yellow	Optical elements, systems, or apparatus	Pink	Devices using stimulated emission
Yellow	Pipes	Pink	Photomechanical production of textured or patterned surfaces
Yellow	Investigating or analyzing materials by determining their chemical or physical properties	Pink	Electric discharge tubes or discharge lamps
Yellow	Geophysics	Pink	X-ray technique
Yellow	Manufacture, shaping, or supplementary processes	Pink	Pulse technique
Yellow	Foundations	Pink	Techniques for handling particles or ionizing radiation
Purple	Mining or quarrying	Pink	Producing a reactive propulsive thrust not otherwise provided for

Table 6. Top Technologies in Global Mining Knowledge Base, by Cluster *(continued)*

Cluster Color	Technology	Cluster Color	Technology
Purple	Working metallic powder	Light red	Processes means (e.g., batteries) for the direct conversion of chemical into electrical energy
Purple	Working stone or stone-like materials	Light red	Manufacture of iron or steel
Purple	Turning	Light red	Hot gas or combustion-product positive-displacement engine plants
Purple	Alloys	Light red	Boiling

Source: Authors' elaboration based on PATSTAT database.

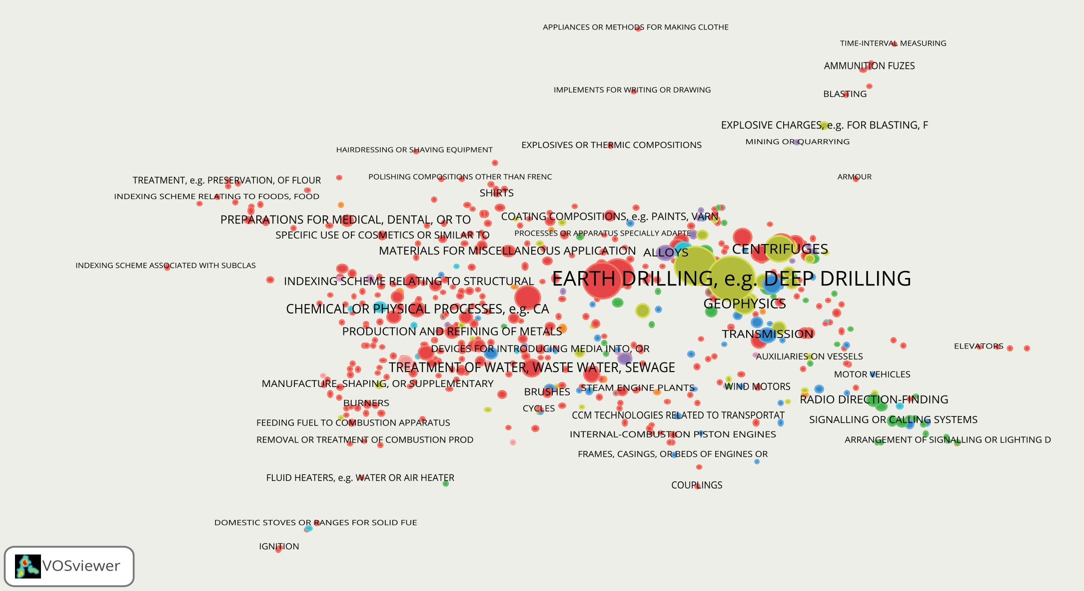
Mapping the Mining Knowledge Base in Latin America

Knowledge proximity

This section develops the maps of the knowledge base in mining technologies for Latin American countries, with a focus on Argentina, Brazil, and Peru and their relative positioning compared with the rest of Latin America and the world.

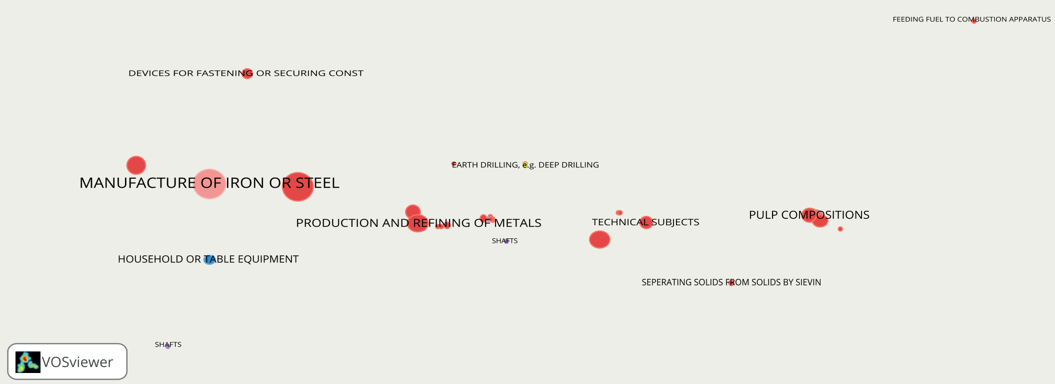
To construct the knowledge base map, we relied on the same procedure used in the previous section. Figure 31 is the map of the knowledge base behind mining patent families in Latin America from 1970 to 2014. The map reveals that in Latin America, innovative efforts in mining technologies are related predominantly to pure mining and exploration, earth drilling and deep drilling in particular, as shown by the largeness of the nodes in the yellow cluster. The wide spread of the red cluster suggests that Latin American mining knowledge also includes technologies related to manufacturing and processes, though mainly related to manufacturing and refinement of basic metals such as iron or steel.

