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A structural path analysis of Chilean mining linkages between 1995 and 2011. What are the channels through which extractive activity affects the economy?

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ABSTRACT

Changes in the extractive industry since the 1990s have been considered an opportunity to increase mining linkages due to the growth of outsourcing and the formation of a more complex organization of the supply chain. Using information from the Chilean input-output tables compiled by the OECD, we analyze whether or not the expected increase in mining linkages has taken place between 1995 and 2011. Furthermore, we extend the study of linkages using a Structural Path Analysis to understand how the effect of mining linkages is either transmitted to other economic activities or has a limited impact on the rest of the Chilean economy. Results show a significant reduction of mining linkages in Chile especially during the period of higher prices. At the same time, the way the influence of mining activity is transmitted to the rest of the economy through sectoral interactions is limited and lacks complexity.

1. Introduction

The promotion of linkages has become one of the main objectives of mining-based economic development strategies since the beginning of 21st century. Historically, mining had been considered an activity with weak backward and forward linkages and closer to a curse than to a blessing (Cardoso and Faletto, 1969; Auty, 1993; Sachs and Warner, 1997, 2001; Singer, 1950). During the last two decades, however, this thesis has been challenged (Korinek, 2013; Badeeb et al., 2017). From a macroeconomic perspective, Lederman and Maloney (2007) emphasize the need for long-term analyses and point out that extractive economies are not doomed to failure. From a more structural approach and based on Hirschman's (1981) contribution, Morris et al. (2012) consider that increasing outsourcing of tasks along the mining value chain since the beginning of the 90 s may be the origin of win-win linkages between extractive activity and the rest of the economy (Farooki and Kaplinsky, 2014).

It does not seem to be a coincidence that this optimistic vision of mining-based development through linkages coincided with the so-called mining price "supercycle" (Humphreys, 2015). The significant rise in the prices of metals that started at the beginning of the 21st century and lasted for more than a decade, predominantly caused by the materials-intensive growth of China, was considered by the governments of extractive economies and particularly by developing countries as an opportunity to capture the benefits of mining industry and to make it the driver of economic development. It is not clear, however, after the slow and progressive decay of mining prices since 2011, to what extent extractive countries have been able to take advantage of these cyclical and structural opportunities, specifically in terms of the way these economies have been able to strengthen the linkages of the mining industry with the rest of the domestic economy and the complexity of this interaction.

The objective of this article is twofold: first, we analyze whether or not the expected increase in mining linkages has taken place in the last two decades in Chile; second, we extend the traditional linkage approach applied to the mining industry in order to understand to what extent and how, even in the case of increasing linkages, the effect of these linkages is either transmitted to the rest of economic activities in the Chilean economy or it remains as a predominantly encapsulated/isolated activity whose linkages, either strong or weak, have a very limited impact in the whole of the economy of a country.

For this purpose, we use the technique of Structural Path Analysis (SPA) (Defourny, 1982; Defourny and Thorbecke, 1984), which provides a comprehensive way of disaggregating mining multipliers and hence of identifying the structural channels or paths along which an exogenous injection into this activity travels across the rest of the

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economy. We focus on the period between 1995 and 2011, based on information from the harmonized national Input-Output Tables (IOTs) compiled by the OECD. From a structural perspective, this period is particularly relevant because it allows us to analyze a transformation in the organization of the mining from vertical integration to increasing externalization. From a cyclical perspective, this period also allows us to compare the changes in the size and transmission of mining linkages to the rest of the economy between 1995 and 2003, years when mining prices were particularly low; and between 2003 and 2011, which coincides with the years of the mining price "supercycle" (Humphreys, 2015).

One of the main components of mining-based development strategies across extractive economies has been the implementation of linkage promotion programs based on strategic collaboration between the main mining companies, both private and public, and mining services suppliers with the aim of strengthening production linkages, competence building and benefit-sharing (Söderholm and Svahn, 2015; Figueiredo and Piana, 2016; Stubrin, 2017). This micro approach to the analysis of mining linkages development is not able, however, to explain to what extent there has been an increase in production linkages in extractive countries and how the effect of these linkages is transmitted to the rest of the economy. From a more macro perspective, structural path analysis technique is especially useful to evaluate to what extent the potential and scope of policies to develop linkages between extractive companies and mining services suppliers have produced a real increase in mining linkages and how the influence of these linkages is transmitted to the rest of the economy through sectoral interactions. If this influence remains limited to just a few industries and does not spill over into other activities, the effect of mining linkages on economic development, even if linkages increase, would be weak.

Chile is an especially relevant case study for many reasons. First, Chile has been historically a paradigmatic example of an extractive economy and mining dependence has persisted in recent decades, representing around 50% of national exports (Meller, 2013; Meller and Gana, 2015). Second, since the beginning of the nineties, when large flows of Foreign Direct Investment (FDI) and some of the largest mining multinationals arrived in the country, Chile has experienced a complete transformation in the organization of mining production. During the 1970s and 1980s, Chilean mining production was almost entirely vertically integrated. In 1990, only 11.7% of the mining labor force was subcontracted, while, since 2009, subcontracted workers have consistently represented over two thirds of all mining workers (Atienza et al., 2018). Third, as a result of the significant rise in mining outsourcing, the number of local service suppliers has undergone a significant increase and, currently, the country has a network of more than 4000 firms that belong to different industries (Fundación Chile, 2014). Fourth, despite the relevance of mining activity and the growing externalization of tasks, production linkages are relatively weak (Aroca, 2001; Arias et al., 2014), especially when compared to other extractive economies such as Australia (Medina, 2017). Fifth, despite being the world leader in the production of some minerals such as copper and nitrates, the Chilean mining service supplier sector is not integrated in the global value chain and the country has a small number of globally competitive firms in this field (Urzúa, 2012; Gobierno de Chile, 2014). Finally, one of the main objectives of the Chilean national mining development strategy has focused over the last two decades on the promotion of production linkages between the mining industry and supplier activities (Fundación Chile, 2014, 2016a).

We find that the positive effect of the "supercycle" on mining output and the structural change in the organization of Chilean mining industry has not been associated with an improvement in the connectedness of this activity with the rest of the economy. In fact, both total backward and forward linkages significantly declined between 2003 and 2011 (−14% and −11%, respectively). The main sectors driving this decrease are transport, commerce, finance, and R&D. On the other hand, using the SPA methodology, we find that the mining sector in Chile lacks complexity. Most of the influence of mining on a target sector is transmitted using the shortest path possible, which means that the mining spillover effect is confined to a direct influence, rather than a complex system of interactions between sectors.

The article is divided into four additional sections: the second section presents data sources and descriptive evidence regarding the evolution of forward and backward mining linkages in Chile between 1995 and 2011, paying special attention to the differences between the period 1995–2003, when mineral prices were low, and 2003–2011, during the mineral price "supercycle", in order to understand to what extent the Chilean economy was able to capture the benefits of growing extractive activity. The third section describes the SPA technique. In the fourth section, SPA is implemented with the purpose of identifying the main paths or channels through which the influence of the mining industry spreads to the rest of the sectors in the Chilean economy. Finally, we conclude with a summary of the main results and an analysis of their implications and future research.

2. Data and descriptive evidence

We use the OECD database of harmonized national Input-Output Tables (IOTs) for Chile between 1995 and 2011 in order to analyze mining multiplier impacts in the Chilean economy.[1] The tables are constructed following an industry by industry approach and are reasonably disaggregated, covering the inter-industrial flows of goods and services produced domestically and imported for 34 sectors (sectors included and their correspondence with ISIC rev. 3.0 are presented in Appendix 1).[2] The OECD´s IOTs have advantages over those produced by the Central Bank of Chile in terms of international comparability and time span coverage. The OECD's IOTs have been produced for the period 1996–2011 while the Central Bank's IOTs were only published for 1996, 2003, 2008, and 2013.[3] However, the OECD's IOTs have the limitation that the mining sector is aggregated, including all related industries (coal, lignite, crude petroleum, natural gas, copper and quarrying).

The Chilean economy has been historically dependent on the mining industry, especially copper production. During the last decade, mining activity has represented between 12% and 15% of total GDP and copper mining has accounted for more than 90% of total mining production (compiled by the authors using the chained GDP series from the Central Bank of Chile).[4] During the period 1995–2011, the average annual growth rate of the copper price was 8%, and the average output growth rate for mining was 15%. Prices of copper started to grow in 2002 from around one dollar a pound to a price of almost four dollars in 2006 (real prices). After a sharp decline between 2007 and 2009 due to the global financial crisis, prices rapidly recovered and reached their highest level in February 2011, at 4.62 dollars a pound (COCHILCO). The increase in annual production was concentrated in the period 1995–2004 when copper output rose from close to 3 million MT to 5.5 million MT per year. After this rise, during the "supercycle", mining annual output remained almost steady, between 5.5 and 6.0 million MT (Comisión Nacional de Productividad, 2017). Considering the relevance of the mining sector in Chile, it would be plausible to assume that when mining output and prices increase, the whole economy might have a good performance, but this does not necessarily mean that mining linkages would increase, particularly in a context of increasing global

[1] http://www.oecd.org/trade/input-outputtables.htm.

