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Original article

Technology, geography, and diversification in a small mineral economy

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A R T I C L E I N F O

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A B S T R A C T

When should a policymaker promote economic diversification in resource-rich regions? What are the necessary structural economic conditions for such policies to work? How compatible are regional and national strategies of diversification? This study focuses on the general equilibrium properties of policies that aim to diversify the economic structure of regions through productive linkages with the resource sector. Using Chile, a major mineral exporter, as a case study, and exploiting variation induced by the expansion of the mining industry and the commodity prices super-cycle, we analyze how a shock in the resource sector affects other sectors and regions through productive linkages. The results are utilized in simulating the economic conditions under which regional diversification is an optimal strategy for resource-based economic development. Our results support the need for a multiscalar approach for resource-driven economic development policies by showing that optimal outcomes of diversification policies on economic growth are found when policies combine regional, sectoral, and national strategies for development.

1. Introduction

Several studies have explored the economic impacts of the direct effects of a resource boom or bust.[1] However, the capital-intensive nature of the resource sector and its indirect impacts on other sectors and regions suggest that general equilibrium effects are likely playing an important role. This is especially relevant when it comes to predicting the expected long-term impacts of policies that focus on the resource sector as a driving force for local and national economic development (Addison and Roe, 2018; Atienza, Arias and Lufin, 2020; Atienza, Fleming and Aroca, 2021). It also provides information about the effectiveness of policies that aim to diversify the economic structure of resource-rich regions by strategically allocating resources to other sectors that are directly or indirectly linked with the resource sector.

More critically, these resource-driven diversification policies implicitly rely on the existence of agglomeration externalities and productivity spillovers induced by demand linkages from the resource sector (Morris, Kaplinsky and Kaplan, 2012; Farooki and Kaplinsky, 2014; Batisda, 2014).[2] However, these external economies of scale are severely constrained by the size and remoteness of resource-rich regions, which might create incentives for policymakers to favor economic diversification on a national rather than regional scale by relying on the comparative advantages of other regions with larger cities and better market access. For example, to foster certain strategic sectors in resource-rich regions, it might be more effective to invest in other regions linked with these key sectors rather than to promote those sectors in resource-rich regions.[3]

Previous arguments appear to suggest a tradeoff between national and regional diversification strategies in resource-rich economies. The

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1 See, for a detailed survey, Van Der Ploeg (2011).

2 For extensive discussion on these policies, see: Atienza, Arias, and Lufin (2020), Atienza, Lufin, and Soto (2021), IISD, (2019), Korinek and Ramdoo (2017), and Korinek (2020).

3 Otherwise, abstracting from distributional concerns, to develop the necessary scale of the local economy for these policies to work in a remote and small region might require large and long-term oriented investments that are likely inefficient (Kline and Moretti, 2014).

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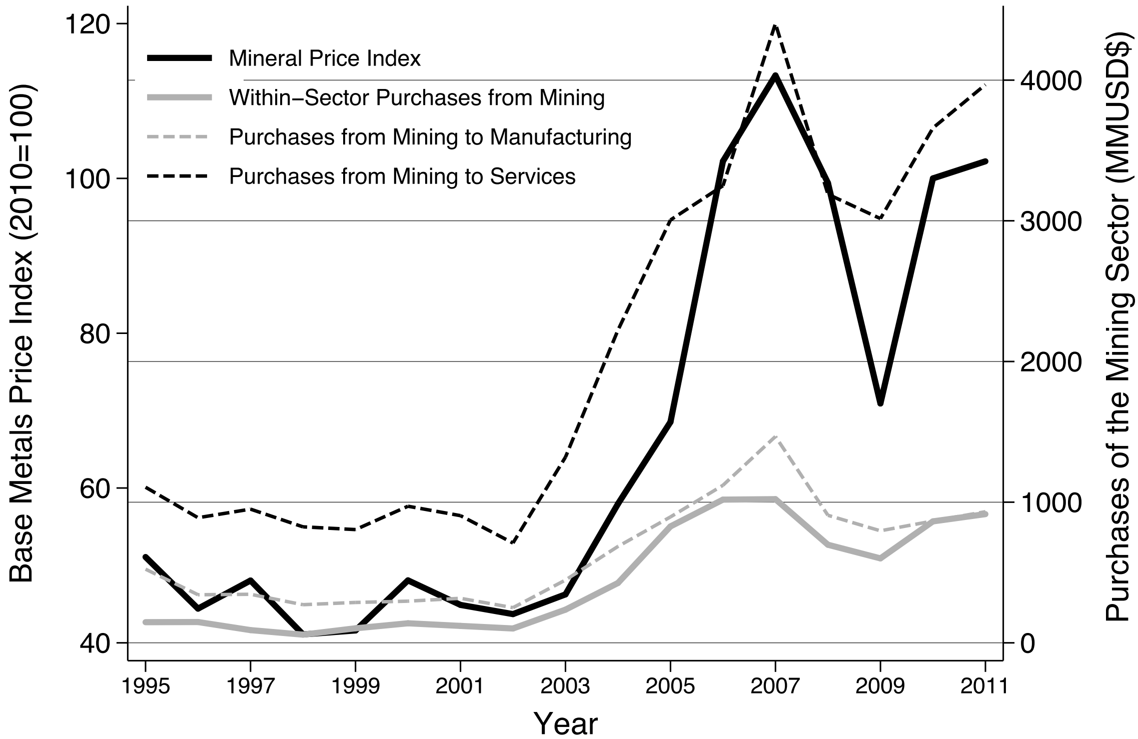

Fig. 1. Mineral price boom and linkage creation
Notes: Figure describes the evolution of the sectoral distribution of purchases in the mining sector and mineral prices. The pattern of purchases of the mining sector is highly correlated with the trends in mineral prices. *Source:* Own elaboration with data from the World Bank Commodity Price Data, and OECD Input-Output Tables.

idea is that this will be affected by the ability of the local economy to generate positive productivity spillovers from investments in other sectors in larger and better-connected regions that are linked to the resource sector. In addressing this argument, appropriate identification of the indirect or general equilibrium effects of the resource sector across other sectors and regions is necessary.[4] This will facilitate the characterization of the structural conditions that are necessary to implement diversification policies in the economy at different spatial scales. It will also provide a better understanding of the potential gains/costs of the strategies that seek to promote economic diversification in resource-rich regions without considering the comparative advantages of other regions and sectors at the national level, and vice versa.

To achieve the research objectives, this paper uses an input-output framework to study how the impacts of a resource boom are propagated in other sectors and regions through demand and supply linkages. Using a theoretical multisector-multiregional trade model with input-output linkages and using input-output data for Chile's mineral price boom in the 2000's we first document the direct and indirect impacts of a resource boom in the mining sector and the potential for productive linkages within this sector to induce diversification. Second, using a simulation exercise based on these outcomes, we analyze the effectiveness of policies that aim to foster diversification by strategically investing in other key sectors at different spatial scales to maximize the gains from the resource boom. Finally, we describe the structural conditions, in terms of the size of the investment shocks in other sectors that the policy would require to induce a diversification path in a resource-rich region.

Results are organized according to two main propositions. First, in line with the work of Atienza et al. (2021), our theory and empirics suggest that although the shock in the resource sector is naturally concentrated in mining regions, large regions (with large market access and subject to more agglomeration externalities) concentrate much of the gains from the resource boom. Mining regions are more likely to overcome the limitations of lower scale when the resource boom is particularly high, in which case the comparative advantage from mineral processing becomes more relevant. This suggests the necessity for some minimum size of the resource shock and scale in mining regions for diversification policies to work. A combination of mining regions with a lack of agglomeration externalities and a weak shock in the resource sector creates an environment in which diversification policies driven by the resource sector is likely to have negligible impacts.[5]

Second, even when the local conditions are favorable for the implementation of diversification policies i.e., when mining regions are endowed with a large pool of workers, or when the shock in the resource sector is sizable, the gains from a resource boom might be largely concentrated in some capital-intensive sectors in which production is highly sensitive to mineral prices, and therefore, likely unsustainable in the long-term. Considering these structural economic conditions, our results suggest that diversification policies, even when they aim to procure long-term economic development in resource-rich regions, should be integrated into a national strategy that combines different

[4] These general equilibrium effects are in nature difficult to measure but could seriously change our understanding of the impacts of a resource boom and bust. Multiple sources of indirect effects of the resource sector can arise, such as crowding-out effects and Dutch Disease (Corden and Neary, 1982; Allcott and Keniston, 2018), or spatial spillovers effects induced by long-distance commuting and the increasing remote operation of mines (Aroca and Atienza, 2011; Paredes, Soto, and Fleming, 2018; Pérez-Trujillo, Oyarzo, and Araya, 2020; Paredes and Fleming-Muñoz, 2021). Other indirect channels also common and widely documented in the resource economics and economic geography literature are environmental externalities (Rivera, 2020), fiscal windfalls (Paredes and Rivera, 2017; Oyarzo and Paredes, 2019), and offshoring by multinational firms (Arias, Atienza, and Cademartori, 2014; Atienza, Lufin, and Soto, 2021; Soto-Díaz, 2022).