Figure 31. Mining Knowledge Base, Latin America, 1970–2014



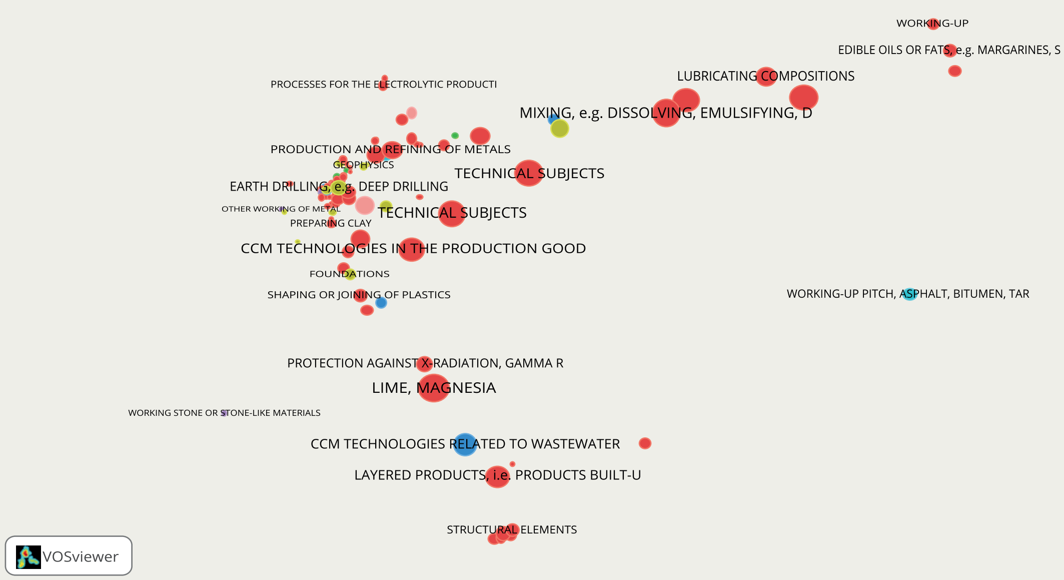
Source: Authors' elaboration based on PATSTAT database.

Figure 32. Mining Knowledge Base, Latin America, 1970–75



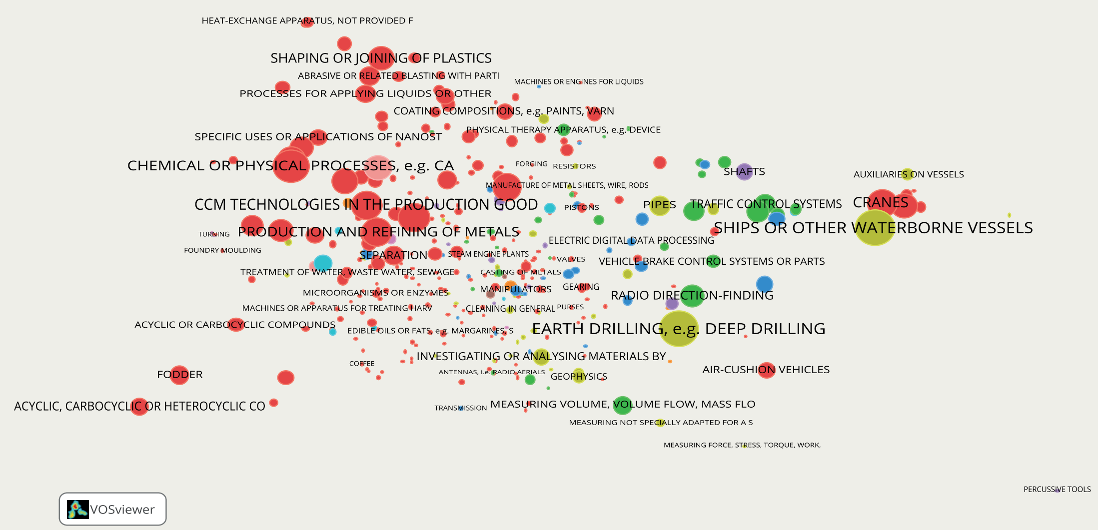
Source: Authors' elaboration based on PATSTAT database.

Figure 33. Mining Knowledge Base, Latin America, 1990–95



Source: Authors' elaboration based on PATSTAT database.

Figure 34. Mining Knowledge Base, Latin America, 2009–14



Source: Authors' elaboration based on PATSTAT database.

As for the global mining knowledge space, mapping the mining knowledge base over the past 40 years provides a useful representation of the key sources of knowledge for innovation in the mining sector. Mapping does not, however, allow identification of the evolutionary patterns of the structure of the mining knowledge base and potential emerging technological domains. We therefore calculated the technological proximity behind mining technologies in Latin America at the beginning of our sample period, from 1970 to 1975 (Figure 32); from 1990 to 1995 (Figure 33); and from 2009 to 2014 (Figure 34).

The map of the mining knowledge base from 1970 to 1975 (Figure 32) shows that, in line with the evidence shown in Figure 18 on the growth of mining patent families, very few innovative activities in mining were taking place in Latin America in the early 1970s. The knowledge base was relatively small and highly concentrated around a small number of technologies related to producing and manufacturing metals.

Twenty years later, in 1990–95, technological mining activities in Latin America started to gain momentum. As shown by the appearance of the yellow nodes in Figure 33, such innovative efforts were increasingly directed toward earth/deep drilling and pipe-related technologies, which constitute the bulk of the overall mining knowledge base in these countries. This trajectory is confirmed by looking at the most recent knowledge map (Figure 34), which shows more and more patents drawing knowledge from pure mining-related technologies. Interestingly, the 2009–14 map shows that only recently did Latin America start to increasingly develop mining technologies related to processing (such as chemical processes), with a focus on sustainability (i.e., climate change mitigation technologies related to good production). Details on the top technologies for each cluster are reported in Table 7.