[2] We aggregate the imports up to one transaction for simplicity.

[3] Central Bank's tables are constructed using the ISIC Rev. 3.0 classification and are disaggregated up to 73 sectors in 1996 and 2003, and up to 111 sectors in 2008. These matrices can be consulted at https://si3.bcentral.cl/estadisticas/Principal1/Excel/CCNN/cdr/excel.html.

[4] https://si3.bcentral.cl/Siete/secure/cuadros/arboles.aspx?idCuadro=CCNN_RATIO_EN_2013.

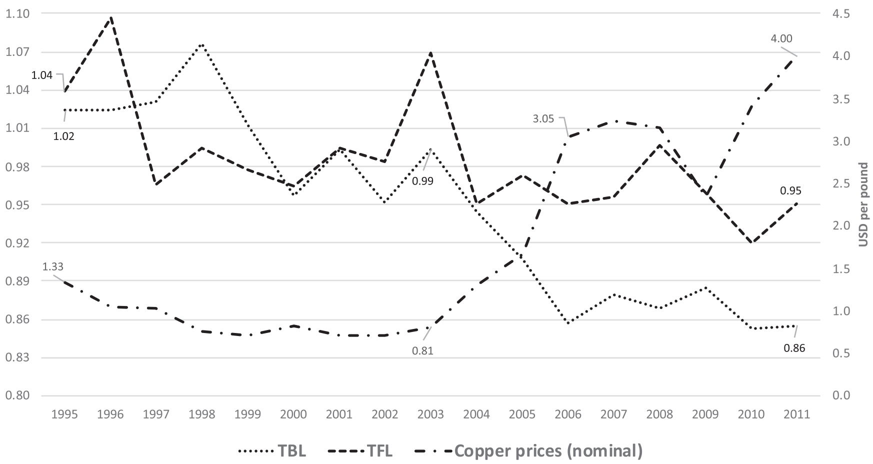


Fig. 1. Copper's prices and mining linkages, 1995–2011.
Notes: Real copper's prices are presented in the right "y" axis and linkages in the left "y" axis. Appendix 2 presents the mathematical formulation used to compute the backward and forward linkages.
Source: Linkages are elaborated using the OECD Input-Output database. Copper's prices come from the Central Bank of Chile and are based on the London Metal Exchange (LME).

externalization of mining related tasks. In fact, the impact of the mining industry both as a buyer and seller on other sectors slowed down despite the remarkable increases in prices and output.

Fig. 1 depicts the evolution of the Total Normalized Backward Linkages (TBL) and the Total Normalized Forward Linkages (TFL) of the Chilean mining industry to the rest of the sectors, along with the evolution of copper prices for the period 1995–2011 (Appendix 2 presents the mathematical formulation used to compute backward and forward linkages). TBL and TFL are measures of economic connectedness of the mining industry with other sectors. TBL measures how a change in the output of the mining industry will increase its demand on other sectors whose goods are used in mining production. On the other hand, TFL measures how a change in the output of the mining industry will increase the availability of mining products as inputs for other sectors that use them in their production. We normalize the value of linkages to evaluate their relative importance compared to the other sectors. A TBL (or TFL) greater than one means that mining has an above average backward (forward) connectedness.

According to Fig. 1, the relative connectedness of the mining industry as a buyer and as a seller decreased during the period in which copper production and prices increased. In 1995, the mining sector's impact as a buyer and as a seller was above the average; however, between 2003 and 2011, the "supercycle" period in which the copper prices grew up by almost 400%, the relative impact of the mining sector as a buyer decreased by − 14%, and as a seller by − 11%.[5]

This result could be explained by different factors that are not mutually exclusive: the evolution of TBL and TFL in non-mining sectors; the behavior of mining companies during the "supercycle" and the size and ownership structure of the mining industry in Chile. Fig. 2 shows that during our period of analysis the majority of sectors in the Chilean economy strengthened their interrelations with other productive industries at a higher rate than the mining industry, increasing their TBL and TFL in the most important sectors of the Chilean economy according to their contribution to the output. Excluding Mining and Basic Metals, all other activities show either an increase in both TBL and TFL, or an increase in one of them. In other words, while many productive sectors have increased their connectedness in the system, the mining industry has not been able to turn its boom in prices and output growth into greater interaction with the rest of the sectors in the economy.

This trend could be also understood, in part, due to the particularities of mining business behavior during the "supercycle". During the boom period, mining companies tried to take advantage of higher prices by increasing the utilization of installed capacity (which is fixed in the short to mid-term). Since there was uncertainty about how long high prices would remain, output maximization strategies generated an increase in costs and an increase in inefficiency (Comisión Nacional de Productividad, 2017). Furthermore, most suppliers increased their prices in order to capture part of the extra profits generated by the price boom. All the efforts of mining companies went to marginal increases of production, despite the higher costs and the reduction in productivity, which were fueled by a more intense use of direct employment and capital investment, both of which more than doubled during the "supercycle", as well as an increasing demand on energy sources (Comisión Chilena de Productividad, 2017). In this sense, innovation, better practices and other policies to foster long-term productivity, which are intensive in linkages with other economic sectors, were restricted to focus the available resources on production-related tasks. From this perspective, it is plausible to expect that linkages decrease when prices rise. In contrast, during downturns the mining companies fight to survive through the incorporation of innovation and better practices. Some of these actions are focused on improving the value chain and the relationships with the suppliers within it, seeking shared long-term productivity gains. In fact, it was after the sharp decline in copper prices that followed the global financial crisis in the second half of 2008 when mining companies started to promote actions for the upgrading of suppliers such as the "world class suppliers program" implemented by BHP Billiton in 2009 and rapidly adopted by CODELCO. As a result, weak copper prices may lead to greater, better and more sustainable interactions between mining companies and suppliers.

The results observed might also be related to the size and ownership structure of the mining industry in Chile. Fig. 3 divides mining output into its different components: national intermediate demand, imports and value added. Value added comprises compensation to employees, taxes on production and imports (less subsidies), and gross operating surplus. It is remarkable that between 1995 and 2003, when mining prices remained relatively low, the contribution of intermediate demand to output decreased while the share of imports significantly increased. This trend could be the result of the increasing global outsourcing of tasks that characterized the transformation of the organization of mining production since the beginning of the 90's (Morris et al., 2012). At the same time, the value-added share remained relatively constant.

In contrast, during the copper price boom (2003–2011), both intermediate demand and imports decreased their contribution to output by − 36% and − 14% respectively, as a likely result of output maximization strategies. Meanwhile, value added increased its contribution

[5] We obtained similar results comparing our data with that from the Chilean Central Bank's IOTs for the available years: 1996, 2003, and 2008 (see Appendix 3). Traditional and normalized backward linkages were similar both in levels and in percentage change for two periods: 1996–2008 and 2003–2008. The forward linkages, on the other hand, depicted a similar trend for the periods mentioned but with differences in levels. Central Bank's forward linkages were between 30% and 46% lower compared to those obtained using the OECD IOTs.

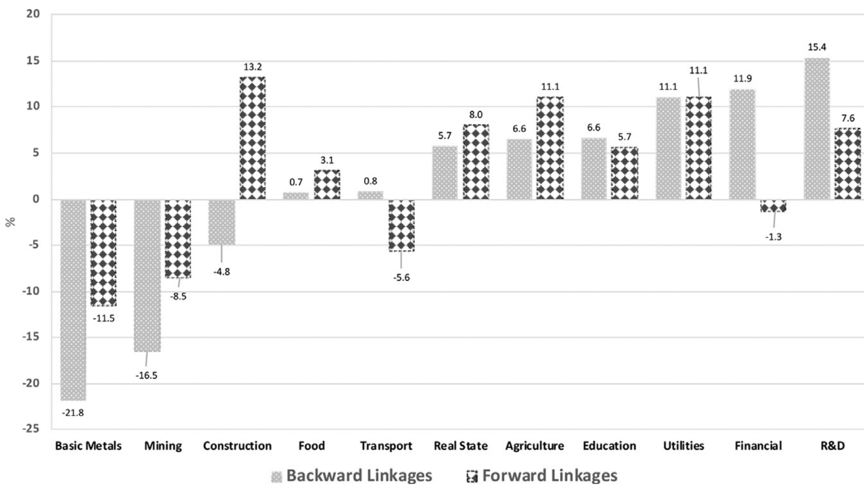


Fig. 2. Normalized Total Backward (TBL) and Forward Linkages (TFL), percentage change 1995–2011. Notes: From left to right the sectors used in Fig. 2 are: Basic metals, Mining (mining and quarrying), Construction, Food (food products, beverages and tobacco), Transport (transport and storage), Real State (real estate activities), Agriculture (agriculture, hunting, forestry and fishing), Education, Utilities (electricity, gas and water supply), Financial (financial intermediation), and R&D (research and development and other business activities). Appendix 2 presents the mathematical formulation used to compute the backward and forward linkages.
Source: Authors' elaboration based on OECD Input-Output database.