[5] This has important implications for policy makers due to the increasing popularity of local content policies in resource-oriented regions (Korinek and Ramdoo, 2017; Katz and Pietrobelli, 2018; IISD 2019).

levels: sectoral, regional, and national aggregate objectives. This would provide the advantage of scale and market access to large cities and ports (Soto and Paredes, 2016) that might enable new firms to operate optimally and overcome a potential resource bust.

The rest of the paper is structured as follows: Section 2 presents the case study and empirical motivation. Section 3 describes the theoretical framework. Section 4 shows the data and methodology and Section 5 discusses the main findings. The concluding remarks and policy implications are presented in Section 6.

2. Background

The super-cycle of mineral prices in the 2000s introduced major changes in the mining industry. China and India's economic growth and the increasing demand for renewable energies resulted in an important variation in the prices and production of mineral commodities. Copper and other sub-products such as molybdenum and lithium were among the most demanded, and Chile, the world's largest copper exporter, experienced large resource windfalls during this period. Despite the short-term benefits from this resource boom, this shock increased specialization in the export of low processed mineral commodities, providing Chile with strong comparative advantages.[6] However, this was at the expense of long-term sustainable economic development in resource-rich regions (Atienza et al., 2020; Atienza et al., 2021; Soto-Díaz, 2022). This strong path dependence is one of the main limitations of local economic development in these regions, and more generally, in peripheral areas (Fernández and Atienza, 2011; Nefke, Henning and Boschma, 2011; Isaksen, 2015; Isaksen and Trippl, 2016).

The recent experience of the super-cycle of mineral prices provides substantive variation to identify the dynamics behind the growth and development of mining regions as well as its spillovers to the rest of the economy. This resource boom induced by the mineral price shock and its potential for resource-driven diversification through productive linkages is represented in Fig. 1. Fig. 1 shows that the potential for diversification linkages is highly concentrated in the services sector. This is consistent with the policy promotion of mining services suppliers (Korinek, 2020). However, it also hides the fact that most of these purchases were made in regions that are far away from mining regions. In fact, in 2013, the capital region of Santiago alone had more than 90% of the total purchases from the mining sector as well as more skill-intensive activities and large firms (Atienza et al., 2021).

Over the relevant years of the expansion of the mining industry in Chile, many policies were applied to attempt to induce a process of endogenous regional development relying on the growth of the resource sector.[7] These resource-driven regional development policies aimed at promoting the formation of a cluster of firms around the resource sector to induce the within- and between-sectoral increasing returns to scale required to generate a process of endogenous growth in those regions (Dietsche, 2014; Pietrobelli, Marin, and Olivari, 2018). However, the effectiveness of these policies is largely dependent on the existence of large external scale economies that would encourage them more than proportional impacts of investments in the resource sector due to local productive linkages.

Moreover, these policies indicated ambiguous long-term impacts on the economic development of mining regions in Chile (Atienza et al., 2020; Atienza et al., 2021). The existence of a cluster around the mining sector has also been challenged by scholars due to the lack of Marshallian externalities in peripheral regions and the strong presence of multinational firms (Arias, Atienza, and Cademartori, 2014; Soto-Díaz, 2022). This motivates research on potential diversification policies and resource-driven economic development that consider the limitations and advantages of the different sectoral, regional, and national levels involved (Fleming, Measham, and Paredes, 2015; Atienza et al., 2021; Korinek and Ramdoo, 2017).

To provide a more detailed analysis of these mechanisms and the extent to which a boom in a key sector can induce regional economic growth and diversification, the following section outlines an economic theory based on a trade model. This theoretical framework would enable us to derive a set of predictions that emerge in an efficient economy but at the same time are consistent with the stylized facts previously documented by Atienza et al. (2021) in their study of the weak form of backward productive linkages in resource-rich regions and the concentration of high-quality linkages in the large and better-connected capital region. We would complement those results by exploiting more of the sectoral unequal distribution of these linkages which we will use later in the paper to simulate the economic impacts and costs of diversification policies.

3. Theory

To inform our empirical analysis, we draw theoretical insights from a multisector, multiregional input-output trade model based on the work of Caliendo and Parro (2015).[8] This section establishes a causal channel on how a final demand shock to a specific sector is propagated to other sectors and regions through productive linkages due to regional and sectoral differences in comparative advantages and technology. Based on this theory, we derive general micro-founded analytical expressions that map to the aggregated input-output data and rationalize the relevant theoretical mechanisms underlying our empirical analysis. Accordingly, we will first describe these theoretical mechanisms in a stylized setting and then show how the input-output data will help us to identify these key underlying effects.

3.1. Technology, geography, and input-output linkages

Let us consider a small economy composed of multiple regions ($J \geq 1$) and sectors ($S \geq 1$). These sectors produce both final goods and intermediate inputs in a competitive economy with a roundabout process. Each destination region j would be endowed with l_j workers with Cobb–Douglas preferences over the consumption of c_j^s final goods in each sector s produced in a sourcing region i.[9] These final goods are produced using intermediate inputs z_i^s and labor l_i^s, with Cobb–Douglas technology. The aggregate production of all varieties of goods Q_i^s in a source region i and sector s assumed a constant elasticity of substitution (CES) technology. Under the assumption that each destination region j will source inputs from the least-cost source region i, we can derive the following expression for the expenditure share of each sector s:

[6] Without many incentives to develop further stages within this value chain (Korinek, 2020).

[7] Bravo-Ortega and Muñoz (2021) present a detailed description of these policies around the mining sector in Chile and the failure to foster regional economic development in peripheral regions. And Atienza, Fleming and Aroca, (2021), summarize the most important trends in the developing of the mining sector and its territorial impacts in Chile.

[8] The theoretical work of Caliendo and Parro (2015) synthesizes a large literature on the role of productive linkages for economic development largely influenced by the work of Hirschman (1958) and Krugman (1991). Despite not modelling directly external economies of scales *a la* Krugman (1991), is able to yield isomorphic equilibrium expressions that are consistent with the idea of how regional differences on comparative advantages and technology shape economic development as in Eaton and Kortum (2002). This has motivated subsequent work not only on the line of formalizing a richer economic theory of spatial productive linkages, such as in Caliendo, Parro, Rossi-Hansberg, and Sarte (2018), but also more general on production networks and value chains (Antràs and Chor (2021)), given the appealing mapping with the input-output Tables

[9] See the Appendix A for the details on the consumer and production structure.

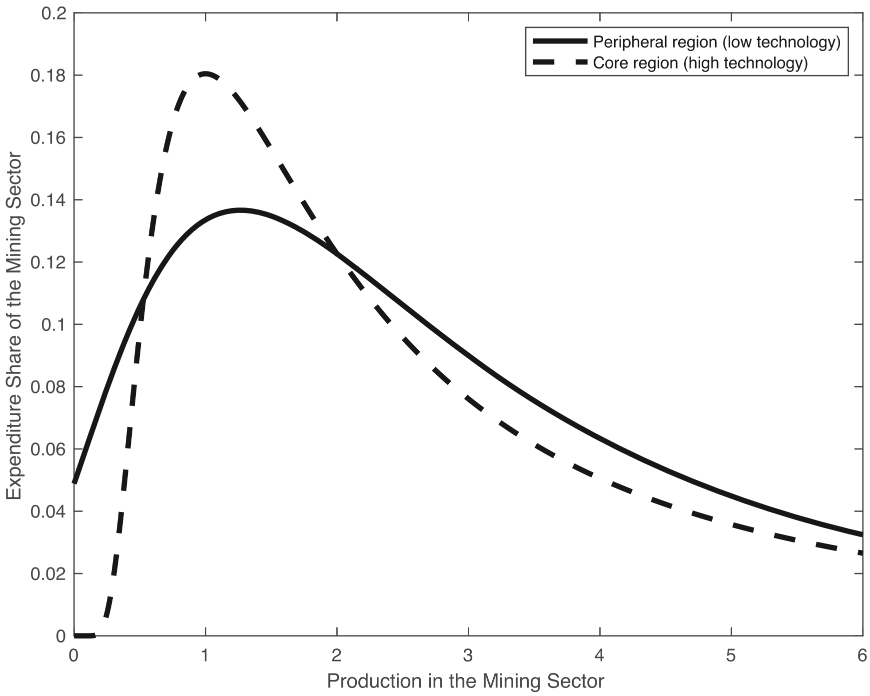

Fig. 2. Expected regional distribution of mining inputs purchases
Notes: The figure illustrates a numerical example of the regional distribution of inputs purchases for the case of two regions with different technology for different levels of production in the mining sector. When the resource boom is large enough, i.e., for high levels of production in the mining sector, the mining -peripheral- region takes a larger share of the expenditures made by the mining sector due to comparative advantages. However, when the resource boom is weak, i.e., for low levels of production in the mining sector, the core region benefits more from the spending of the mining sector.