Table 7. Top Technologies in Latin America Mining Knowledge, by Cluster

Cluster color	Technology	Cluster color	Technology
Blue	Transmission of digital information, e.g. telegraphic communication	Orange	Displaying
Blue	Transmission	Orange	Articles for writing or drawing upon
Blue	Climate Change Mitigation technologies related to wastewater treatment or waste management	Orange	Organic dyes or closely related compounds for producing dyes
Blue	Data processing systems or methods	Pink	Electric discharge tubes or discharge lamps
Blue	Vehicle wheels	Pink	Photomechanical production of textured or patterned surfaces
Blue	Electric digital data processing	Pink	Devices using stimulated emission
Blue	Handling thin or filamentary material, e.g. sheets, webs, or cables	Pink	Pulse technique
Brown	Measuring length, thickness, or similar linear dimensions	Pink	Techniques for handling particles or ionizing radiation
Brown	Recognition of data	Pink	X-ray technique
Brown	Static electricity	Purple	Alloys
Brown	Registering the receipt of cash, valuables, or tokens	Purple	Other metalworking
Green	Antennas, i.e. radio aerials	Purple	Shafts
Green	Radio direction-finding	Purple	Construction of, or surfaces for, roads, sports grounds
Green	Vehicle suspension arrangements	Purple	Working metallic powder
Green	Measuring volume, volume flow, mass flow, or liquid level	Purple	Machines, devices, or processes for grinding or polishing
Green	Signaling or calling systems	Purple	Mining or quarrying
Green	Vehicles, vehicle fittings, or vehicle parts	Red	Technical subjects
Light blue	Modifying the physical structure of ferrous metals	Red	Shaping or joining of plastics
Light blue	Cracking hydrocarbon oils	Red	Sewers
Light blue	Launching, hauling-out, or dry-docking of vessels	Red	Working or processing of sheet metal or metal tubes, rods, or profiles
Light blue	Reclamation of contaminated soil	Red	Relating to textiles
Light blue	Working up pitch, asphalt, bitumen, or tar	Red	Treatment of water, waste water, sewage, or sludge
Light blue	Electric heating	Red	Chemical or physical processes, e.g. catalysis or colloid chemistry
Light blue	Nuclear reactors	Red	Lubricating compositions
Light blue	Methods or apparatus for combustion using only solid fuel	Yellow	Earth drilling, e.g. deep drilling
Light red	Manufacture of iron or steel	Yellow	Pipes
Light red	Processes or means, e.g. batteries, for the direct conversion of chemical into electrical energy	Yellow	Centrifuges
Light red	Hot gas or combustion-product positive-displacement engine plants	Yellow	Geophysics
Light red	Boiling	Yellow	Measuring temperature
Orange	Semiconductor devices	Yellow	Ships or other waterborne vessels
Orange	Printed circuits	Yellow	Investigating or analyzing materials by determining their chemical or physical properties
Orange	Measurement of nuclear or x-radiation	Yellow	Rotary-piston, or oscillating-piston, positive-displacement machines for liquids
Orange	Photosensitive materials for photographic purposes		

Source: Authors' elaboration based on PATSTAT database.

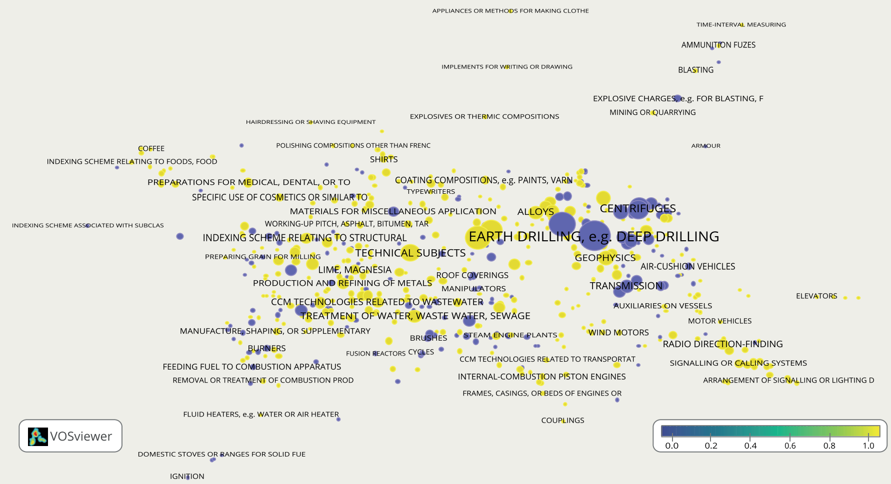
To explore the relative positioning of the three focus countries in terms of mining knowledge capabilities, we turn to the concept of revealed technological advantage (RTA). Often referred to as location quotient or the Balassa index (when using industry data), the RTA provides an indication of the relative specialization of a given country in selected technological domains. It is calculated as the ratio of the share of a given technology in a country's patent citation portfolio to the share of the same technology in a larger set of countries (e.g., Latin American countries or World). The RTA equals 1 when the country's share in the technology equals its share in the overall economy. An RTA greater than 1 indicates a relative specialization. To ease the visual representation of the index, we dichotomized countries' RTAs: equal to 1 when it is greater than 1 (signaling the presence of specialization) and equal to 0 when it is smaller than 1 (indicating no specialization).

We calculated the RTAs of Argentina, Brazil, and Peru in mining-related technologies compared with Latin America and the world. Figure 35 combines the knowledge base map of mining patent families in Brazil, Argentina, and Peru with the Latin American knowledge base from 1970 to 2014. Yellow nodes represent technologies in which the three countries show a relative specialization compared to the rest of Latin America, while violet nodes indicate technologies in which the share of the three countries is lower than that of Latin America as a whole. The map reveals that the relative predominance of drilling and exploration related technologies in Latin America does not depend on specialization by Argentina, Brazil, and Peru. The three countries, however, seem to specialize mainly in pipes, manufacturing materials, and processes, in relation to Latin America.

Figure 36 shows Argentina, Brazil, and Peru's position in the global knowledge base. As in Figure 35, yellow nodes represent technologies in which these countries show a relative specialization compared with the rest of the world. In relation to the global mining knowledge base, Argentina, Brazil, and Peru seem to specialize mainly in pipes, manufacturing materials, and processes (as they do in relation to Latin America). However, while these countries are not specialized in earth drilling and pure mining technologies compared with Latin America, they do show relative specialization in such technologies in relation to the rest of the world.

Figures 37, 38, and 39 offer a closer look at the relative specialization of the three focus countries by comparing them individually with the global map. The figures show that Brazil plays a leading role in Latin America in the development of mining technologies, as highlighted by the high number of technologies in which Brazil shows a relative technological specialization (Figure 37). Many of Brazil's specializations are shared by Argentina, which, despite its limited number of mining patent families, shows specialization in key technologies for Latin America, such as earth/deep drilling and pipes (Figure 38). Peru, however, seems to be slightly behind the other two focus countries. Still, it shows relative specialization in quite a few technologies, though mainly related to simple mining and quarrying technologies (Figure 39).

