

Kaldor meets Dosi: an approach to the technological structure of regional production

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Abstract

This paper proposes a theoretical connection between the ideas of economists Nicholas Kaldor and Giovanni Dosi, based on an analysis of the technological structure of regional output using the input-output methodology created by Wassily Leontief, and applies this connection to the economy of the Brazilian Legal Amazon, specifically the state of Pará. Illustratively, the focus is placed on the mining sector, which accounts for a large share of output in the state. To summarize the findings, applying the Kaldor-Dosi approach made it possible to identify the importance of intersectoral technological diffusion at the international level through global value chains and the effects of these on local economic dynamics. This preliminary application of the Kaldor-Dosi perspective with the aid of the input-output matrix shows that mining is export-oriented and therefore linked to the trajectories of global technologies in the sectors for which it produces inputs.

Keywords

Economists, industrialization, mining industry, industrial development, technological change, input-output analysis, regional economics, Brazil

JEL classification

O14, O33, R11, C67

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I. Introduction

This study seeks to establish a theoretical connection between the formulations proposed by Kaldor (1966) and Dosi (1984), analysing the technological structure of regional output in the state of Pará in Brazil with the input-output methodology created by Leontief (1936). Illustratively, it focuses on the mining sector, which accounts for a large share of economic output in the state.

According to Santos (2017), the mining economy in Pará has generated processes that have accelerated population growth and urbanization, with the creation of new municipalities and the installation of road, energy and communications infrastructure. The economic dynamics of south-eastern Pará exerted a strong influence on the state's economic performance both in the period from the 1960s to the 1980s, with the implementation of major agribusiness projects and a large wave of migration into the mesoregion, and again from the 1980s, when mining became strongly established. In 2022, according to data from the Brazilian Mining Institute (IBRAM), mining companies in Pará recorded revenues of 92.4 billion reais, second only to Minas Gerais with 100.5 billion reais.

The objective of this paper is to estimate changes in multiplier effects in the Pará industrial sector between 2011 and 2015 by examining the set of industrial activities operating in the state in the first and last year of the period, and to identify indicators for the share of economic output attributable to the iron ore extractive industry in 2015 from a Kaldorian perspective. Thus, the guiding research question of the paper can be expressed as follows: “How did the relative importance and multiplier effects of Pará’s industrial sector evolve between 2011 and 2015?”

Observing Brazil's export-oriented vocation, Ferreira and Schneider (2015) point out that the Organisation for Economic Co-operation and Development (OECD) and the World Trade Organization (WTO) began to measure countries' participation in global value chains in 2013, distinguishing between forward and backward linkages. Among the authors' conclusions is that large exporters of mineral products, such as Australia and Brazil, tend to have less foreign content in their exports. Furthermore, in Brazil, the most strongly forward-linked sectors are mining, agriculture, chemicals, and basic minerals and metals.

Araújo, Perobelli and Faria (2021) show that Brazil's participation in global value chains increased between 1990 and 2015 and became more internationally fragmented, with most activity taking place at the global level, although regional integration (with South America) increased by more than global integration. Other developments have included a process of deindustrialization in Brazil over recent decades and the implementation of reindustrialization policies in different countries (Guisan et al., 2017; Przywara, 2017; Maldonado Atencio, 2019; Moczadlo, 2020).

With the approach taken in this paper, economic growth can be understood as a phenomenon that originates in a large but specific sector of the economy. In the case dealt with here, that sector is industry, as conceived by Nicholas Kaldor (and expressed in Kaldor's laws) and subsequent economists. Many later theoretical and empirical developments have been considered in relation to Brazil, for example in Lamonica et al. (2007), Oreiro, Nakabashi and Souza (2010) and Morceiro (2012).

The approach of this paper is similar to that of Romero (2019), who related the Kaldorian and Schumpeterian literatures to create a multisectoral growth model which proved more complete than the Kaldor-Dixon-Thirlwall model, highlighting the importance of demand and supply factors for economic growth. Romero (2021) also summarizes the main ideas of the Schumpeterian macroeconomic approach to economic growth. Similar theoretical or methodological approaches can be found in various studies such as Pan (2006), Grodzicki and Skrzypek (2020), Borghi (2017) and Silva and Hasenclever (2010).

This paper seeks to apply the Kaldorian framework to Brazil, and especially Pará, in respect of the importance of the industrial sector. To this end, it conducts an input-output analysis based on the Pará input-output matrices for 2011 and 2015. The input-output model will serve both to characterize Pará's economy through an analysis of its production structure and, using the techniques that form part of the model, to present evidence of relationships that combine the theories of Kaldor (1966) and Dosi (1984).

The information sources for this paper are the Pará interregional input-output matrices for 2011, prepared by Haddad, Gonçalves Júnior and Oliveira Nascimento (2017), and for 2015, published by the Amazon Development Superintendence (SUDAM). Data from the Brazilian Institute of Geography and Statistics (IBGE), the Annual Industrial Survey (PIA) and the regional accounts are also used, as are the OECD Trade in Value-Added (TiVA) indicators.

The main contribution of this paper is to connect and draw conclusions from elements of distinct theoretical frameworks and to carry out an application using a specific methodological benchmark. Specifically, it connects Kaldor's and Dosi's theories to input-output analysis for the economy of Brazil, a country considered to be undergoing deindustrialization, with a focus on Pará, a state that is outside the dynamic core of that economy, emphasizing an activity of global importance, the iron ore extractive industry.