$$\pi_{ij}^{s} = \frac{T_i^s\left(c_i^s\tau_{ij}^s\right)^{-\theta^s}}{\sum_{k=1}^{J} T_k^s\left(c_k^s\tau_{kj}^s\right)^{-\theta^s}} \tag{1}$$

where T_i^s is the technology, and τ_{ij}^s are iceberg trade costs.[10] The technology came from the aggregation of the production of each variety in which a Hicks-neutral productivity shifter is assumed to follow a type II Fréchet extreme value distribution. This distribution is characterized by the scale parameter T_i^s and the dispersion parameter θ^s. These parameters capture the role of comparative advantages of each region and sector on interregional trade. For a particular region *i* and sector *s,* if the technology parameter is high then comparative advantages in that region and sector are high. However, the relative importance of these comparative advantages on overall trade would be determined by the dispersion parameter. As larger θ^s lowers the role that these comparative advantages play in trade.

The expression for the expenditure share on a sector *s* given in Eqn. (1) yields a thought-provoking result about the implications that a key sector, such as the resource sector in a resource-rich region, might have for economic development. An implication that is driven by the extreme value distribution assumption over the production of the different goods. The use of this probabilistic approach implies that the model has simple analytical closed-form expressions, despite its complexity with multiple regions and sectors, and types of goods involved. More importantly, it allows us to predict how the spending of the resource sector would be allocated among regions depending on the size of those regions and the magnitude of the resource boom under the assumption that technological differences are captured by the size of regions.

For a clearer understanding, it is important to illustrate these effects with a numerical example. Focus is placed on the impacts of one sector (mining) over two regions (core and mining -peripheral- region). Then, expression (1) will reflect the expenditure share of the mining sector in the mining -peripheral- region i, concerning a core region j. Additionally, it is assumed that the core region has a large technology given by its size (proxy of agglomeration externalities) in comparison to the mining -peripheral- region. The expenditure share for a continuum of values that the production in the mining sector can take is also computed. This numerical example is represented in Fig. 2.

Fig. 2 highlights the role of comparative advantages and scale of the region, captured by technology, in the spending allocation of the resource sector, i.e., the formation of backward productive linkages. The comparative advantages of the high production levels in the mining region can be advantageous to the backward productive linkages, while for low production levels the core region surpasses the mining region in terms of productive linkages. The importance of this effect is determined by the role that comparative advantages play by widening the tails of the distribution of the expenditure shares. Where the two regions have the same technology but one of them is endowed with natural resources, a high production level is compared against a low production level in the same curve.

The previous illustration enables us to focus on the extent to which the scale of the region, as a proxy of the technology in those regions, might help to foster a process of regional development through productive linkages with the resource sector depending on the size of the resource boom. However, the extent to which this linkage creation implies higher diversification also depends on how this spending is indirectly allocated to other sectors as well. Empirically, this will be informed by the matrix of indirect requirements among sectors and regions of the input-output data.

4. From theory to data

4.1. Input-output tables

The previous theoretical model informs our empirical analysis by providing a structural interpretation of the input-output coefficients. This input-output data is obtained from the OECD Harmonized Input-Output Tables and is complemented with region-by-sector GDP and employment data from the Chilean Central Bank. The information of the input-output tables is summarized in the intermediate transaction matrix **Z**. This contains information on the intermediates sales and purchases of physical goods z_{ij} between sector *i* and sector*j*. Exogenous

[10] Arkolakis, Costinot, and Rodriguez-Clare (2012) shows that this expression is standard an isomorphic to a wide variety of trade models.

Table 1
Policy scenarios

	Model (1): Product-Oriented and Spatially Blind	Model (2): Sector-Oriented and Spatially Blind	Model (3): Sector-Oriented and Spatially Sensitive	Model (4): Region-Oriented and Spatially Sensitive
Objective Function	Total national GDP; Total national employment; National diversification index based on GDP; National diversification index based on employment	National mining GDP; National mining employment; National mining growth rate	National mining GDP; National mining employment; Regional diversification index based on GDP, Coefficient of Variation of the regional average labor productivity	Regional diversification index based on GDP; Regional diversification index based on employment; Regional employment growth rate; Regional GDP growth rate
Constraints	1. Total investment plan $\leq$ 1,000 MMUSD 2. Diversification index of the investment plan $\geq$ 25% of the initial diversification index based on GDP 3. Total employment growth $>$ 0	1. Total investment plan $\leq$ 1,000 MMUSD 2. Diversification index of the investment plan $\geq$ 25% of the initial diversification index based on GDP 3. Total employment growth $>$ 0 4. Total national GDP growth $>$ 0	1. Total investment plan $\leq$ 1,000 MMUSD 2. Diversification index of the investment plan $\geq$ 25% of the initial diversification index based on GDP 3. Total employment growth $>$ 0 4. Total national GDP growth $>$ 0	1. Total investment plan $\leq$ 1,000 MMUSD 2. Diversification index of the investment plan $\geq$ 25% of the initial diversification index based on GDP 3. Total employment growth $>$ 0 4. Total national GDP growth $>$ 0

Note: The Antofagasta Region in Chile was used as the interest Region-Oriented scenario.

demand (such as household consumption, government expenditure, gross fixed capital formation, changes in inventories, and exports) of sector i are defined in the vector of final demand $\mathbf{f}$. And the GDP of sector$i$, is defined as $x_i = \sum_{j=1}^{n} z_{ij} + f_i$ or equivalently as $\mathbf{x} = \mathbf{Zi} + \mathbf{f}$, with

$$\mathbf{x} = \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix}; \mathbf{Z} = \begin{bmatrix} z_{11} & \cdots & z_{1n} \\ \vdots & \ddots & \vdots \\ z_{n1} & \cdots & z_{nn} \end{bmatrix} \text{and} \mathbf{f} = \begin{bmatrix} f_1 \\ \vdots \\ f_n \end{bmatrix}$$

4.1.1. *Technological sectoral differences*

The technical coefficients or direct requirements of intermediates from each sector are defined as $a_{ij} = z_{ij}/x_j$ or $\mathbf{A} = \mathbf{Z}\mathbf{x}^{-1}$, with

$$\mathbf{A} = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \text{and } x^{-1} = \begin{bmatrix} 1/x_1 & \dots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \dots & 1/x_n \end{bmatrix}$$

where a_{ij} is the proportion of the GDP represented by the sales and purchases of sector i to sector j. As shown in Antràs and Chor (2021), the Caliendo and Parro (2015) multisector multiregional model previously described delivers a structural interpretation for the technical coefficients a_{ij}^{rs} which takes the following form

$$a_{ij}^{rs} \equiv \frac{z_{ij}^{rs}}{x_j^s} = \frac{\Sigma_{k=1}^{J} z_{kj}^{rs}}{x_j^s} \frac{z_{ij}^{rs}}{\Sigma_{k=1}^{J} z_{kj}^{rs}} \frac{\gamma_j^{rs}}{\Sigma_{k=1}^{S} \gamma_{kj}^{ts}} \pi_{ij}^{s} = \frac{\gamma_j^{rs}}{\Sigma_{k=1}^{S} \gamma_{kj}^{ts}} \frac{T_i^s \left(c_i^s \tau_{ij}^s\right)^{-\theta^s}}{\Sigma_{k=1}^{J} \left(c_i^s \tau_{ij}^s\right)^{-\theta^s}} \tag{2}$$

where T_i^s is the technology of each region i and sector s. This technology, as well as consumption c_i^s and trade costs τ_{ij}^s, is embedded in the cross-sectoral intermediate transactions z_{ij}^{rs}, as shown in Eqn. (2). Note here, that the mechanisms underlying Fig. 2 are embedded in this equation.