Figure 35. Brazil, Argentina, and Peru's Positioning in Latin America Based on Revealed Technological Advantage, 1970–2014

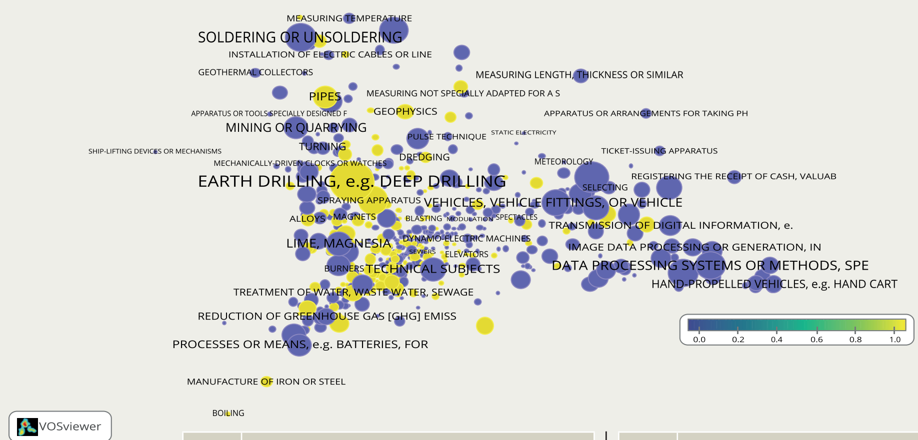


RTA	Top Technology
0	Earth drilling, e.g. deep drilling
0	Pipes
0	Centrifuges
0	Sewers
0	Working or processing of sheet metal or metal tubes, rods, or profiles

RTA	Top Technology
1	Shaping or joining of plastics
1	Technical subjects
1	Geophysics
1	Relating to textiles
1	Treatment of water, waste water, sewage, or sludge

Source: Authors' elaboration based on PATSTAT database.

Figure 36. Brazil, Argentina, and Peru's Positioning in Global Knowledge, Based on Revealed Technological Advantage

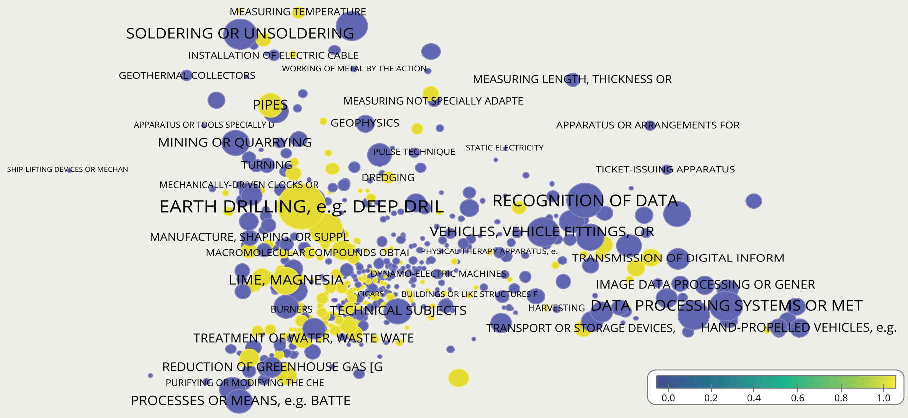


RTA	Top Technology
0	Recognition of data
0	Soldering or unsoldering
0	Data processing systems or methods
0	Optical elements, systems, or apparatus
0	Vehicles, vehicle fittings, or vehicle parts
1	Earth drilling, e.g. deep drilling

RTA	Top Technology
1	Technical subjects
1	Pipes
1	CCM technologies in the production goods
1	CCM technologies related to wastewater treatment or waste management

Source: Authors' elaboration based on PATSTAT database.

Figure 37. Brazil's Positioning in Global Knowledge, Based on Revealed Technological Advantage

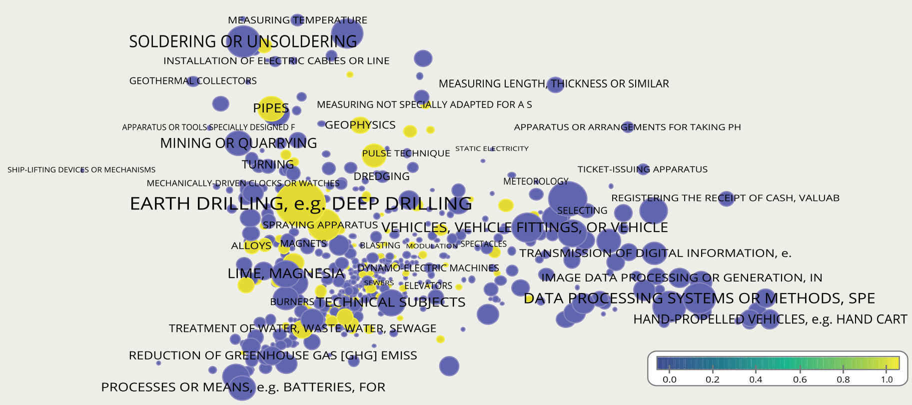


RTA	Top Technology
0	Recognition of data
0	Soldering or unsoldering
0	Data processing systems or methods
0	Vehicles, vehicle fittings, or vehicle parts
0	Mining or quarrying

RTA	Top Technology
1	Earth drilling, e.g. deep drilling
1	Technical subjects
1	Lime, magnesia
1	Pipes
1	CCM technologies in the production goods

Source: Authors' elaboration based on PATSTAT database.

Figure 38. Argentina's Positioning in Global Knowledge, Based on Revealed Technological Advantage

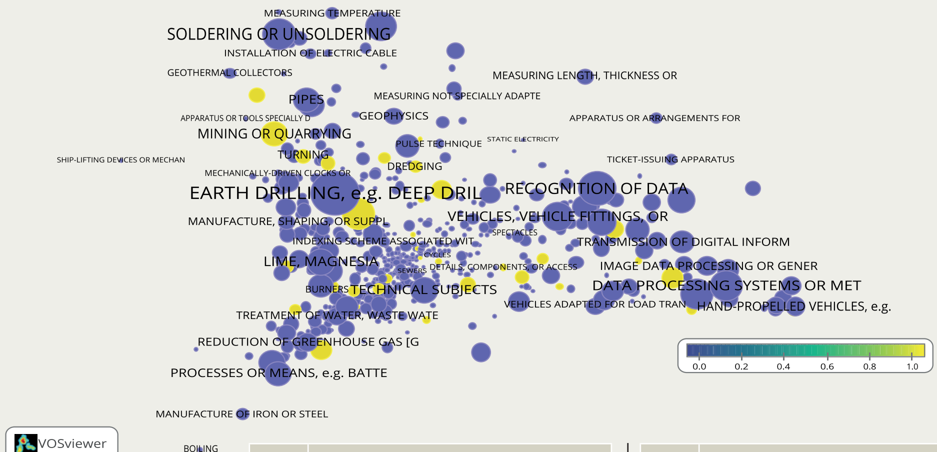


RTA	Top Technology
0	Recognition of data
0	Soldering or unsoldering
0	Data processing systems or methods
0	Systems for controlling or regulating nonelectric variables
0	Lime, magnesia
1	Earth drilling, e.g. deep drilling

RTA	Top Technology
1	Technical subjects
1	Pipes
1	Investigating or analyzing materials by determining their chemical or physical properties
1	Treatment of water, waste water, sewage, or sludge

Source: Authors' elaboration based on PATSTAT database.