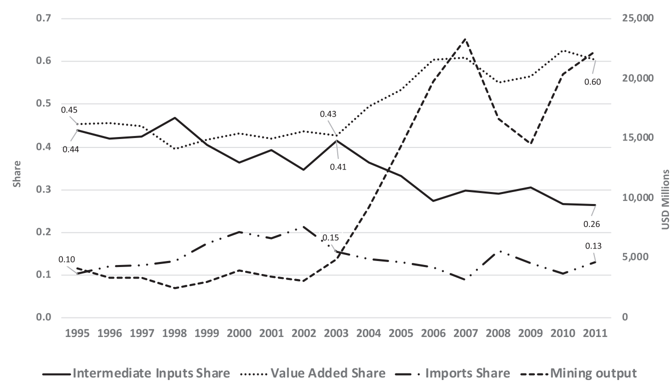


Fig. 3. Decomposition of the mining output, 1995–2011. Notes: Mining output (in nominal USD millions) is presented in the right "y" axis and the decomposition of the mining output is presented in the left "y" axis. The OECD database only decompose the mining output into three components: intermediate inputs, value added, and imports. The share depicted on the left y axis represents the contribution of each one the components to the mining output. For instance, the contribution (share) of the value to the mining output is defined as $\frac{Value\ Added}{Output}$.
Source: Authors' elaboration based on OECD Input-Output database.

by 41%. This means that most benefits related to higher copper prices were captured by the value-added account, something that could be either positive or negative for the local economy. It could be positive because it represents a higher compensation for the Chilean government, mining employees or growth in employment in response to new production, or both. However, it could be also interpreted in a negative way if most of this value added is transferred abroad in the form of profits. In Chile, the negative component is expected to overcome the positive. The mining industry in Chile is dominated by large companies that are mostly foreign-owned, which represent around two thirds of mining output, and it has been suggested that this structure promotes the excess of economic profitability going abroad in the form of dividends and profits (Rivera and Aroca, 2014). Our results in fact support this idea. Appendix 4 presents the disaggregation of the value-added account between 1995 and 2011. We found that during the "supercycle" share of gross operating surplus in value added increased by 9% points (from 82% in 2003 to 91% in 2011), while the share of labor compensation decreased by 8% points (from 17% in 2003 to 9% in 2011). This means that during the "supercycle" the increase in gross operating surplus was higher relative to the increase in labor compensation (due to the increase in production), which might be interpreted as evidence that most of the value added was transferred abroad in the form of profits.

The descriptive evidence depicted so far shows a mining sector that has been unable to translate the increase in copper prices and its output into economic connectedness with other productive sectors. Although there are some cases of Chilean mining service suppliers that have been able to upgrade and innovate during the "supercycle" (Fundación Chile, 2016b, 2017), this result contradicts, at least in Chile, the optimistic perspective regarding increasing opportunities for mining linkages in relation to the structural transformation in the organization of mining production (Morris et al., 2012; Farooki and Kaplinsky, 2014).[6] In this sense, it seems that the negative effect of the "supercycle" on productive linkages were stronger than the potential positive effect of increasing externalization.

In this context, it is relevant to analyze which activities were most affected by this trend. The impact of mining activity on other industries can be summarized by individual multipliers.[7] Fig. 4 presents the percentage change in mining multipliers for three periods: 1) 1995–2003 (characterized by a stable mining output and low copper prices); 2) 2003–2011 (characterized by an upward trend in mining output and copper prices); and 3) the whole period 1995–2011 (figure is sorted according to the change between 1995 and 2011). Additionally, Fig. 5 depicts the mining multipliers in absolute terms and their change for the periods described. The industries that received the highest multiplier effect from the mining sector at the beginning of our analysis were utilities, R&D, commerce, transport, coke, and financial (figure is sorted from the highest to the lowest multiplier in 1995). These multipliers reflect the increase in output of one sector caused by one unit increase in the output of the mining sector. For instance, the multiplier effect of the mining sector on the utilities sector in 2011 was 0.105, which means that one million dollars' increase in the output of the mining sector is associated with an increase of 0.105 million dollars in the output of the utilities sector (Fig. 5).

In an ideal scenario, we would expect an increase in mining multipliers on other sectors during the "supercycle" period (2003–2011). However, Figs. 4 and 5 show a different story. During that period, almost all multipliers decreased. The only exception was the utilities sector, something that could be related to the increasing need for energy and water to maximize mining output. In contrast, the mining multipliers on transport, commerce, financial and R&D declined by − 57%, − 21%, − 66% and − 25% respectively. Interestingly, during

[6] It is important to acknowledge that these authors are especially interested in the promotion of high quality and knowledge-intensive linkages, something that we are not able to analyze in this article.

[7] These individual multipliers are cells in the Leontief Matrix related with the mining sector (column) and represent the increase in sector i output caused by one unit increase (one million dollars in our case) in the final demand for mining output.

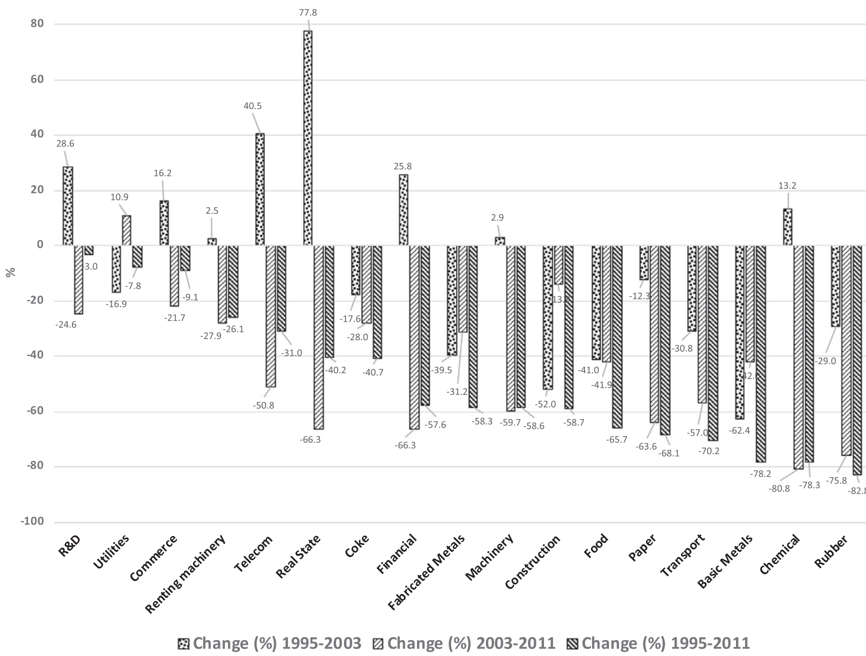


Fig. 4. Change (%) in mining multipliers on key sectors, 1995–2011. Notes: Figure is sorted from the highest to the lowest change between 1995 and 2011. From left to right the sectors used in Fig. 2 are: R&D (research and development and other business activities), Utilities (electricity, gas and water supply), Commerce (wholesale and retail trade), Renting Machinery (renting of machinery and equipment), Telecom (post and telecommunications), Real State (real estate activities), Coke (coke, refined petroleum products and nuclear fuel), Financial (financial intermediation), Fabricated Metals (fabricated metal products), Machinery (machinery and equipment), Construction, Food (food products, beverages and tobacco), Paper (pulp, paper, paper products, printing and publishing), Transport (transport and storage), Basic Metals, Chemical (chemicals and chemical products), and Rubber (rubber and plastics products).
Source: Authors' elaboration based on OECD Input-Output database.