4.1.2. *Productive linkages*

The backward and forward productive linkages from each sector are computed from the inverse Leontief matrix. Specifically, given $\mathbf{x} = \mathbf{Ax} + \mathbf{f}$, we obtain $\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f}$ with $\mathbf{I}$ a n x n identity matrix, and $(\mathbf{I} - \mathbf{A})^{-1}$ being the Leontief inverse matrix $\mathbf{L} = \begin{bmatrix} l_{11} & \dots & l_{1n} \\ \vdots & \ddots & \vdots \\ l_{n1} & \dots & l_{nn} \end{bmatrix}$, where each l_{ij} represents the indirect requirements of the sector i to the sector j, which can be interpreted as the change in the GDP of sector i due to a change in the final demand of sector j, i.e., $\frac{\partial x_i}{\partial f_j}$. The backward and forward productive linkages are computed as the row and column sum of the Leontief inverse matrix respectively.

To understand the relative influence of the mining sector on the formation of these backward and forward productive linkages we use a methodology known as spheres or fields of influence. This methodology was first proposed by Hewings, Sonis, and Jensen (1988), and, more recently, used by Soza-Amigo, Fuders, and Aroca (2021) for the case of Chile. More precisely, following Sonis and Hewings (1992), we used a first-order field that is defined as a matrix $\mathbf{F_{ji}} = \mathbf{L_j}\mathbf{L_i}$ where $\mathbf{L_j}$ is the "j-th" column-vector and $\mathbf{L_i}$ is the "i-th" row-vector of the Leontief's Inverse matrix $\mathbf{L}$. To summarize the whole information in that field, Frobenius' Norm was used.

4.1.3. *Spatial distribution of sectoral shocks and diversification*

Considering the change between two static equilibrium points from the model, we can present evidence of the theoretical predictions described in Fig. 2. Specifically, the changes in input-output requirements can be decomposed on changes induced by a final demand shock and technology-induced changes. This is obtained by a standard structural decomposition following a study by Dietzenbacher and Los (1998). Thus, the changes in a sectoral GDP vector between two years can be expressed as:

$$x_{i,t=1} - x_{i,t=0} = \underbrace{(\mathbf{I} - \mathbf{A}_{t=0})^{-1} \left(f_{j,t=1} - f_{j,t=0}\right)}_{Final\ Demand\ Shock} + \underbrace{\left[(\mathbf{I} - \mathbf{A}_{t=1})^{-1} - (\mathbf{I} - \mathbf{A}_{t=0})^{-1}\right] f_{i,t=1}}_{Technological\ Change} \tag{3}$$

We studied the implication of these changes for regional diversification by analyzing the spatial diffusion of these effects under the assumption that the diffusion of these shocks is proportional to the region-by-sector product and employment distribution.[11] More precisely, applying a top-down perspective, the national input-output system is spatialized by using a matrix of sectoral GDP shares by region $\mathbf{R_s}$. Following this, a national impact can be distributed among regions using $\mathbf{x_s} = \mathbf{R_s}(\mathbf{I} - \mathbf{A})^{-1}\mathbf{f}$. Additionally, a matrix of sectoral employment coefficients by region (a matrix $\mathbf{E_s}$) can be also used to transform the expected changes in the sectors based on the GDPs of the different regions to determine the expected changes in regional employment, by using $\mathbf{E_s}\mathbf{x_s}$. Both elements enable movement from a national perspective to a

[11] This is in line with our theoretical framework, in which in equilibrium, given the trade balance condition and labor market clearing, the regional sectoral employment equalizes total value-added in each region (Antràs and Chor, 2021).

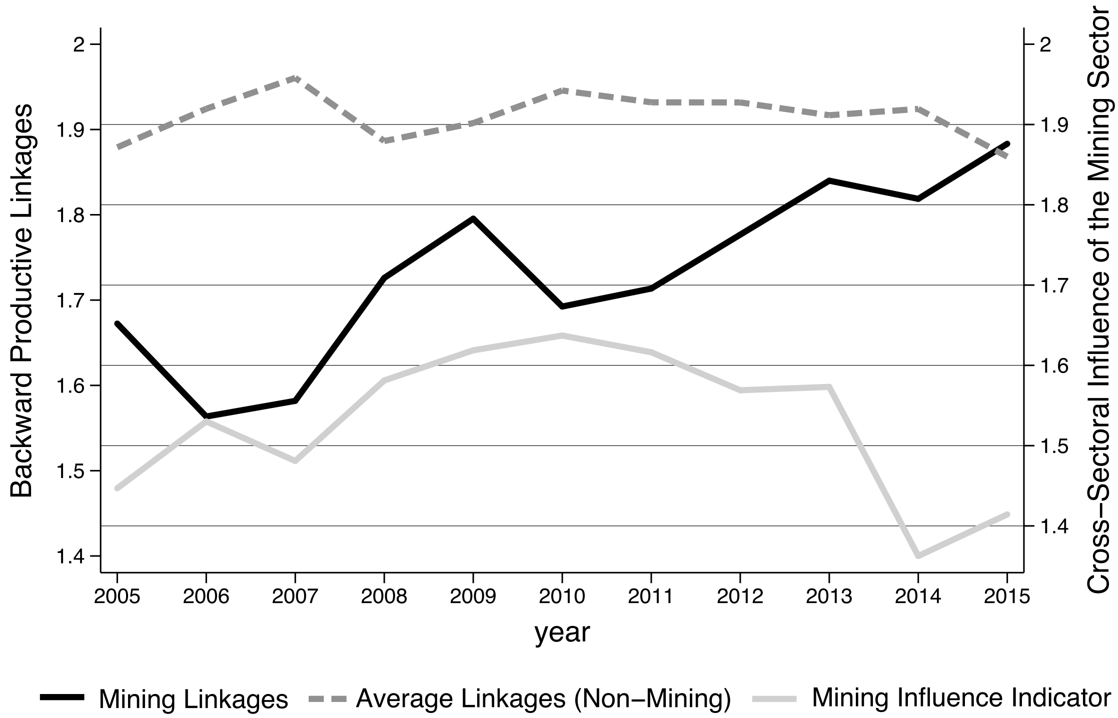

Fig. 3. Mining linkages and its potential for diversification
Notes: Figure displays the evolution of backward productive linkages in the mining sector and the rest of the economy. In addition, an indicator of the influence of the mining sector for diversification is represented (gray line).

regional one.[12] To measure if the shock in the resource sector is concentrating or diversifying the economy, we compute a diversification index, as the additive Inverse of Herfindahl's concentration Index (Kelly, 1981):

$$D = \left[1 - \sum_i \left(\frac{x_i}{x}\right)^2\right] \in [0, 1] \tag{4}$$

where $\frac{x_i}{x}$ represents sectoral GDP or employment shares. A zero value is interpreted as no diversification (total concentration) and a value of one means total diversification (or zero concentration).

4.2. Simulation analysis

Finally, using the previous input-output structure, we performed a series of simulation exercises where we evaluated a set of particular investment plans with different spatial and sectoral orientations. These investments were allocated among the different sectors and regions to maximize an objective function composed of a set of observable indicators of economic performance and diversification that are relevant for the policymaker, subject to a fiscal constraint. These simulation exercises rely on the assumption that different policymakers have a set of political goals on which their decisions are based (Brennan and Buchanan, 1978; Romer, 1988). Similar to a managerial discretion model (Williamson, 1963), the policymaker is maximizing a social welfare function that depends on a set of observable indicators. These indicators will define four types of policy scenarios.

A spatially blind set of strategies are divided into (1) a product-oriented policymaker that prioritizes overall GDP and employment growth and diversification; and (2) a sector-oriented policymaker that gives more relevance to growth in the mining sector. There are also two sets of spatially sensitive policies, i.e., strategies that consider regional indicators of economic performance. These are divided into policies that (3) prioritize the mining sector in a specific region, and (4) prioritize economic growth and diversification in a mining region. Table 1 details the indicators of economic performance and constraints for each policy scenario. The investment allocation decision is constrained by (1) the total investment budget, (2) that should not reduce the present level of employment and GDP, and (3) that should allocate the investment with at least a 25% of diversification among the sectors, measured on GDP.[13]

5. Results

The results are divided into two parts. First, we describe the input-output structure of the economy during the resource boom between 2005 and 2015 and compute a series of indicators that help us to understand the resource sector's potential to induce growth and diversification. Second, we discuss the findings of the simulation analysis of the various resource-driven policies with different orientations and present insights into the complementarity of different policy approaches that promote growth and diversification on different spatial scales.