Figure 39. Peru's Positioning in Global Knowledge, Based on Revealed Technological Advantage



RTA	Top Technology
0	Earth drilling, e.g. deep drilling
0	Recognition of data
0	Soldering or unsoldering
0	Data processing systems or methods
0	Systems for controlling or regulating non-electric variables

RTA	Top Technology
1	Technical subjects
1	Mining or quarrying
1	Control or regulating systems in general
1	CCM technologies in the production goods
1	Signaling or calling systems

Source: Authors' elaboration based on PATSTAT database.

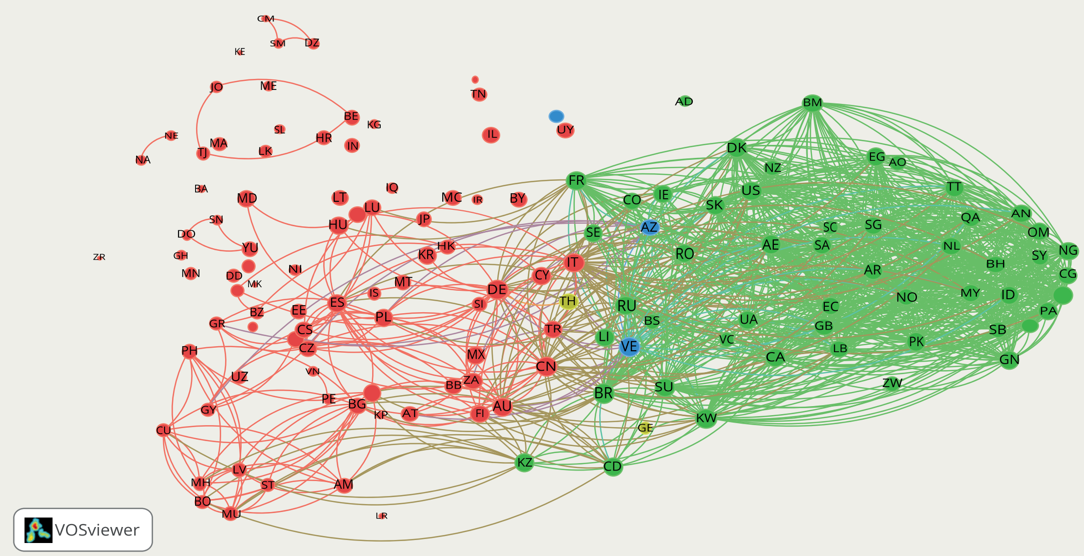
Country proximity

The identification of technological classes related to mining knowledge production in the patent citation portfolio of countries allowed us to build an overview of the main sources of technological knowledge that enable innovative advancements in the mining sector. Using the co-relational structure of knowledge reduced the bipartite network of patents in countries and cited technologies to a one-mode network of technologies. These technologies represent the nodes of the network and their links are revealed by the co-citation of the technologies in patent documents. However, the bipartite network can also be reduced to a network in which countries are the nodes, linked by the similarity of technologies from which they are drawing their knowledge.

In this report, to measure countries' technological proximity we calculated the cosine similarity between vectors of occurrence of technology classes in countries' patent citations. In this way, the more two countries cite technological classes in a similar way, the more proximate they are.

Figure 40 presents the map of similarity in the mining knowledge base among all world countries from 1970 to 2014. Nodes size is proportional to the number of different technology classes in a country's patent citation portfolio. Nodes are colored according to the identified clusters of countries. Two large clusters are clearly identifiable: a highly connected green one and a sparser red one. It is also worth noting the presence of two very small clusters (yellow and blue), which seem to play mainly a bridging role, positioned in the intersection of the two large clusters. Interestingly, two of our focus countries, Argentina and Brazil, belong to the green cluster, with Argentina also connected to the red cluster, while Peru, in the red cluster, is poorly connected.

Figure 40. Brazil's, Argentina's, and Peru's Proximity in Mining Technologies, 1970–2014



Source: Authors' elaboration based on PATSTAT database.

Scientific publication in the mining sector

Recent research suggests that mapping scientific production may provide an interesting depiction of knowledge flows in specific scientific domains. To perform this task, we used scientific publication data and related information extracted from the Web of Science Core Collection platform (version 5.32).[9] Publications related to the mining sector were identified by applying a specific research query to titles, abstract, and keywords.[10] The search strategy retrieved 1,760 scientific publications related to mining covering the period 1985 to 2018.