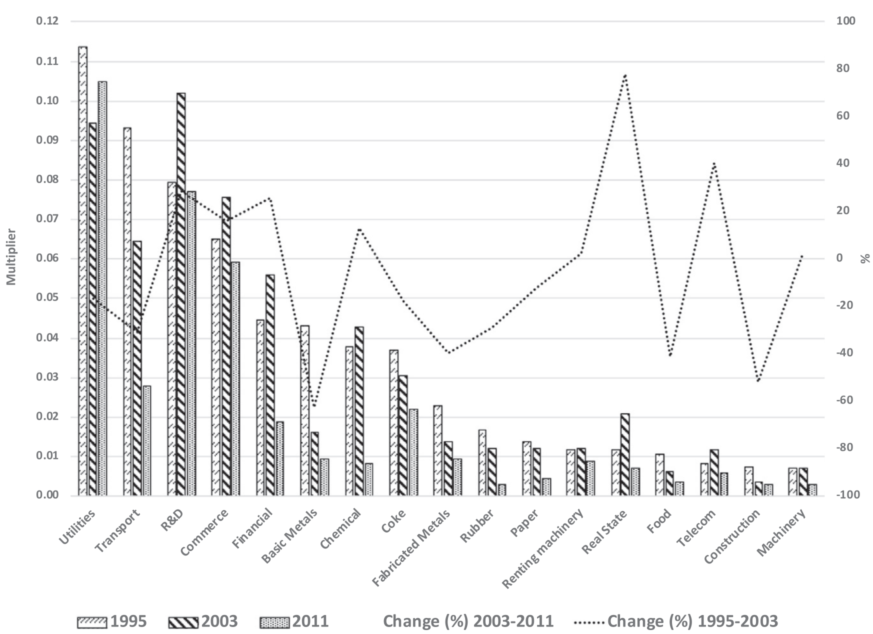


Fig. 5. Mining Multipliers on key sectors and their change (%) for selected periods. Notes: The figure depicts the percentage change in mining multipliers for periods 2003–2011 and 1995–2003 with dashed lines on the right "y" axis, and the mining multipliers in absolute terms for the years 1995, 2003, and 2011 with bars in the left "y" axis. Numbers are sorted according to the mining multipliers in 1995. From left to right the sectors used in Fig. 5 are: Utilities (electricity, gas and water supply), Transport (transport and storage), R&D (research and development and other business activities), Commerce (wholesale and retail trade), Financial (financial intermediation), Basic Metals, Chemical (chemicals and chemical products), Coke (coke, refined petroleum products and nuclear fuel), Fabricated Metals (fabricated metal products), Rubber (rubber and plastics products), Paper (pulp, paper, paper products, printing and publishing), Renting Machinery (renting of machinery and equipment), Real State (real estate activities), Food (food products, beverages and tobacco), Telecom (post and telecommunications), Construction, and Machinery (machinery and equipment).
Source: Authors' elaboration based on OECD Input-Output database.

the previous period, characterized by stable mining output and low copper prices (1995–2003), we find an increase in the mining multipliers on commerce (16%), financial (26%), R&D (29%), real estate (78%), and telecommunications (40%).

The trends observed in Figs. 4 and 5 reinforce the idea that the benefits expected from the international boom in copper prices and the steady increase in mining output have not been associated with an improvement in the connectedness of the mining sector. These results are especially worrying if we consider that Chilean mining production linkages were already relatively weak in 1996 (Aroca, 2001) and that they might also expose some of the traits of multinational mining enclaves, i.e., a set of multinational companies that exploit the natural resources of the host country without sustainable long-term positive effects on local communities, with weak integration with local/national production activities (Phelps et al., 2015), and with negative effects in its sovereignty, government ethics and macroeconomic performance (Auty, 2006).

These results are also relevant from a public policy standpoint because some of the crucial sectors that have been the target of linkage development policies such as transport, financial services, commerce and R&D show a substantial reduction in the impact received from mining activity during the full period (1995–2011), but especially during the period characterized by higher copper prices (2003–2011). These results stress the relevance and the need to reinforce the strategy of developing a mining cluster and the programs to upgrade mining services suppliers that the Chilean government and some mining companies have implemented since the beginning of the "supercycle" at a regional and national level.

The descriptive evidence presented so far shows the diminishing evolution of the effects of Chilean mining multipliers on relevant sectors such as transport, commerce, financial and R&D between 1995 and 2011. However, we do not know what structural mechanisms are responsible for these multiplier effects and how these mechanisms have evolved in a context of increasing externalization of production and a potentially more complex relationship between the mining industry and the rest of the economy. We will now focus on the implementation of a Structural Path Analysis (SPA) to identify the mechanisms that explain mining multiplier effects and to open the black box of the total multiplier matrix and identify the paths along which a given injection is transmitted from one sector of origin (the mining sector) to its ultimate destination sector (e.g. R&D, transport, commerce, etc.). This analysis will also allow us to determine what sectoral interactions have lost relevance and therefore may be responsible for the overall reduction in the mining multipliers observed for the period studied. At the same time, this analysis could be useful for policy design either to take advantage of these linkage paths or to focus on more promising paths. The results will be presented for the ten sectors that have the largest mining multipliers in 2011, namely, utilities, R&D, commerce, transport, coke, financial, fabricated metals, basic metals, renting machinery and chemical. The next section presents the technique and discusses its importance for the identification and disaggregation of aggregated mining multiplier effects.

3. SPA methodology

The input-output model is defined by the following system of equations (Miller and Blair, 2009):[8]

$$\sum_{j=1}^{n} z_{ij} + f_i = x_i \quad , \quad \forall \quad i = 1, ..., \quad n; \tag{1}$$

Where: z_{ij} represents interindustry sales by sector i (also know as intermediate sales) to all sectors j (including itself, when $j = i$); f_i is the value of the final demand for sector i's product; x_i is the value of the total output of sector i. Similarly, the technical coefficients are given by:

$$a_{ij} = \frac{z_{ij}}{x_j} \quad \forall \quad i, j = 1, ..., \quad n. \tag{2}$$

Where a_{ij} represents the amount of inputs (in dollars or other measure) from sector i used by 1 unit of output of sector j. The reduced form of the IO model can be obtained by introducing the technical coefficients definition into the basic equation:

$$x_i = \sum_{j=1}^{n} a_{ij}{*}x_j + f_i, \quad \forall \quad i = 1, ..., \quad n; \tag{3}$$

Or in matrix form:

$$X = AX + F$$
$$X = (I - A)^{-1}F$$
$$X = LF \tag{4}$$

The matrix $(I - A)^{-1}$, often called the Leontief inverse matrix or total requirements matrix (L), represents the change in the output of sector j ΔX_j by varying the final demand to sector i by Δf_i. The traditional analysis of multipliers in the Input-Output (IO) framework allows us to capture the global (direct, indirect, and induced depending whether we decide to close the system with respect to households) effects of exogenous injections (government, investment, exports, etc.) on the rest of the sectors in an economy. These total (global) multiplier effects are represented by the cells in the Leontief inverse matrix $(I - A)^{-1}$ and they provide us valuable information to understand the interdependence between sectors in an economy and to implement ex ante policy impact evaluation. However, these multipliers are still a black box, in the sense that they are just scalar numbers that are the result of sequential round by round impacts of the increases in the components of the final demand on the different productive sectors. Consequently, the multipliers do not uncover the structural channels of transmission (sectors) through which an exogenous injection is transmitted directly and indirectly to a target or endogenous sector.

Structural Path Analysis (SPA) (Defourny, 1982; Defourny and Thorbecke, 1984), is a methodology that provides a comprehensive way of decomposing multipliers and hence of identifying the structural channels or paths along which an exogenous injection travels. SPA allows us to identify the whole network of paths through which influence is transmitted from one sector of origin (origin pole) to its ultimate destination (destination pole) (Isard et al., 1998, p. 308).[9] SPA considers three concepts of economic influence: direct influence, total influence and global influence.

3.1. Direct influence

The technical coefficient a_{ij} represents the direct effect of an exogenous injection in sector j on sector i. Therefore, the intensity of the arc (ji) is a measure of direct influence transmitted from the origin pole j to the destination pole i. A sequence of consecutive arcs constitutes a path whose length is the number of arcs that comprises it. An arc is simply a path of length one. A path that does not pass more than once through the same pole is an elementary path (Fig. 6), while a circuit is a path whose first pole (pole-origin) coincides with the last (pole-destination) (Fig. 7).

Formally, the direct influence of a production sector i on a production sector j, transmitted by an elementary path, is the change in the production of sector j induced by a unitary change in the production of the sector i, with the production of the poles except those along the selected elementary path remaining constant.[10] Then, the direct influence of i on j along the arc (i, j) is defined by:

$$I^D_{(i \to j)} = a_{ji} \tag{5}$$

And the direct influence of i on j on any elementary path is equal to the product of the intensities of the arcs composing the path:

$$I^D_{(i...j)} = a_{jk}{*}....{*}a_{mi} \tag{6}$$

For instance, in Fig. 6 there are two arcs (i, j) and (j, k), thus the direct influence is $I^D_{(i,j,k)} = a_{ji}{*}a_{kj}$

3.2. Total influence

The total influence is the aggregation of all the direct effects and their amplification through the adjacent circuits. The purpose of the total influence is to capture the effect of the amplification effect of the circuits that complement the direct influence. Formally, the total influence transmitted along the path $(i...j)$ can be defined by:

$$I^T_{(i...j)} = I^D_{(i...j)}{*}M_{(i...j)} \tag{7}$$

Where $M_{(i...j)}$ is known as the path multiplier of the elementary path $(i...j)$ and is equal to the ratio between the total influence and the direct influence $M_{(i...j)} = \frac{I^T_{(i...j)}}{I^D_{(i...j)}}$ and therefore measures the amplification power conferred on the path by the circuits which are adjacent to it.

Total influence is related to global influence. Global influence is the sum of the total influences transmitted from pole i to pole j along all the elementary path running from i to j. For instance, Fig. 8 contains three elementary paths from i to j ((i, x, y, j), (i, s, t, j), and (i, v, t, j)) and

[8] The index i refers to the rows and the index j to the columns of the Input-Output tables.