5.1. Linkages for diversification?

The expansion of the productive linkages of the mining sector indicates the sector's potential to induce a process of diversification through related activities. The evolution of these linkages between 2005 and 2015 is described in Fig. 3. Backward productive linkages of the

[12] This differs from traditional bottom-up regionalization methods that uses location employment coefficients to weight the national technical coefficients. Our methodology instead distributes the shocks according to a top-down perspective.

[13] This last restriction was imposed to avoid a corner solution.

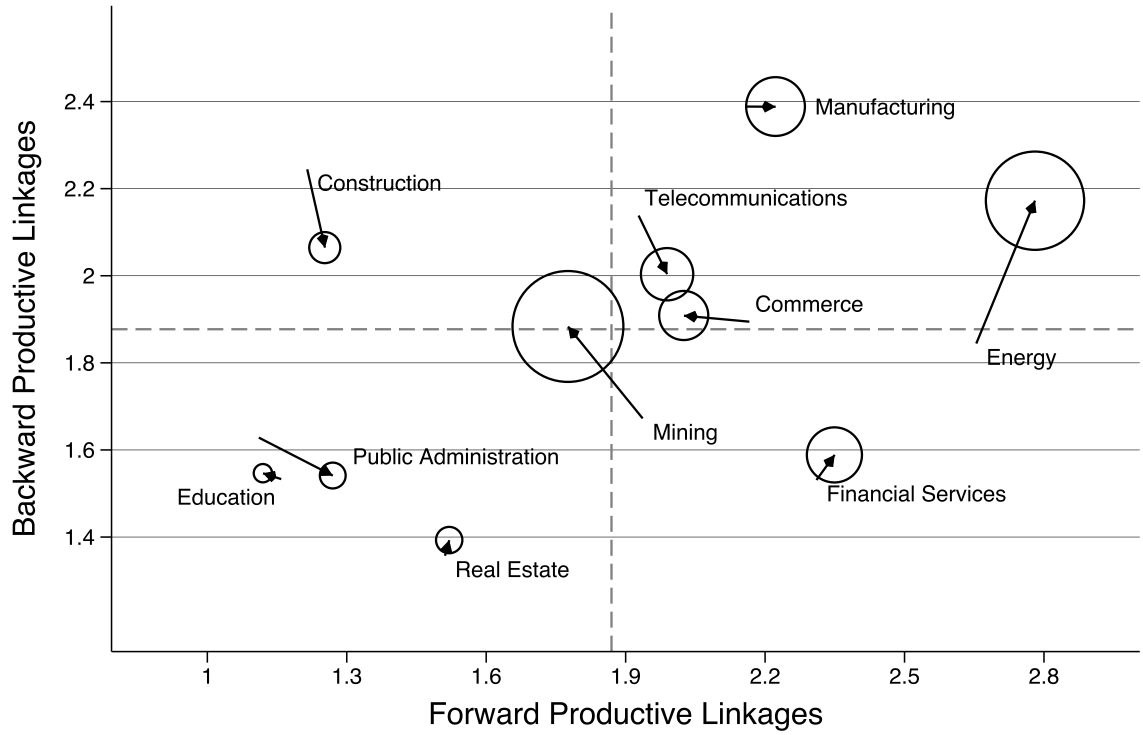

Fig. 4. Evolution of key sectors and its mining influence
Notes: Figure displays the evolution of productive linkages between 2005 and 2015. Markers are weighted by the participation of mining in the sector in 2015.

mining sector are compared to the national average backward productive linkages in other sectors, excluding mining. Mining linkages were expanded during the decade studied but the gap in productive linkages with other sectors has been declining.[14] This indicates that the mining sector has become more integrated with the economy. However, this should be taken with caution because, as shown by Atienza et al, (2021) and predicted by our theoretical framework, these linkages are highly concentrated in large agglomerations far away from resource-rich regions.

To the extent that the increase in backward productive linkages of the mining sector is also highly concentrated in sectors with low added value and low potential to induce technological change, the increase in backward linkages does not necessarily imply a greater potential for the mining sector to induce diversification in other sectors at a national scale. For an in-depth study of this argument, Fig. 3 incorporates an indicator of the influence of the mining sector in inducing diversification, i.e., how concentrated are these productive linkages of the mining sector.[15] The indicator reveals that the influence of the mining linkages to induce diversification has been declining in the last half of the decade following a pattern that is contra cyclical to the measure of backward productive linkages. This is consistent with the idea that these backward linkages of the mining sector are highly and increasingly concentrated in specific sectors.

5.2. Key sectors and mineral price volatility

To provide more evidence on how concentrated the linkages of the mining sector are, and the potential of these linked key sectors to indirectly induce more diversification in the economy, Fig. 4 shows the change in backward and forward sectoral productive linkages between 2005 and 2015. In addition to a measure of the mining sector's relative importance in the formation of these linkages (markers in Fig. 4 are weighted by the value of this measure in 2015), this indicator of the cross-sectoral influence of the mining sector is computed as the percentual change in sectoral GDP induced by a negative shock in the mining sector, using a hypothetical extraction methodology. This shows the extent of the impact in other sectors of the economy in a counterfactual situation in which the resource sector is absent.[16]

The first fact that comes to our attention from Fig. 4 is that the key sectors of the national economy in terms of backward and forward productive linkages are also the sectors that are most affected by mining activity (as the size of the markers show). They include energy, manufacturing, telecommunications, commerce, and financial services. This provides an idea of the importance of mining in the overall structure of the Chilean economy. Interesting to note also, is how the magnitude of the growth in backward productive linkages of the mining sector corresponds to the growth in forward productive linkages of the energy sector, which is by far the most linked sector to mining. More precisely, around 1/3 of the overall activity in the energy sector is explained by the linkages with the mining sector, which is particularly high in comparison to other key sectors connected to mining where the size of the activity is explained by mining linkages is between 4% to 6%. These results displayed little temporal variation in the relative influence of the mining sector on other sectors of the economy.[17]

Given that most of the impacts of the mining sector are highly

[14] This pattern is slightly different from Atienza, Lufin, and Soto (2021) due to differences in the period studied.

[15] This indicator is computed using the fields of influence methodology previously described. That allow us to measure how the effect of a marginal change in a technical coefficient propagates to other sectors.

[16] Intertemporal changes in this indicator are relatively small. The changes between 2005 and 2015 are reported in the Fig. B1.

[17] See the Fig. B1, in the Appendix, for the intertemporal change in the indicator of mining influence among sectors.