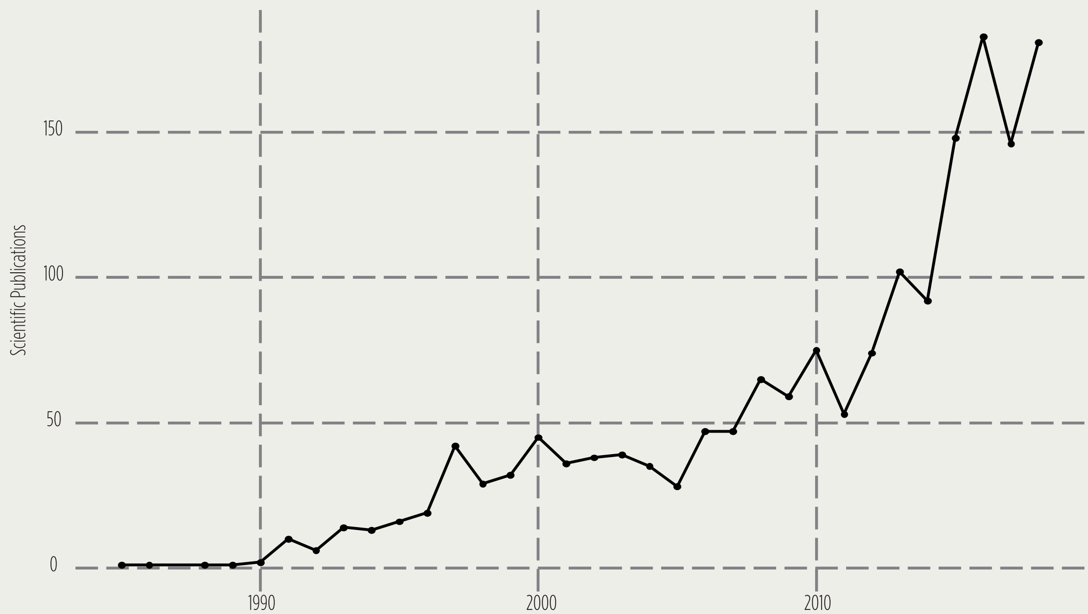
Scientific investigation

Figure 41 plots the annual number of scientific publications in the mining sector from 1985 to 2018. The figure shows that the number of publications related to mining steadily increased over time, though with some fluctuations. Interestingly, scientific publication experienced a steep increase from 2005, in line with the evolution of mining patent families presented in Figure 13. To better understand whether this increase may suggest that mining is becoming more knowledge-intensive, we compared the growth of mining-related publications with global scientific publications. Figure 42 shows that while there has been a general increase in scientific publishing, mining publications increased at a faster pace and remained steadily above the overall rate from the early 2000s onward.

9 Information on this database is available at https://clarivate.com/webofsciencegroup/solutions/web-of-science-core-collection/.

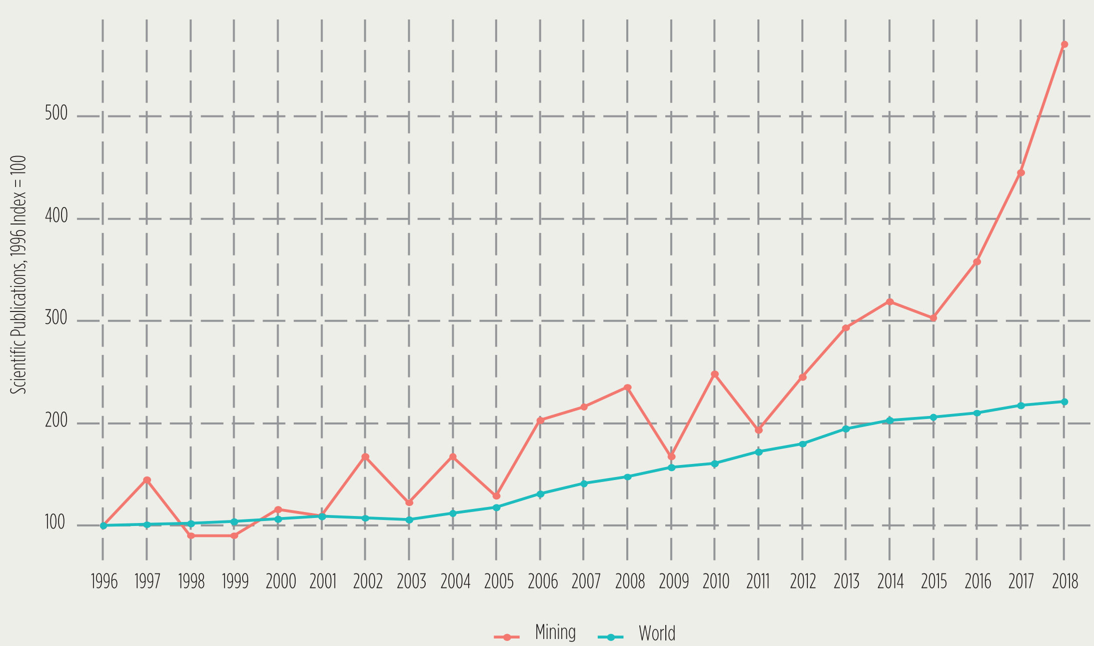
10 The search query combined a set of competence keywords related to core mining activities (mining AND quarry), excluding possible confusing topics (AND NOT data mining).

Figure 41. Growth in World Mining-Related Scientific Publishing, 1985–2018



Source: Authors' elaboration based on Web of Science database.

Figure 42. Growth in Mining-Related Scientific Publishing Compared to Total World Publishing, 1996–2018



Source: Authors' elaboration based on Web of Science database.
Note: Series index = 100 at 1996.

Web of Science also reports the country of origin of scientific publications based on the affiliation of the authors. Table 8 reports the top 20 countries ranked according to their total number of mining publications. The most active country is the United States, which accounts for almost 10 percent of global scientific publishing in the mining sector, followed by Italy (7.6 percent) and Russia (6.3 percent). Brazil is the only one of our focus countries to appear among the top 20, with 41 scientific mining publications (about 2.3 percent of the total). We extrapolated the world's 20 most active institutions publishing in mining science (Table 9).

Table 8. Top 20 Countries in Mining-Related Publishing, 1996–2018

Rank	Country	Number of Publications	Share of Total (%)
1	United States	168	9.54
2	Italy	135	7.67
3	Russia	111	6.31
4	Spain	108	6.14
5	Czech Republic	102	5.80
6	Turkey	98	5.57
7	Poland	93	5.29
8	England	92	5.23
9	Australia	86	4.89
10	Germany	80	4.55
11	China	76	4.32
12	India	63	3.58
13	France	61	3.47
14	Canada	57	3.24
15	Romania	49	2.78
16	Iran	46	2.61
17	Brazil	41	2.33
18	Ukraine	37	2.10
19	Malaysia	34	1.93
20	South Africa	31	1.76

Source: Authors' elaboration based on Web of Science database.