[9] The SPA has been used mainly as an alternative way to decompose the matrix of accounting multipliers in the Social Accounting Matrix framework (SAM) (Defourny and Thorbecke, 1984). However, its initial application was within the IO framework (Defourny and Maree, 1978; Defourny, 1982). The mathematical development of SPA was proposed by Lantner (1974) and Gazon (1976) under the concept of economic influence.

[10] According to the definition of the technical coefficient, $x_{ji} = a_{ji}{*}y_i$, then we have $\Delta y_j = a_{ji}{*}\Delta y_i = a_{ji}$ when the pole i increases its production by one unit. Therefore, the matrix A can be called the matrix of direct influences.

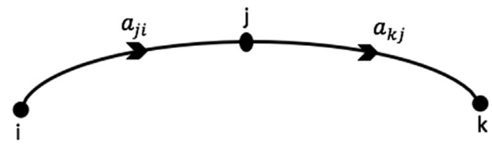


Fig. 6. Elementary path (***i***, ***j***, ***k***).
Source: based on Defourny (1982).

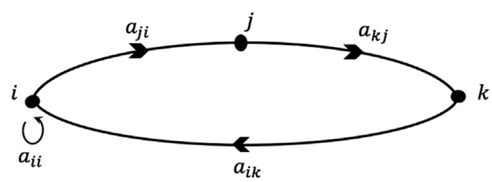


Fig. 7. Circuit (***i***, ***j***, ***k***, ***i***).
Source: based on Defourny (1982).

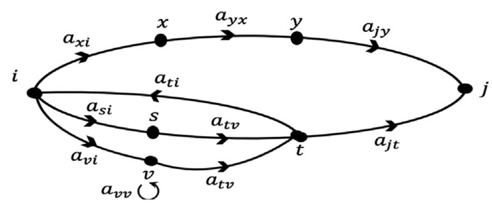


Fig. 8. Graphical representation of the total influence along all the elementary paths running from ***i*** to ***j***.
Source: based on Defourny (1982).

three circuits ((i, s, t, i), (i, v, t, i); and (v, v)). Thus, global influence in this graph is obtained by the sum of the total influence for each elementary path[11]:

$$I^G_{i\to j} = I^T_{(i,x,y,j)} + I^T_{i,s,t,j} + I^T_{i,v,t,j} \tag{8}$$

$$I^G_{i\to j} = I^D_{(i,x,y,j)} * M_{(i,x,y,j)} + I^D_{(i,s,t,j)} * M_{(i,s,t,j)} + I^D_{(i,v,t,j)} * M_{(i,v,t,j)} \tag{9}$$

Then for n elementary paths running from i to j, the global influence is defined

$$I^G_{i\to j} = \sum\nolimits_{p=1}^{n} I^T_{(i\ldots j)_p} = \sum\nolimits_{p=1}^{n} I^D_{(i\ldots j)_p} * M_{(i\ldots j)_p} \tag{10}$$

3.3. Global influence

The global influence of a production sector i on a production sector j is the total increase in the production of pole j, following a unit increase in the production of pole i. The concept of global influence in SPA is equivalent to the concept of total multiplier in the traditional I-O analysis. Therefore, the global influence of a change in the final demand of the production sector i on the production sector j is given by the cell (j, i) in the Leontief Inverse Matrix $(I - A)^{-1}$.

It is important to distinguish the difference between direct influence and global influence. The direct influence of one pole on another is related to a path which is completely isolated from the rest of the structure. For instance, in Fig. 7, the direct influence of the elementary path (i, j, k) is analyzed, keeping the circuit effect from k to i constant. Therefore, direct influence measures the immediate effect of an exogenous impulse along this path. On the other hand, global influence counts the direct influence by all the elementary paths connecting the two poles and quantifies their effect as part of one structure and not in isolation as direct influence does. Thus, global influence cumulates all the induced and feedback effects caused by the adjacent circuits. For instance, in the circuit path depicted in Fig. 7, when the sector i responds to one unit increase in its demand, it must buy the amount a_{ji} from sector j, which in turn, must buy the amount $a_{kj}*a_{ji}$ from sector k to satisfy this demand, and since sector k must in turn buy inputs from sector i, a circuit appears. Consequently, sector i will buy inputs from sector j and so on. Ultimately, the total influence is the aggregation of all the direct effects and their amplification through the adjacent circuits.

In this document, SPA is used to understand the main structural channels through which an exogenous change in the final demand for mining products (origin) travels to some target sectors (destination), e.g., financial, utilities, commerce, transport, etc. In this sense, SPA is able to decompose the multiplier effect in terms of multiple layers that are involved through circuit effects among and along different sectors embedded in complex inter-industrial relations that characterize an economic system.

4. Results

Table 1 shows the results of the Structural Path Analysis for the 10 sectors with the highest mining multipliers in the year 2011. Only the most relevant paths in terms of their contribution to global influence are presented.[12] Different measures are presented in five columns for three years 1995, 2003 and 2011.[13] Column (1) for each year depicts global influence I^G, which is equivalent to the total multiplier effect shown in the Leontief inverse matrix (also depicted in Fig. 5); column (2) shows total influence I^T; column (3) shows the total influence contribution as a percentage of the respective path on the global influence $\left(\frac{I^T}{I^G}\right)$; column (4) shows the associated path multiplier M; and column (5) presents the direct influence contribution as a percentage of the respective path on the total influence $\left(\frac{I^D}{I^T}\right)$.

The first notable result is that the global influence of the Chilean mining industry is predominantly transmitted along the shortest paths or a direct route (column 3 for each year in Table 1). For instance, consider the influence transmitted from the mining sector as a pole of origin to the utilities sector as a destination (MIN→UTI): In 1995, 91.1% of the global influence is transmitted through the shortest path (i.e. the path from mining to utilities directly) and 1.8% is transmitted through a path of length greater than one (MIN→BMT→UTI).[14] This feature did not significantly change during our period of analysis (Fig. 9) and implies lack of complexity. In 1995, 66% or more of the global influence of the mining sector was transmitted through the

[11] The path multiplier for the first elementary path (i, x, y, j) is equal to one since the path does not have adjacent circuits.

[12] For some sectors, such as chemicals and fabricated metals, most of the global influence is transmitted through the shortest path possible, so most of the intermediate paths are less relevant and therefore they are not presented. However, in other sectors, such as financial and basic metals, the intermediate paths (those paths with length greater than one) play a bigger role and therefore they are included in Table 1. Why are complex paths (those of length 2 or greater) not present? The answer is related to the multiplication rule (see footnote 14): the direct influence might be weaker when a path has more arcs, so complex paths carrying a weaker initial direct influence will have a less important role in the system. Although mathematically there could be paths involving all sectors and the procedure calculates all of them (if all the sectors have some interaction), empirically, the important paths are given by the complexity of the system being analyzed and the Chilean mining sector certainly lacks complexity (see results for the backward and forward linkages).

[13] Results for the rest of the years are available from the authors upon request.

[14] This result is explained by the multiplication rule in relation to direct influence: direct influence will be weaker when a path has more arcs and the initial shock is low. Direct influence, therefore, falls rapidly as soon as the path lengthens. The longer a path is and the more circuits adjacent to it, then, the stronger is the amplification of the direct influence. However, if the initial direct influence is weak, the amplification effect carried out by the adjacent circuits will have less impact.

Table 1
Structural Path Analysis (SPA) for the impact of the mining sector on selected sectors, 1995, 2003, and 2011.
Source: Authors' elaboration.