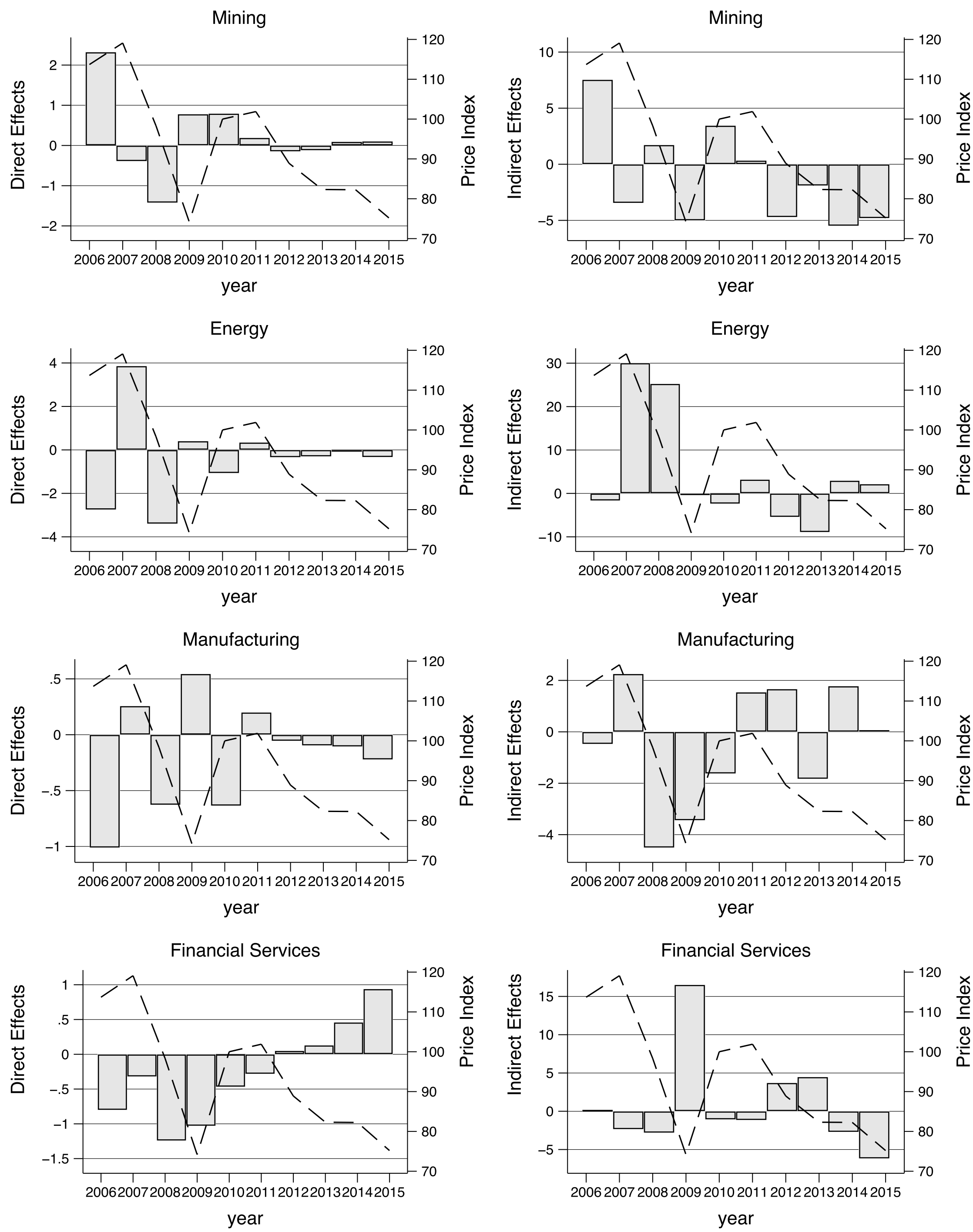

Fig. 5. Direct and indirect effects of key sectors and mineral price volatility
Notes: Figure displays the temporal association between base metals mineral prices (dashed line) and the annual change in the direct (left) and indirect impacts (right) of the mining sector and key sectors linked to mining.

Table 2
Policy simulations

	Initial Level	Percentual Change Induced by the Policy Shock Model (1)	Model (2)	Model (3)	Model (4)
Panel A. National Indicators					
Growth in National GDP	470,239.63	**0.513**	0.405	0.408	0.394
Growth in National Employment	8,135.88	**0.371**	0.201	0.209	0.231
Diversification of the National GDP (Eqn 4)	0.888	-0.031	0.001	-0.003	0.001
Diversification of National Employment (Eqn 4)	0.842	**0.032**	0.028	0.027	0.017
Panel B. Mining Sectoral Indicators					
Growth in Sectoral GDP	50,686.80	0.343	**2.092**	**2.081**	**2.066**
Growth in Sectoral Employment	248.679	0.343	**2.092**	0.492	**2.066**
Diversification of the Sectoral GDP (Eqn 4)	0.718	0.000	0.000	0.000	0.000
Coefficient of Variation (GDP_r /E_r)	0.681	-0.120	**0.520**	**0.492**	**0.517**
Panel C. Regional Indicators					
Growth in Regional GDP		0.423	**1.138**	**1.116**	**1.116**
Growth in Regional Employment		0.345	**0.519**	**0.522**	**0.540**
Diversification of Regional GDP (Eqn 4)	0.721	**0.048**	-0.503	-0.507	-0.503
Diversification of Regional Employment (Eqn 4)	0.840	**0.025**	-0.021	-0.022	-0.027
Coefficient of Variation (GDP_i /E_i)	2.705	**-0.077**	-0.612	-0.588	-0.570

Notes: The table describes the results of the policy simulations. Model (1) national spatially blind product-oriented, allocated the investment optimizing over the four indicators in Panel A). Model (2) spatially blind sectoral oriented focuses on growth in both national and sectoral GDP and national employment. Model (3) spatially sensitive sectoral oriented focuses in both national GDP and sectoral employment in mining, in addition to diversification of sectoral mining GDP and GDP/Er, both between regions. Finally, model (4), spatially sensitive regional-oriented chooses the indicators described in Panel C).

concentrated in the energy sector, which is strongly linked to the economy in terms of backward and forward productive linkages, there may be a high potential to induce a process of diversification as an indirect second-order effect in this sector. However, a special concern of this potential channel is the volatility of these linked sectors. To shed some light on this, a decomposition of the direct and indirect effects of the growth in final demand of these key sectors (with high backward and forward productive linkages), is compared to the yearly variation in base metals mineral prices in Fig. 5.

Following Eqn. (3), Fig. 5 decomposed the total annual change in gross value of production in an effect that is induced by a change in final demand (direct impacts) and another effect that is provoked by a change in the inverse of the Leontief matrix (indirect impacts). The figure shows a strong serial correlation among all these sectors. This volatility is strong and procyclical, both in terms of the direct and indirect impacts of each of these sectors.[18] Although this correlation is more evident in the energy and manufacturing sectors, and less strong for financial services, it suggests that these sectors are highly sensitive to the volatility of mineral prices, and therefore, unlikely to induce a sustainable pattern of economic development.

5.3. Diversification policies in resource-rich regions

Using the input-output structure previously described, we perform an optimization exercise simulating four types of resource-driven policies of diversification and economic growth with different sectoral and spatial orientations.[19] This aims to provide insights into the complementarities among these different types of policies and the extent to which diversification is feasible in resource-rich regions. The policy shock in this set of simulations is 1,000 MMUSD.[20] The potential outcomes of each type of policy scenario are computed according to the four different models described in the methodology and detailed in Table 1. Table 2 describes the average impacts of the different policy simulations between 2013 and 2015.[21]

The first thing to note from Table 2 is that all the different policies achieve small effects on the diversification indicators at the different spatial levels. This is likely explained by the highly concentrated input-output structure of the economy. Surprisingly, however, when the policy has a national orientation, in Panel A) model (1), it achieves higher indicators of regional diversification both in terms of GDP (0.048%) and regional employment (0.025%). For every other policy scenario (models 2 to 4), the change in the indicators of diversification at the regional level is negative and very similar (approximately −0.05% for GDP and −0.02% for employment). The change in the variation coefficient at the regional level, however, is negative for all models, and larger for the regional-oriented policy (model 4, −0.57%) compared to the case of the national-oriented policy (model 1, −0.08%).

Although diversification in the mining region is higher in the case of the national-oriented policy (model 1), the achievements in regional GDP and employment growth are significantly smaller than those in other policy approaches (models 2 to 4). This is consistent with the hypothesis of a tradeoff between diversification and overall growth, which might be explained by the fact that to induce diversification, some investments must be allocated in sectors within less specialized regions with lower comparative advantages and investments that might be much more profitable in the long-term rather than in the short-term.

There are small differences in the GDP and employment growth among policy approaches that have a more sectoral or regional orientation (models 2 to 4). These approaches have an impact on regional GDP growth of about 1.1% and regional employment growth of approximately 0.5%. This is also likely because sectoral and regional

[18] See the Fig. B2, in the Appendix, for the comparison of the evolution of mineral prices and change in final demand by sector.

[19] Our input-output analysis is different from a structural estimation of the general equilibrium model. Because it allows the production and consumption structure of the economy vary due to a final demand shock in the mining sector. While a structural estimation of the model would imply the identification of constant elasticities and parameters of the production and consumption structure of the economy that define the counterfactual scenario.

[20] We use the Region of Antofagasta as a benchmark of a mining region. See Aroca (2001) for a detailed description of the mining region of Antofagasta.

[21] Due to data availability on region-by-sector GDP and employment we limit the simulation analysis to 2013–2015.

approaches prioritize investments in sectors where the mining region has larger comparative advantages and similar effects.