Table 9. Top 20 Institutions in Mining-Related Publishing, 1996–2018

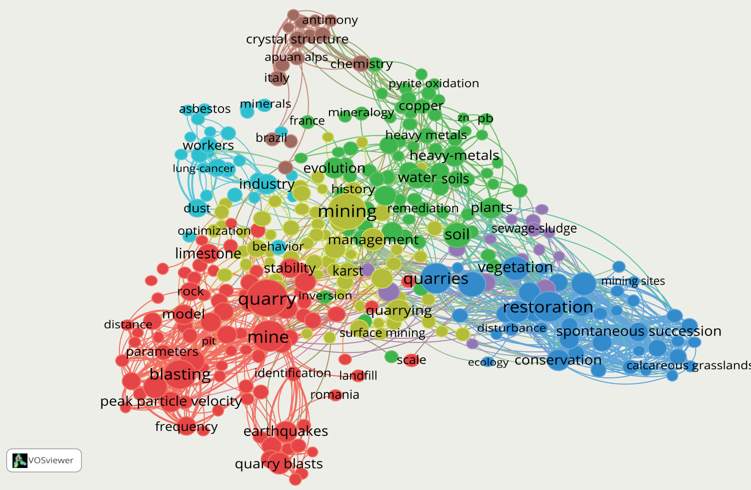
Rank	Publishing Institution	Number of Publications	Share of Total (%)
1	Russian Academy of Sciences	52	2.90
2	Technical University of Ostrava	31	1.73
3	Czech Academy of Sciences	29	1.62
4	National Center for Scientific Research (France)	24	1.34
5	Charles University Prague	20	1.12
6	National Research Council (Italy)	20	1.12
7	Islamic Azad University (Iran)	20	1.12
8	AGH University of Science Technology (Poland)	19	1.06
9	Polytechnic University of Turin	19	1.06
10	University of Technology, Malaysia	18	1.01
11	Istanbul University	17	0.95
12	Kuzbass State Technical University	16	0.89
13	University of South Bohemia, České Budějovice	16	0.89
14	Dokuz Eylül University (Turkey)	14	0.78
15	Indian Institutes of Technology	14	0.78
16	Institute of Botany of the Czech Academy of Sciences	14	0.78
17	Technical University Košice	14	0.78
18	Chinese Academy of Sciences	13	0.73
19	National Research Council (Spain)	13	0.73
20	Satbayev University (Kazakhstan)	13	0.73

Source: Authors' elaboration based on Web of Science database.

An advantage of using Web of Science as the main source of data is that, together with the collection of harmonized publication keywords, the Web of Science Core Collection provides a detailed categorization of the publications into main scientific fields. The Web of Science categorization scheme comprises 252 subject categories in science, social science, art, and humanities. Every journal and book covered by the Core Collection is assigned to at least one subject category. By using harmonized keywords and the scientific classification of publications, it is possible to develop global maps of the scientific space, which can provide valuable information about promising areas and the positioning of specific entities. As with the technology classes in patents, we built a proximity measure for keywords and subject categories and mapped them in a network. The two proximity measures are based, respectively, on the co-occurrence of keywords and the co-occurrence of subject categories in mining-related publications.

Figure 43 shows the relevance of keywords in mining publications. The size of the nodes is proportional to the number of times a keyword appears in publications. Node color identifies the empirically derived cluster a keyword belongs to. As expected, mining and quarries (and their root modifications) are the most central keywords (meaning they are the most common), supporting a correct identification of the set of publications. Two other clusters (around these main clusters) are related to materials and instruments (red and green clusters) and a blue cluster of keywords related to mining processing.

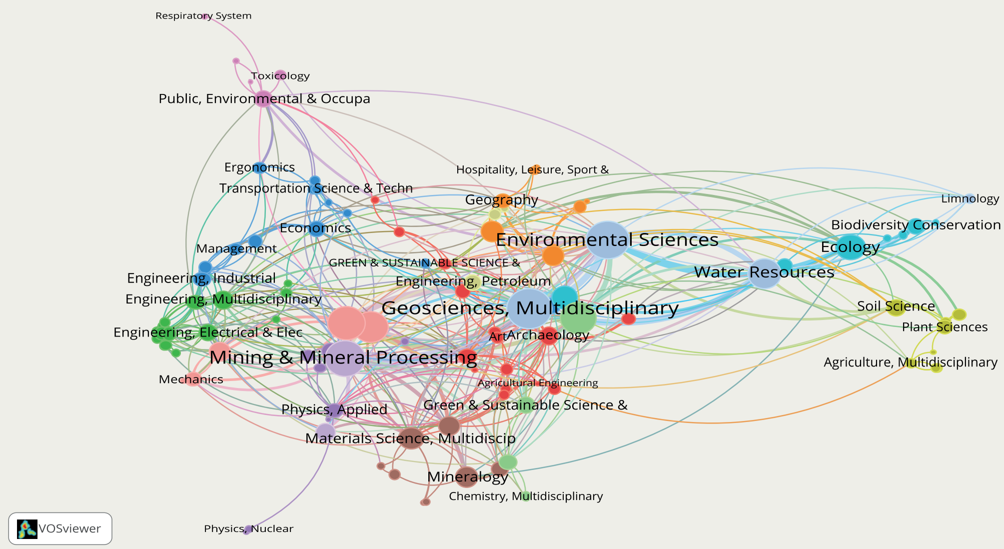
Figure 43. Worldwide Scientific Publishing in the Mining Sector, 1996–2018, by Keyword



Source: Authors' elaboration based on Web of Science database.

Figure 44 plots scientific mining publications based on subject categories. As in Figure 43, node color identifies the empirically derived clusters that keywords belong to, while the size of the nodes is proportional to the number of publications in each subject category. The core of the scientific space in the mining sector is mining and mineral processing, multidisciplinary geosciences, and environmental sciences. The core is strictly related to geological engineering, materials, water resources, and ecology sciences. It is worth noting the relevance of promising scientific research areas such as biotechnology and microbiology, biodiversity conservation, and green and sustainable science and technologies.

Figure 44. Worldwide Scientific Publishing in the Mining Sector, 1996–2018, by Web of Science Subject Category



Source: Authors' elaboration based on Web of Science database.

GENERAL CONCLUSIONS

The analysis carried out in this study allows us to draw some critical conclusions about the characteristics and challenges of the mining GVCs in Argentina, Brazil, and Peru.

A preliminary general consideration concerns the need to use fresh data to get an overall picture of mining GVCs. Once we acknowledge the importance of mining as a pivotal sector in the current wave of production fragmentation, we should also acknowledge the unavailability of detailed information at the international level about the value of mining and its related manufacturing and services activities embedded in global production. But despite the recent efforts of international agencies (e.g., the OECD and the WTO) at the aggregate level, we are not yet able to provide a more granular identification of the value added produced, exported, and absorbed by each country in the world for each of the most important products that make up the mining sector. The same is true for mining-related services. This gap implies a structural barrier to the improvement of knowledge in the field, and we should promote general reflection about fostering high-quality mining data among scholars, policymakers, companies, and international agencies.