Origin (i)→ Destination (j)	Paths	1995					2003					2011				
		(1) I^G	(2) I^T	(3) $\left(\frac{I^T}{I^G}\right)$	(4) M	(5) $\left(\frac{I^D}{I^T}\right)$	(1) I^G	(2) I^T	(3) $\left(\frac{I^T}{I^G}\right)$	(4) M	(5) $\left(\frac{I^D}{I^T}\right)$	(1) I^G	(2) I^T	(3) $\left(\frac{I^T}{I^G}\right)$	(4) M	(5) $\left(\frac{I^D}{I^T}\right)$
MIN→COK	MIN→COK		0.025	67.1	1.09	92.0		0.020	67.2	1.08	92.9		0.014	65.1	1.08	92.9
	MIN→TRA→COK	0.037	0.006	17.1	1.26	79.2	0.030	0.005	16.2	1.26	79.1	0.022	0.002	9.6	1.28	78.2
	MIN→UTI→COK		0.002	4.4	1.63	61.4		0.000	0.9	1.64	61.0		0.003	12.9	1.81	55.3
MIN→CHE	MIN→CHE		0.030	79.7	1.20	83.1		0.037	87.2	1.23	81.4		0.007	88.4	1.13	88.5
	MIN→RUB→CHE	0.038	0.002	4.0	1.36	73.5	0.043	0.001	3.4	1.32	76.0	0.008	0.000	2.4	1.20	83.5
	MIN→UTI→CHE		0.001	2.2	1.80	55.5		0.000	0.3	1.87	53.4		0.000	0.7	1.90	52.5
MIN→BMT	MIN→BMT		0.030	69.2	1.19	84.2		0.009	58.5	1.17	85.4		0.005	57.7	1.14	87.7
	MIN→FMT→BMT	0.043	0.005	11.3	1.23	81.2	0.016	0.003	16.3	1.21	82.7	0.009	0.002	21.5	1.18	85.0
	MIN→MAC→BMT		0.002	3.7	1.20	83.2		0.001	4.8	1.19	83.8		0.000	3.9	1.15	87.0
MIN→FMT	MIN→ FMT		0.019	83.8	1.10	91.2		0.013	90.5	1.10	91.0		0.008	92.0	1.09	91.9
	MIN→UTI→FMT	0.023	0.001	3.1	1.64	60.9	0.014	0.000	0.7	1.67	59.7	0.009	0.000	1.5	1.83	54.6
	MIN→TRA→FMT		0.000	1.9	1.28	78.1		0.000	0.3	1.30	77.2		0.000	0.3	1.30	77.1
MIN→UTI	MIN→UTI	0.114	0.104	91.1	1.58	63.3	0.095	0.089	93.7	1.62	61.7	0.105	0.097	92.4	1.77	56.4
	MIN→BMT→UTI		0.002	1.8	1.78	56.3		0.000	0.2	1.78	56.1		0.000	0.1	1.92	52.1
MIN→CMM	MIN→ CMM		0.043	66.3	1.12	89.0		0.056	73.1	1.16	86.5		0.048	80.8	1.14	87.9
	MIN→TRA→CMM	0.065	0.005	7.4	1.30	77.0	0.076	0.002	2.7	1.35	73.9	0.059	0.001	1.3	1.35	74.1
	MIN→COK→CMM		0.002	2.8	1.16	86.5		0.002	2.2	1.17	85.6		0.001	2.0	1.16	86.1
MIN→TRA	MIN→TRA		0.074	80.0	1.23	81.0		0.048	73.1	1.25	79.7		0.018	65.0	1.26	79.6
	MIN→CMM→TRA	0.093	0.006	6.1	1.30	77.0	0.065	0.006	9.8	1.35	73.9	0.028	0.004	15.8	1.35	74.1
	MIN→COK→TRA		0.002	1.9	1.26	79.2		0.000	0.7	1.26	79.1		0.000	1.1	1.28	78.2
MIN→FIN	MIN→FIN		0.031	68.4	1.15	87.3		0.036	64.4	1.26	79.7		0.009	45.0	1.23	81.2
	MIN→UTI→FIN		0.003	5.6	1.72	58.3		0.004	7.4	1.91	52.3		0.002	10.3	2.07	48.3
	MIN→CMM→FIN	0.045	0.001	2.4	1.22	82.0	0.056	0.002	4.1	1.36	73.4	0.019	0.002	12.4	1.33	75.2
	MIN→TRA→FIN		0.001	3.0	1.34	74.7		0.002	3.2	1.48	67.6		0.001	2.9	1.47	68.1
	MIN→R&D→FIN		0.001	1.5	1.17	85.2		0.002	4.4	1.36	73.8		0.002	10.9	1.41	70.9
MIN→RMA	MIN→RMA		0.010	79.4	1.07	93.5		0.009	75.0	1.07	93.8		0.006	70.8	1.08	92.7
	MIN→TRA→RMA	0.012	0.001	8.6	1.25	80.0	0.012	0.000	1.1	1.26	79.6	0.009	0.000	5.4	1.29	77.8
	MIN→UTI→RMA		0.000	1.4	1.60	62.5		0.000	3.0	1.62	61.6		0.000	1.4	1.82	55.0
MIN→ R&D	MIN→R&D		0.060	75.6	1.08	92.4		0.082	80.0	1.15	86.9		0.059	76.1	1.21	82.5
	MIN→UTI→R&D	0.079	0.004	5.1	1.62	61.7	0.102	0.003	3.2	1.75	57.0	0.077	0.002	2.0	2.04	49.0
	MIN→TRA→R&D		0.002	2.3	1.27	79.1		0.001	1.2	1.36	73.8		0.001	1.0	1.44	69.3

Notes: Sectors' acronyms are as follows: MIN = Mining and quarrying; COK = Coke, refined petroleum product and nuclear fuel; TRA = Transport and storage; UTI = Electricity, gas and water supply; CHE = Chemicals and chemical products; RUB = Rubber and plastic products; BMT = Basic metals; FMT = Fabricated metals; MAC = Machinery and Equipment; R&D = Research and development and other business activities; and CMM = Wholesale and retail trade. Columns denoted by (3) and (5) are presented in percentage (%).

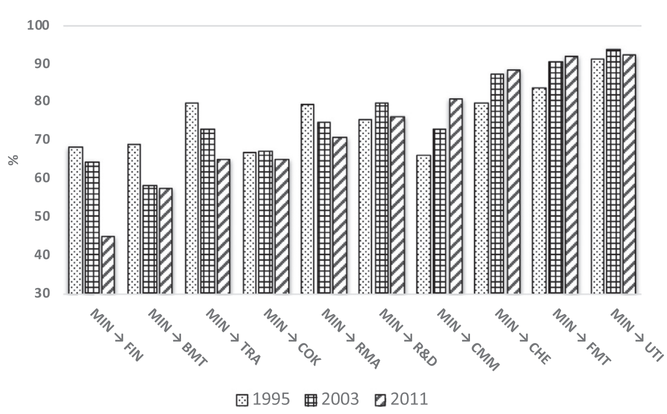


Fig. 9. Shortest path contribution (%) to the global influence of the mining sector on selected sectors for 1995, 2003, 2011. Notes: The figure depicts the contribution of the shortest path to the global influence transmitted from the mining sector to other important sectors for selected years. The higher the contribution of the shortest path means that the transmission of influence from the pole (mining) to other sectors lacks complexity. Sectors' acronyms are as follows: MIN = Mining and quarrying; COK = Coke, refined petroleum product and nuclear fuel; TRA = Transport and storage; UTI = Electricity, gas and water supply; CHE = Chemicals and chemical products; RUB = Rubber and plastic products; BMT = Basic metals; FMT = Fabricated metals; MAC = Machinery and Equipment; R&D = Research and development and other business activities; and CMM = Wholesale and retail trade.
Source: Authors' elaboration.

shortest possible path in all the sectors. In 2003, the pattern was similar with the exception of the impact of mining on the basic metals (BMT) and financial (FIN) sectors: 58.5% of the global influence of the mining sector on the basic metals sector (MIN→BMT) and 64.4% of the global influence of the mining sector on the financial sector (MIN→FIN) were transmitted through the direct channel. Finally, in 2011, only the financial sector had less than the 50% of the global influence of the mining sector transmitted through the shortest path (Fig. 9).

Fig. 9 also depicts the trends in the importance of the shortest path through the years. The shortest path's contribution to the global influence of mining decreased between 1995 and 2011 for the following sectors: Financial (−23 pp.), Basic Metals (−11.5 pp.), Transport (−15 pp.) and Renting Machinery (−8.6 pp.). On the other hand, this contribution increased for the sectors: Commerce (14.5 pp.), Chemical (8.7 pp.), and Fabricated Metals (8.2 pp.).

Ceteris paribus (i.e. keeping the global effect constant), when the direct path decreases its contribution to the global effect, and the contribution of other paths of length two or more increases, the system of interrelations between the mining sector and the target sector becomes more complex as it involves more circuits and more sectors are likely to be affected by the initial injection. However, the trends observed in Fig. 9 should be interpreted with caution. We do not know whether the increase or decrease in the relative importance of the shortest path is due to the weakening of the direct relationship (normally observed through a shrinkage in the use of inputs of the mining sector per unit of its output and thus easily detected by means of the study of the technical coefficients matrix), or to the strengthening of the

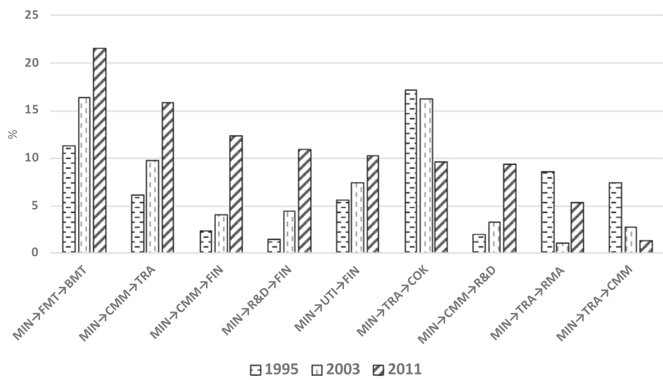


Fig. 10. Some important paths of length two according to their contribution (%) to the global influence of the mining sector on selected sectors for 1995, 2003, and 2011. Notes: Fig. 10 shows some important paths of length 2 and their evolution between 1995 and 2011. Although the direct paths concentrate most of the impact of the mining sector on other sectors (see Fig. 9), there is a significant portion of influence transmitted through paths whose length is greater than one. These paths are important because they involve a more complex configuration of the relationship between the mining sector as pole of origin and the selected destination poles. Paths of length two or greater have more adjacent circuits that contribute to amplifying the initial effect of an injection into the mining sector. Sectors' acronyms are as follows: MIN = Mining and quarrying; COK = Coke, refined petroleum product and nuclear fuel; TRA = Transport and storage; UTI = Electricity, gas and water supply; CHE = Chemicals and chemical products; RUB = Rubber and plastic products; BMT = Basic metals; FMT = Fabricated metals; MAC = Machinery and Equipment; R&D = Research and development and other business activities; and CMM = Wholesale and retail trade.
Source: Authors' elaboration.

indirect relationship (a relationship in which the mining sector affects its target sector through the influence of one or more sectors), or to both effects. We will discuss the paths that explain the observed change in the global multipliers between 1995 and 2011 later in the article.