In terms of sectoral GDP and employment growth, the optimal results are also obtained with sectoral and regional policy approaches (models 2 to 4). The changes induced in the diversification of sectoral GDP are null but are similar among the policies in terms of the Coefficient of Variation. At this point, results suggest that the sectoral and regional approaches (models 2 to 4), disregarding the spatial orientation of these policies, achieve very similar and positive results. This might be due to the high specialization of mining regions and the overall national economy in key sectors linked to mining, which have shown to be correlated with mineral prices. Given this structure of the economy, there is not much difference between sectoral and regional orientations of resource-driven development policies. Despite their significant impacts on sectoral and regional GDP and employment growth, they all accomplish very little results in terms of the different diversification indicators.

Regarding the overall national GDP and employment growth, some notorious differences among the various policy scenarios exist. When the policymaker has a national orientation, it achieves a high indicator of growth in GDP (0.51%) and employment (0.37%). However, in all other policy scenarios with sectoral and regional orientation, the GDP and employment growth at the national level are about 0.4% and 0.2% respectively. These are important magnitudes considering the baseline level of GDP and employment. This indicates that sectoral and regional-oriented policies have a cost in terms of the efficiency of the national economy of roughly 0.1% of the GDP compared to a counterfactual situation in which those resources were spent with a national and spatially blind orientation.

These differences between sectoral and regional vs national and spatial blind-oriented policies are particularly interesting because policies that have a sectoral and regional orientation have shown to have a highly significant impact on the growth of sectoral and regional GDP and employment compared to the national-oriented policy scenario. Specifically, they make up almost 2% of GDP and employment growth in the mining sector, about 0.7% in regional GDP growth, and 0.2% in regional employment growth. These results, in line with the work of Atienza et al. (2021), suggest that the gains from national-oriented resource--driven policies might be captured by the metropolitan region, given the low increase in sectoral and regional GDP and employment growth in the case of the national-oriented policy scenario (model 1).

The optimization exercise underlying each policy simulation also displays optimal allocations of the public investments among sectors to achieve growth in the performance indicators assumed in each scenario. Of the 1,000 MMUSD investment in model (1), 87% is spent in manufacturing and 13% on energy. In model (2), the optimal public investment allocation is 88% in the mining sector, 4% in manufacturing, 6% in energy, and 2% in construction. Similarly, in model (3), the optimal sectoral investment allocation is 88% in mining, 11% in manufacturing, and 2% in energy. Finally, in model (4), 88% is invested in mining, 10% in public administration, and 3% in commerce. There is little difference among the years both in terms of the optimal allocation of the public investments and in terms of the changes in the indicators induced by these investments (see Table 3).

It is important to mention that the small changes in the diversification indicators might provide a wrong sense of achievement of these policies. This has led us to examine how large the public policy shock must be to achieve a significant change in diversification: we set this at 3%. The results suggest that to achieve this goal, a particularly large policy shock of about 100,000 MMUSD is necessary coupled with about 89,304 MMUSD for the case of the regional-oriented policy approach (see Table 3). Despite how unrealistic these investments may appear over such a short period, they demonstrate the magnitude of the difficulties involved in inducing a strong process of diversification in resource-rich regions. Consistent with our theoretical predictions, these results are in line with the idea that the shock in the resource sector must be particularly large to induce important changes in the allocation of spending and changes in technology within the resource sector of those regions, and, consequently, diversify the mining regions.

6. Concluding remarks

In responding to the question of how resource-rich regions can generate a path toward regional diversification and economic development, this paper provides empirical evidence of the structural economic conditions required for the feasibility of such a diversification process. First, from a theoretical perspective, we describe how a shock in the resource sector is distributed among regions through productive linkages, considering both technological differences among regions and the role of comparative advantages in each sector. Then, we provide an empirical macroeconomic description of a small mineral economy to determine the potential for diversification through productive linkages in the mining sector. Using this input-output structure, we simulate the impacts that diversification that policy shocks with different objectives of sectoral, regional, and national orientation would have on economic growth. The results provide insights on two main fronts to guide policymakers.

6.1. What kind of diversification?

The idea that regions experience growth and diversification over time due to the growth and development of related activities linked to key sectors is important in the field of economic geography. This theory suggests that resource-rich regions (or more generally, peripheral areas), can move from their path dependence by developing these related activities. This paper complements this view by showing that a large policy shock might be required to induce a process of considerable diversification in the context of resource-rich regions. This is arguably because of the high dependence on primary activities and remoteness of these regions. However, to the extent that the resource boom is large enough, comparative advantages in mineral processing in mining regions can substantially help to foster diversification. Otherwise, the scale effect of large regions better connected to markets takes much of the gains from the resource sector.

Our paper also suggests that because linkages of the mining sector are spatially concentrated and highly concentrated in some specific capital-intensive sectors, the scope for diversification policies focusing on linkage creation is limited. As an example, the energy sector of the case study captures about one-third of the backward productive linkages that are being generated in the mining sector. And despite the recent important technological changes faced by this sector, its growth and indirect impacts are strongly correlated with mineral price shocks as in other sectors where mining plays an important role, i.e., manufacturing and financial services. All this might support the idea of more complex forms of diversification strategies that exploit comparative advantages at different sectoral and spatial scales.

6.2. A multiscalar approach to resource-driven economic development

The central contribution of this paper is to offer insights on the importance of a multiscalar approach in the design and implementation of resource-driven regional development policies. The analysis of such a question inevitably requires the consideration of the indirect impacts of the resource sector through a general equilibrium analysis. Our simulations based on input-output data suggest that mining peripheral regions can exploit their comparative advantages and induce technological change while they can also rely on the advantages of larger regions better connected to markets which might endure the positive productivity spillover effects from a resource boom and strengthen the competitiveness of the sector.

More precisely, our simulation results over the input-output data for Chile show that optimal results for diversification and economic growth are founded when regional, sectoral, and national levels of policy orientation are combined. On the one hand, a national-oriented policy that is spatially blind to the objectives of economic growth, employment formation, and diversification, is associated with small effects on economic growth in mining regions. On the other hand, a policy of regional development that only focuses on the objectives of promoting growth in mining regions is also associated with losses in terms of national economic growth.

6.3. Limitations and further research

Our paper describes the aggregate structural features of the economy that are necessary to induce a significant process of diversification driven by the mining sector. In a context in which several diversification studies with important causal implications and detailed data, fail to quantify the overall importance of productive linkage mechanisms with the resource sector. Our paper complements the literature by offering an aggregate picture of how relevant these linkage channels are for diversification and how limited they are by the macroeconomic structural conditions.

Despite the usefulness of input-output data to our research objectives, it also imposes important limitations to the analysis that are worth mentioning. These are mainly related to the lack of interregional trade flows, wide sectoral aggregation, and unobserved within-sector heterogeneity, which might have important consequences for our results. Along this line, some studies have used microdata in innovative ways to compute more reliable measures than the ones obtained from input-output data, such as employment multipliers (Fleming and Measham, 2014). With the availability of more granular data on input-output firm-to-firm relations, others have been able to carefully explore the role of firms' heterogeneity and their participation in global production networks and global value chains (Arkolakis, Huneeus, and Miyauchi, 2021; Antràs and Chor, 2021).

The microdata might lead to interesting extensions on the implications for diversification. For example, a common argument to avoid diversification policies in a resource-rich region is that they might induce distortions due to the misallocation of resources toward less competitive sectors in less competitive regions. This might explain some of the potential efficiency losses in our simulation analysis for regional-oriented policies. A proper structural estimation of a general equilibrium model using detailed microdata of firms would enable the measurement and quantification of these effects. More importantly, our conclusions assumed a Hicks-neutral technological change, however, there might be unintended consequences for diversification and economic growth that emerge from the effects of labor-saving technologies in the mining sector, and how these improvements are passed to other sectors through productive linkages.

Finally, despite the peculiarities of the case study, Chile shares several features that also contribute to improving our understanding of other so-called emerging mineral economies. The idea of an emerging economy with an important export based on the resource sector whose activities are developed in remote regions and where the small market size suggests that there can be no significant effect on international prices. Peru and South Africa are obvious examples where the mining sector represents a large share of their GDP, although with a more important informal sector. More importantly, however, our conclusions might extend to more general situations generated by the lack of coordination between local and national policymakers in the design of regional diversification and economic development policies.