A second general remark concerns the positive global trends of the mining sector as well as the existing patterns of mining trade. On one hand, Asia's massive appetite for mining products dramatically increased exports in the entire sector. China played a pivotal role as the main global importer. On the other hand, contrary to conventional wisdom, the benefits of this increasing trend do not go primarily to developing and emerging countries but are more mixed, since most industrialized countries are listed among the top mining product exporters (e.g., the United States, Canada, and Australia). This is true because the availability of mining resources is a necessary but not a sufficient condition to become a global—or even a net—exporter in the mining sector. A country's position and participation in a given value chain largely depends on its comparative advantage and, therefore, the mix of skills and resource endowments it brings to international production.

Exporting countries need to invest in the appropriate technologies and in related services, but must also provide ad hoc policies, institutions, training, and a business environment that support the full participation of businesses in GVCs, including compliance with international standards—primarily environmental but also social and good governance activities. These are typically medium- to long-term investments that require structural transformation not only of the mining sector but also of the entire business environment. These changes also demand a new generation of economic policies able to foster the added value of international tradable inputs. Recent analyses take also benefit of new sound measures of GVC position of industries in GVCs. These measures overall seem to undermine the narrative of "upstreamness" to compete, further emphasizing the relative importance of global participation.

A third observation concerns the relative situation of Latin American countries, specifically Argentina, Brazil, and Peru, that still have limited involvement in the mining GVC. Although many Latin American countries have significant reserves of raw materials, specifically minerals, their exports of mining products are decreasing as a percentage of their GDP. Exports are aimed primarily at the regional market and China, and show a very small amount of diversification in the past decade. Furthermore, most of the value added in the mining products of the three focus countries is domestic and, consistent with the nature of the sector, is collocated upstream within the GVC (i.e., exports in the sector are used in many further stages of intermediate and final goods production). The rest of the value added produced in the three countries' mining sectors is absorbed by regional foreign markets (i.e., Latin American countries, the United States, and Canada) but mainly by China. Finally, none of the top global providers of mining services is a Latin American country.

A final general comment comes from the in-depth investigation of the dynamics of innovation in the mining sector. Our results show that overall the sheer number of patent applications increased in the late 2000s. Data about patents per millions of dollars of production show that the positive dynamics observed since the 2000s are somehow driven by innovation efforts in the Latin American countries. The increasing rate of innovation in Latin America in the mining sector has been accompanied by a change in the direction of technological evolution. Specifically, we observed an increasing weight of environmentally friendly technologies on one hand and advanced digital technologies on the other. These trends seem to be closely intertwined and linked to the need to improve efficiency and ensure optimal exploitation of resources and production factors in view of the decline in commodity prices over time.

Innovation dynamics have become more and more science-intensive over time, as shown by the dynamics of scientific publishing. In this context, out of our countries of interest, only Brazil seems to follow this trend. Overall, in Latin America, Brazil and Argentina appear to be more linked to the observed evolutionary patterns of the mining knowledge base over time, being part of a core of highly connected countries, while the other countries are poorly connected and seem to be disjointed from the observed qualitative trends. This evidence is in line with the literature, stressing the importance of trade relationships in shaping the direction of technological efforts. China's increasing attention to environment-friendly technologies seems to be a good candidate to explain Brazil's and Argentina's evolutionary trajectories in mining technologies.

Overall, these results point to the importance of demand-driven technological efforts and to the increasing importance of the open innovation mode to meet the growing need for green technological solutions. From a policy viewpoint, it will be important to create conditions that enable participation in international science and technology networks. This goal implies the need to strengthen the local knowledge base to develop innovation capabilities and improve absorptive capacity. Moreover, dedicated resources could be allocated to the promotion of collaborative innovation projects aimed at the creative adaptation of green and digital technologies to activities and processes in the mining sector.

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APPENDIX

Table 10. Mining Products in the Harmonized System (HS) Nomenclature

Section XV Base Metals and Articles of Base Metals
– 72 Iron and steel.
– 73 Articles of iron or steel.
– 74 Copper and articles thereof 75 Nickel and articles thereof.
– 76 Aluminum and articles thereof 78 Lead and articles thereof
– 79 Zinc and articles thereof. 80 Tin and articles thereof.
– 81 Other base metals; cermets; articles thereof.
– 82 Tools, implements, cutlery, spoons and forks, of base metal; parts thereof of base metal.
– 83 Miscellaneous articles of base metal.

Source: UN Trade Statistics.

The Trade in Value Added Dataset

The TiVA database[11] includes 64 countries, including seven in Latin America (Argentina, Brazil, Chile, Colombia, Costa Rica, Mexico, and Peru) for 2005–15. The database covers 36 industrial sectors and related aggregates and is based on the latest System of National Accounts (SNA08) statistics and industrial classification (ISIC Rev. 4).

The new version (December 2018) provides a better disaggregation of mining data by breaking down the "mining and quarrying" sector into the subsectors reported in Table 11.

11 https://www.oecd.org/sti/ind/measuring-trade-in-value-added.htm

Table 11. Mining Products in the Trade in Value Added Dataset

ISIC Rev. 4 Classification	Mining and Quarrying Description
D05- D06	Mining and extraction of energy producing products (coal and lignite; petroleum and natural gas)
D07- D08	Mining and quarrying of non-energy producing products (metal ores; others)
D09	Mining support service activities

Source: OECD (2018).
Note: ISIC = International Standard Industrial Classification of All Economic Activities.

Given that the mining industry uses a variety of services throughout the life of a mine, services are also considered in this analysis; they are substantial inputs into the mining sector. Services used are generally sourced domestically. However, countries such as Chile, Brazil, and Peru are among the largest countries in terms of the imports of services by the mining sector in value added terms. These flows are measured as "Mining support service activities."

By using TiVA data we can trace value addition into and out of the mining sector throughout the entire value chain. It will be possible to envisage all stages of the mining value chain by considering direct and indirect linkages between countries and sectors.

IDB