Although the direct paths concentrate most of the impact of the mining sector on other sectors, there is a significant portion of influence transmitted through paths whose length is greater than one. These paths are important because they involve a more complex configuration of the relationship between the mining sector as pole of origin and the selected destination poles. Paths of length two or greater have more adjacent circuits that contribute to amplifying the initial effect of an injection into the mining sector. Fig. 10 shows some important paths of length 2 and their evolution between 1995 and 2011. The graph is sorted according to the size of the paths' contribution in the initial year (1995).

The interpretation of a path of length two is as follows: consider the path MIN→CMM→TRA. In 2011, an initial increase of one million dollars in the final demand for output of the mining sector (initial pole) results in an increase in the output of the transportation sector equal to 0.028 million dollars considering all the direct, indirect and amplification effects (see Table 1, year 2011, column 1, MIN→TRA relationship). Nonetheless, only 65% of this additional output (0.0182 million dollars) is addressed by the transportation sector itself. The remaining 35% (0.0098 million dollars) satisfies the demand of other intermediate sectors that are also developing their activity in response to the request of the mining sector. One of these intermediate sectors that mediates the relationship between the mining sector and the transportation sector is the commerce sector; 15.8% (0.0042 million dollars) of the global influence transmitted from the mining sector to the transportation sectors is facilitated by the commerce sector (MIN→CMM→TRA).

The study of these paths of length two or more and the identification of their importance is key to inform economic policy design for at least two reasons: firstly, it reveals the way in which an initial impulse of one sector is transmitted to the rest of the economy; and secondly, it

Table 2
Percentage growth rate (%) of important paths of length two for three selected periods: 1995–2003, 2003–2011, and 1995–2011.
Source: Authors' elaboration.

Path	1995–2003	2003–2011	1995–2011
MIN→CMM→TRA	12.3	− 30.5	− 22.0
MIN→CMM→FIN	112.6	2.6	118.1
MIN→CMM→R&D	113.0	112.7	353.2
MIN→FMT→BMT	− 46.3	− 25.8	− 60.2
MIN→R&D→FIN	265.0	− 15.9	206.8
MIN→TRA→COK	− 23.2	− 56.5	− 66.6
MIN→TRA→CMM	− 57.3	− 62.6	− 84.1
MIN→TRA→RMA	− 87.2	268.2	− 52.9
MIN→UTI→COK	− 83.4	951.1	74.3
MIN→UTI→FIN	64.4	− 52.8	− 22.3

Notes: Sectors' acronyms are as follows: MIN = Mining and quarrying; COK = Coke, refined petroleum product and nuclear fuel; TRA = Transport and storage; UTI = Electricity, gas and water supply; CHE = Chemicals and chemical products; RUB = Rubber and plastic products; BMT = Basic metals; FMT = Fabricated metals; MAC = Machinery and Equipment; RMA = Renting of machinery and equipment; R&D = Research and development and other business activities; and CMM = Wholesale and retail trade.

identifies which sectors play an important role in the transmission mechanism. Consider for instance Fig. 10, which shows the most important paths of length two according to their contribution to the global influence of mining as a pole of origin and the destination pole. In this graph, we can identify that the commerce, transport, and utilities sectors are crucial in the transmission mechanism of the mining sector, which could be related to the need to maximize output by buying and moving goods and increasing the access to water and energy sources. In contrast, R&D, which has been one of the main targets of mining-based development strategies in Chile oriented towards increasing linkages with mining service suppliers, only mediates significantly the relation between the mining industry and financial services.

Thus, these sectors may determine the scope of policy intervention in the mining sector (or some other sector in an extended analysis) because they could facilitate or may very well constitute a bottleneck which obstructs the transmission of influence from the mining sector to a target sector. In the case of the mining sector in Chile, we can easily identify which sectors may have been facilitators or obstructers of the transmission of its influence during the period 1995–2011. Table 2 presents the growth rate of total influence (I^T) transmitted by the paths shown in Fig. 10 for three different periods: 1995–2003, 2003–2011, and 1995–2011. In general, we can observe that the commerce sector has increased its ability to transmit influence between the mining sector and the financial and R&D sectors. The total influence of the path MIN→CMM→FIN has increased by 118% between 1995 and 2011. Also, the total influence of the path MIN→CMM→R&D has increased by 353% in the same period. R&D has also significantly improved its capacity to transmit influence between mining and financial services. The total influence of the path MIN→R&D→FIN has increased by 206.8%.

During the period 1995–2001, the transportation sector may be considered a bottleneck because it decreased its ability to transmit influence between the mining industry and the coke, commerce and renting machinery sectors; the total influence of the paths MIN→TRA→COK, MIN→TRA→CMM and MIN→TRA→RMA decreased by − 66.6%, − 84.1%, and − 52%, respectively. Obviously, these results are in part explained by the shrinkage of the global effect of the mining industry on the transportation sector: during the same timespan the global effect of the mining industry on the transportation sector decreased by 70% (see Fig. 4). Finally, the utilities sector has mixed results. On the one hand, it has improved its capacity to transmit influence between the mining and coke sectors (global influence increased by 74.3% during the period 1995–2011). On the other hand, it has decreased its ability to transmit influence between the mining sector and the financial sector (global influence decreased by 22.3% during the same timespan).

The results depicted in Fig. 10 and Table 2 show the crucial sectors that play an important role in the transmission mechanism from the mining sector to target sectors and therefore allow us to identify the sectors that require a precise knowledge of their prevailing conditions at a given moment in order to understand the limits of a policy intervention or to explore the possibility of orienting decision-makers towards other solutions. Secondly, the results can guide the policy efforts made by the Chilean government since the beginning of the 21st century by recognizing the relevance of transport, commerce, R&D, utilities, and financial sectors as crucial elements of mining policy. However, it is important to be cautious, as these results are only a partial proof of their relative ineffectiveness:

1. Excluding the utilities sector, the mining multipliers on the rest of the key sectors (transport, commerce, R&D and financial) diminished during the period 2003–2011 when the copper prices were historically high (see Fig. 4).
2. The evidence of the capacity of the mentioned sectors to transmit the influence of the mining sector on others during the period 2003–2011 is mixed (see Table 2). The commerce sector increased its capacity to transmit influence between the mining and the R&D sector (112%), but decreased its ability to transmit influence between the mining and transport sector (−30.5%). The transport sector increased its capacity to transmit influence between the mining and renting machinery sector (268%), but decreased its ability to transmit influence between the mining and coke sector (−56.5%) and between the mining and commerce sector (−62.6%). Finally, the utilities sector improved its ability to transmit influence between the mining and coke sector (951%), but reduced its capacity to transmit influence between the utilities and financial sector (−52.8%).

These trends of structural change in the Chilean mining industry reflect, to a large extent, the changes that have taken place in the large copper mining industry. According to the Comisión Nacional de Productividad (2017), in its analysis of the evolution of the productivity of copper mining (2000–2014), this industry has shown a negative trend for more than one decade, including the period of the "supercycle". The same source notes that, although this trend is common to other countries that are intensive in natural resources, estimates for the Chilean case show a sharper fall in comparative terms. This is associated with phenomena such as the intensity in the use of energy, the drop in the grade of mineral deposits and the effects of the fall in factor productivity.

COCHILCO (2013, 2014) has also highlighted that the expansion of production during this period was not homogeneous in terms of the use of various strategic factors. Between 2000 and 2014, capital investment grew by 178%, labor recruitment by 157% and energy consumption by around 79%. This implies that the sector opted for an expansive production strategy clearly aimed at making the price cycle opportunity profitable. This form of growth is also reflected in the forms of inter-industry linkage identified through structural path analysis, characterized by short inter-industry scope and low systemic complexity. These findings are similar to those obtained by Aroca and Garrido (2017), who were capable of evaluating intra-sectoral and inter-sectoral diffusion effects on the Chilean Total Factor Productivity (TFP) for the 1996–2010 period, using a completely different methodological approach. Their results place the mining industry in a relatively weak position within the group of sectors whose growth impacted on the TFP with positive inter-sectoral diffusion effects.