Appendix A

A.1. Multisector multiregion input-output trade model

Consumers' Cobb–Douglas preferences over goods within sector s in each region j are given by

$$u(C_j) = \prod_{s=1}^{S} \left(C_j^s\right)^{\alpha_j^s}$$

where C_j^s is the aggregate consumption of a sector s in each region, and α_j^s is the expenditure share on each sector and region, with $\sum_{s=1}^{S} \alpha_j^s = 1$. Each sector is composed of a continuum number of varieties $\omega^s \in [0,1]$ where the production of each variety in each sector y_i^s is also Cobb–Douglas with labor l_i^s and intermediate inputs z_i^s, according to

$$y_i^s(\omega^s) = z_i^s(\omega^s)\left(l_i^s(\omega^s)\right)^{1-\sum_{r=1}^{S}\gamma_i^{rs}} \prod_{r=1}^{S} \left(\mathscr{M}_i^{rs}(\omega^s)\right)^{\gamma_i^{rs}}$$

where $\mathscr{M}_i^{rs}(\omega^s)$ is the total intermediate inputs from industry r used to produce a variety ω^s in region i, and γ_i^{rs} is the share of costs spent on those inputs, with $0 < \gamma_i^{rs} < 1$, and $0 < \sum_{r=1}^{S} \gamma_i^{rs} < 1$. $z_i^s(\omega^s)$ is a productivity shifter in the intermediates and is drawn from a type II Fréchet extreme value distribution with cumulative distribution function $F_i^s(z) = \exp\{-T_i^s z^{-\theta^s}\}$, scale parameter T_i^s (technology) and dispersion parameter $\theta^s > 1$. There is a CES aggregator over all varieties in each sector and region, which is given by

$$Q_i^s = \left(\int q_i^s(\omega^s)^{\frac{(\sigma^s-1)}{\sigma^s}} d\omega^s\right)^{\frac{\sigma^s}{(\sigma^s-1)}}$$

where $q_i^s(\omega^s)$ corresponds to the amounts of ω^s that are purchased from the least-cost region. These least-cost source locations are determined by a unit cost of production c_i^s from each origin region i and sector s, plus iceberg trade costs τ_{ij}^s. This, in equilibrium, shapes the expenditure share that each origin-destination pair spends on each sector displayed in Eqn. (1) in the main document, which is similar to the study by Eaton and Kortum (2002). Given the probabilistic formulation of the model induced by Fréchet distribution draws, the cost-minimizing production in a destination region is $c_j^s = \Upsilon_j^s w_j^{1-\sum_{r=1}^{S}\gamma_j^{rs}} \prod_{r=1}^{S} (P_j^r)^{\gamma_j^{rs}}$ where $\Upsilon_j^s =$, and the price index is defined as $P_j^r = \kappa^r \left[\sum_{i=1}^{J} T_i^r (c_i^r \tau_{ij}^r)^{-\theta^r}\right]^{-1/\theta^r}$. The model is closed by imposing the market-clearing in each industry and region, and balance trade, which implies that imports in a region equal exports and a deficit term. While market-clearing implies that the total expenditure in each sector and region $X_j^s = \sum_{i=1}^{s} X_{Ij}^s$, equals the value of gross output in that region and sector Y_j^s.

A.2.

Table 3
Outcomes for a policy shock with a 3% diversification objective

	Initial Level	Percentual Change Induced by the Policy Shock Model (1)	Model (2)	Model (3)	Model (4)
Panel A. National Indicators					
Growth in National GDP	470,239.63	44.867	52.925	53.201	50.144
Growth in National Employment	8,135.88	34.739	40.144	41.161	43.087
Diversification of the National GDP (Eqn 4)	0.888	0.701	0.203	0.252	0.708
Diversification of National Employment (Eqn 4)	0.842	2.968	3.042	3.020	2.975
Panel B. Mining Sectoral Indicators					
Growth in Sectoral GDP	50,686.80	19.359	26.588	26.506	25.836
Growth in Sectoral Employment	248.679	19.359	25.588	26.506	25.836
Diversification of the Sectoral GDP (Eqn 4)	0.718	0.000	0.000	0.000	0.000
Coefficient of Variation (GDP_r /E_r)	0.681	-2.388	-1.389	-1.842	2.055
Panel C. Regional Indicators					
Growth in Regional GDP		39.856	49.822	49.207	48.123
Growth in Regional Employment		32.216	38.749	39.115	37.821
Diversification of Regional GDP (Eqn 4)	0.721	6.592	6.408	6.342	6.167
Coefficient of Variation (GDP_i /E_i)	2.705	-5.171	-6.861	-6.087	-6.165
Total Investment		100,000	100,000	100,000	89.304

Appendix B

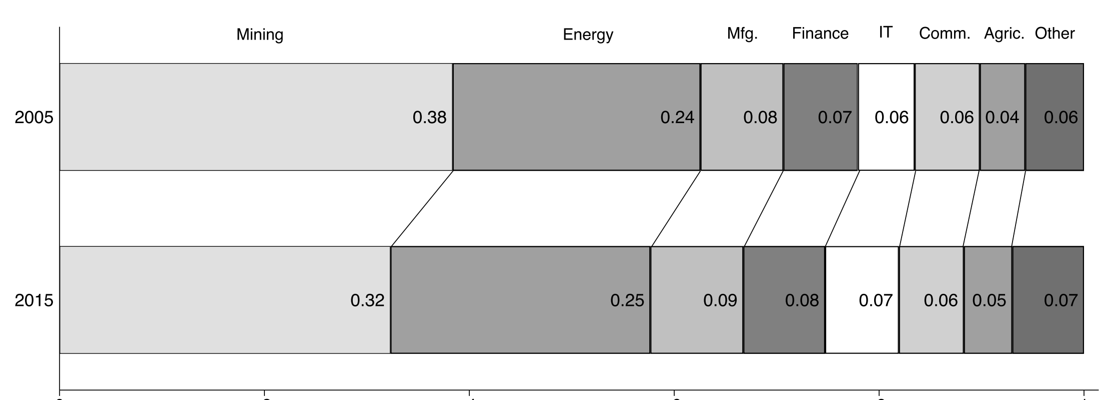

Fig. B1. Proportional impacts of mining among sectors

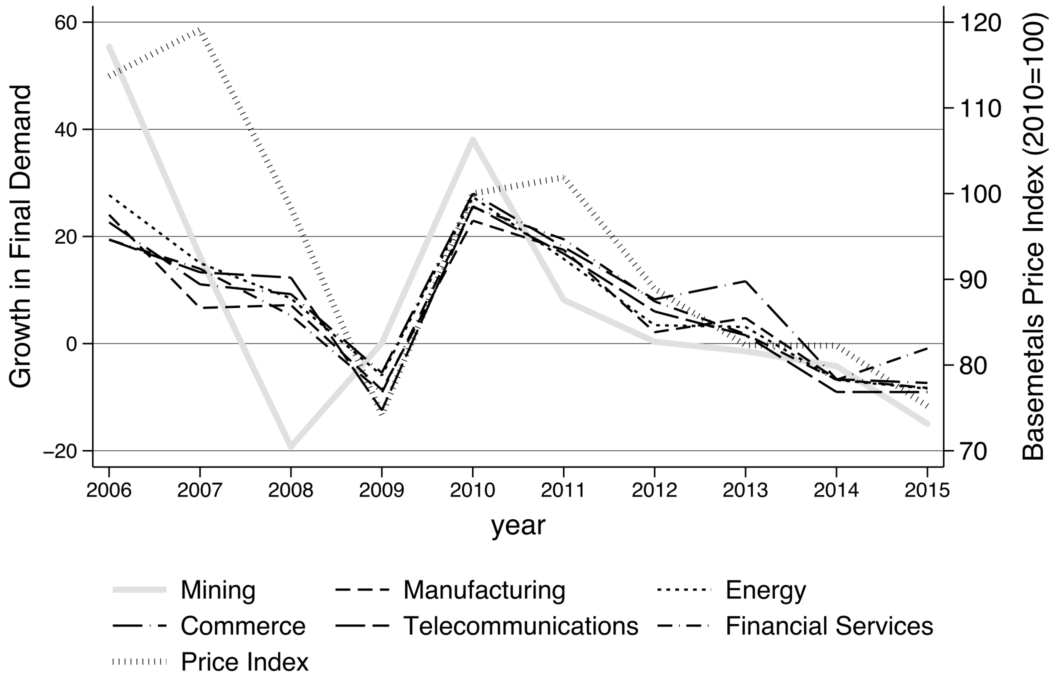

Fig. B2. Growth in final demand and mineral prices volatility

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