5. Conclusions

During the first decade of the 21st century, the mining price "supercycle" was very positive for most extractive economies in terms of fiscal revenues and economic growth, a trend that may recover in the near future if the increase in mining prices that started in 2016 continues. It is, by no means as clear that, as some authors expected, these extractive countries were able to take advantage of this long period of expansion to build a more complex and developed economy in which the mining industry acted as a platform for increasing linkages with and across other economic activities. Our results for the case of Chile between 1995 and 2011 support this concern.

The positive effect of the "supercycle" on mining output and the structural change in the organization of Chilean mining industry as a complex network of mining service supplier firms during this period have not been associated with an improvement in the connectedness of this activity with the rest of the economy. Despite some cases of upgrading of innovative Chilean mining service suppliers, both total backward and forward linkages significantly declined between 1995 and 2011, and mainly after 2003 when the "supercycle" started. The decline in the Chilean mining multipliers affected almost all activities, including those traditionally more related to extractive industry such as transport, construction and financial and R&D services. The only exception was the utilities sector, probably due to the increasing need for water and energy of mining companies following an output maximization strategy during the "supercycle". This result is especially worrying if we consider that mining production linkages were already relatively low at the beginning of our period of analysis (Aroca, 2001) and also when compared to other mining countries such as Australia (Medina, 2017).

Not only have Chilean mining linkages declined, but the way the influence of mining activity is transmitted to the rest of the economy through sectoral interactions also lacks complexity and has not increased significantly. The Structural Path Analysis (SPA) implemented shows that the global influence of mining activity is predominantly transmitted along the shortest paths or through a direct route. This means that impacts on the Chilean mining industry mostly affect those activities directly related to this industry and have scarcely spilled over into other activities. Despite changes in the organization of mining production through increasing externalization, the strong predominance of direct routes of mining activity remained throughout the period of analysis. We do not find long paths of indirect influence in the Chilean mining activity, but only some relevant paths of length two and three. Changes between 1995 and 2011 show that Commerce and R&D increased their role as facilitators, which significantly improved their capacity to transmit influence between mining and other activities. In contrast, the transportation sector may be considered a bottleneck.

Unfortunately, the mining industry in Chile still shows some of the traits of traditional enclave economies due to the lack of capacity of this activity to interact with the rest of the economy, neither in strength nor complexity. In this sense, Chile was not able to take advantage of the opportunities that the "supercycle" brought in terms of the creation of stronger and more complex linkages in the mining industry. The causes of this situation are diverse, such as the higher growth of linkages in other activities compared to mining; the strategy of output maximization followed by the mining companies during the "supercycle"; the structure of the capital ownership in the main mining companies located in Chile, which in most cases tended to capture and export abroad the majority of the value added in the industry; and the lack of sufficient technological capabilities installed in the activities most closely related to mining activity. In this sense, Chile faces both a sectoral problem related to the reduction of linkages in the mining industry and also a systemic problem related to the lack of complexity of its economy. From a policy perspective, these problems require not only sectoral policies and industry actions to improve mining linkages, reinforcing the mining cluster policies and supplier upgrading programs that have been already implemented in Chile at a regional level since 2000 (and at a national level since 2007 in the latter case), but also major economic reforms and plans to increase the complexity and the diversification of the whole economy. For this purpose, further research is needed to understand these causes in more detail and identify the differences between Chile and other countries where mining has become one of the drivers of increasingly complex development.

Appendix 1. Sectors Included in OECD IOTs and corresponding ISIC3 divisions

Industry Code	Sector	ISIC3 Corresponding Divisions
C01T05	Agriculture, hunting, forestry and fishing	01, 02, 05
C10T14	Mining and quarrying	10, 11, 12, 13, 14
C15T16	Food products, beverages and tobacco	15, 16
C17T19	Textiles, textile products, leather and footwear	17, 18, 19
C20	Wood and products of wood and cork	20
C21T22	Pulp, paper, paper products, printing and publishing	21, 22
C23	Coke, refined petroleum products and nuclear fuel	23
C24	Chemicals and chemical products	24
C25	Rubber and plastics products	25
C26	Other non-metallic mineral products	26
C27	Basic metals	27
C28	Fabricated metal products	28
C29	Machinery and equipment, nec	29
C30T33X	Computer, Electronic and optical equipment	30, 32, 33
C31	Electrical machinery and apparatus, nec	31
C34	Motor vehicles, trailers and semi-trailers	34
C35	Other transport equipment	35
C36T37	Manufacturing nec; recycling	36, 37
C40T41	Electricity, gas and water supply	40, 41
C45	Construction	45
C50T52	Wholesale and retail trade; repairs	50, 51, 52
C55	Hotels and restaurants	55
C60T63	Transport and storage	60, 61, 62, 63
C64	Post and telecommunications	64
C65T67	Financial intermediation	65, 66, 67
C70	Real estate activities	70
C71	Renting of machinery and equipment	71
C72	Computer and related activities	72
C73T74	R&D and other business activities	73, 74
C75	Public administration and defence; compulsory social security	75
C80	Education	80
C85	Health and social work	85
C90T93	Other community, social and personal services	90, 91, 92, 93
C95	Private households with employed persons	95

Appendix 2. Normalized Backward and forward linkages

The total normalized backward linkages for the sector j are defined as:

$$T\bar{B}L_j = \frac{BL_j}{\frac{1}{n}\sum_{j=1}^{n} BL_j} \text{ for } j = 1, \ldots, 33.$$

BL_j is the backward linkages for sector j. Backward linkages are defined as the column sum of the Leontief matrix. Sector j's backward linkage is divided by the average of all backward linkages, so sectors with a value greater (lower) than the average can be considered to have stronger (weaker) backward linkages.

The calculation of the normalized forward linkages follows the same idea. The total normalized forward linkages for the sector j are defined as:

$$T\bar{F}L_j = \frac{FL_j}{\frac{1}{n}\sum_{j=1}^{n} FL_j} \text{ for } j = 1, \ldots, 33.$$

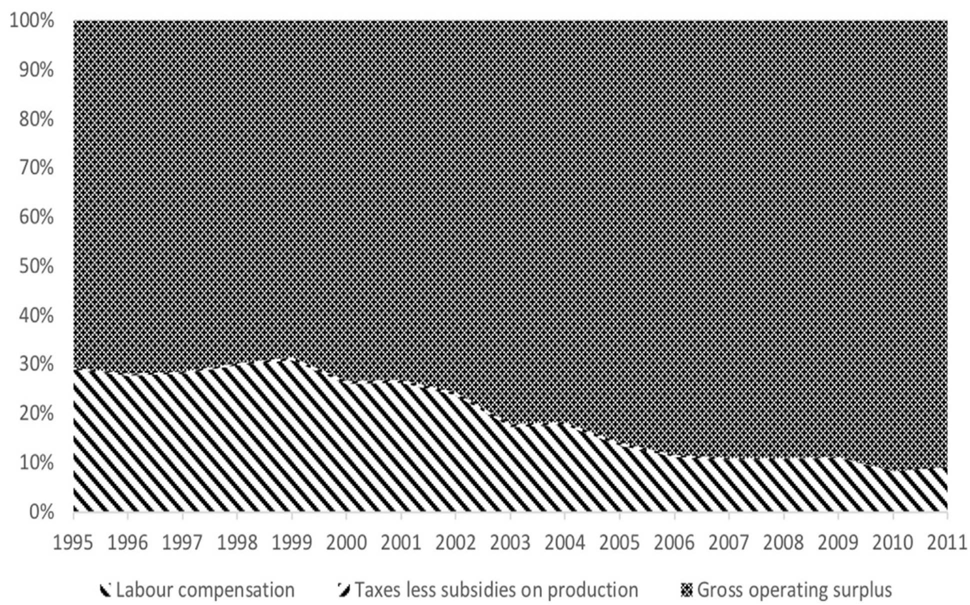
Appendix 3. Comparison of TBL and TFL between OECD and Central Bank of chile input-output tables

Source: Authors' elaboration. OECD sectors are aggregated up to 34 sectors. IOTs from the Central Bank of Chile were constructed according to the ISIC Rev 3.0 for 1996, 2003, and 2008. The mining sector was aggregated (includes copper mining, extraction of oil, coal, and iron, and quarrying) to make it comparable with the definition of the mining sector in the OECD IOTs.

	1996	2003	2008	% change 1996–2008	% change 2003–2008
OECD					
Traditional					
TBL	1.66	1.70	1.51	− 9.5%	− 11.2%
TFL	1.84	1.83	1.68	− 8.5%	− 8.3%
Normalized					
TBL	1.02	0.99	0.87	− 15.2%	− 12.6%
TFL	1.10	1.07	1.00	− 9.2%	− 6.7%
Central Bank					
Traditional					
TBL	1.63	1.69	1.54	− 5.3%	− 8.7%
TFL	1.30	1.25	1.29	− 1.1%	2.8%
Normalized					

TBL	0.99	0.98	0.86	− 12.8%	− 11.9%
TFL	0.78	0.74	0.71	− 8.5%	− 3.4%

Appendix 4. Decomposition of the value-added account for Chile, 1995–2011



Source: Authors' elaboration based on OECD Input-Output database.

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