Following this introduction, section II discusses the theoretical issues surrounding Kaldor's laws and Dosi's paradigms and technological trajectories, connecting them to the importance of industry and technological change within this framework. Section III presents the methodology and the data sources and input-output techniques used. Section IV contains the results and discussions, and section V concludes.

II. Theoretical considerations

1. The Kaldorian approach to economic growth

Kaldor's Keynesian background heavily influenced his work, and in this connection, at least two major phases of his intellectual output can be identified. In the first, Kaldor was concerned with solving problems strictly related to Keynes' ideas, stating (Kaldor, 1957) that the ultimate objective of economic growth theory should be to show the nature of the non-economic variables associated with economic growth.

The start of the second major phase of Kaldor's thinking can be dated to his inaugural lecture at Cambridge in 1966 on the causes of the United Kingdom's slow growth rate. As Thirlwall (1983) shows, Kaldor (1966) presented a series of "laws" to explain the differences in growth rates between advanced capitalist countries. He later elaborated on these laws in a lecture at Cornell University (1967). These laws, and their interpretation and validity, have been the subject of considerable scrutiny and debate, and Kaldor himself clarified and modified his position after his initial statement of them.

Kaldor's first law states that there is a strong relationship between manufacturing output growth and GDP growth. Kaldor argued that a rapid rate of economic growth was associated with a rapid rate of growth in the manufacturing sector, which in turn was a feature of the transition from "immaturity" to "maturity". "Immaturity" is defined as a situation in which productivity is lower outside industry (particularly in agriculture), so that labour is available for use in industry in practically unlimited quantities (Thirlwall, 1983).

Kaldor's second law states that there is a strong positive relationship between the growth rate of manufacturing productivity and the growth of manufacturing output. A Verdoorn-type relationship is also found in construction and utilities.

The primary sector, and specifically agriculture and mining, does not display the same relationship as manufacturing. In both agriculture and mining, productivity growth reflects a large trend component that is independent of total output growth, and the regression coefficient is not significantly different from unity, as Thirlwall's (1983) calculations showed.

In long-run average terms, productivity growth was the dominant contributor to output growth across countries. In the case of transport and communications, Kaldor did not find a correlation between productivity growth and output growth. In trade, there is a high correlation, but the constant term in the equation given by Thirlwall (1983) is negative.

Kaldor's third law states that the stronger the growth of manufacturing output, the higher the rate of transfer of labour from non-manufacturing to manufacturing sectors, so that overall productivity growth is positively related to growth in manufacturing output and employment and negatively associated with the growth of employment outside manufacturing. The implications of this law can be developed into a fourth law, which is that the long-run growth of the economy is constrained not by supply, but by demand.

There are clear affinities between Kaldor's ideas and those of Albert Hirschman, who criticized balanced development theorists and advocated a development strategy driven by a sequence of imbalances initiated in specific sectors of the economy, given the effects of existing forms of intersectoral interdependence (Hirschman, 1961).

Along the same lines, Dixon and Thirlwall (1975) argued that differences in regional growth rates could be explained by a Kaldorian model, with demand growth driving productivity and so creating virtuous or vicious circles that reinforced regional inequalities. This argument was advanced by Kaldor (1970), who advocated regional policies to correct structural disparities, since more developed regions tended to grow faster because of accumulated learning advantages and economies of scale created by the process of cumulative circular causation.

McCombie (1988) complements this view by contrasting the neoclassical and post-Keynesian theories of regional growth, highlighting the way the neoclassical approach, based on long-term convergence, ignores dynamic constraints associated with effective demand and structural imbalances. Conversely, the post-Keynesian perspective suggests that productive specialization and balance-of-payments constraints are determining factors in the growth trajectory of a region, aligning with Thirlwall (2007), who argues that regional problems are essentially balance-of-payments problems. This means that the growth of a region depends on its export capacity and the income elasticity of its imports, suggesting that industrial and innovation policies are essential to reverse low-growth trajectories and promote structural changes favourable to regional development.

2. Paradigms and technological trajectories in Giovanni Dosi

Giovanni Dosi approaches Kaldor's conception by a different path. For Dosi (1984), the economic system constitutes a complex environment in which change and transformation arise from the interaction of its constituent parts and partially exogenous variables, with two variables being of paramount importance: the evolution of the technological system and the system of social relations in a broad sense. From a Schumpeterian perspective, Dosi devotes his theoretical efforts to the former and develops a theoretical framework that is widely recognized for highlighting the role of technical change in the economy.

Thus, Dosi (1984) proposes the concept of a technological paradigm, defined as a model or pattern for solving selected technological problems on the basis of certain principles derived from the natural sciences and specific material technologies. The notion of a technological paradigm is Dosi's analogy to Thomas Kuhn's concept of a scientific paradigm, found in his work *The Structure of Scientific Revolutions* (Kuhn, 1962).

Dosi also discusses the transmission mechanisms for technical change and the relationship with macroeconomic transformation, which occurs through diffusion. He notes that the effects of technical change spread across economic sectors (and especially industries) because of the input-output relationships between them, with the discussion being tantamount to an analysis of technological and economic variables that lead to a specific configuration of inputs and outputs (Dosi, 1984, p. 395).

Input-output analysis represents the bridge linking the microeconomic level at which research is conducted to macroeconomic trends (Dosi, 1984, p. 396). In other words, the spread of technological innovations is intrinsically linked to interindustrial relationships, which can be analysed through input-output matrices.

According to Dosi (1984), diffusion may result from the expansion of innovative firms or imitation by competitors, and may be driven by production, when associated with innovations and incremental improvements, or by demand, when minor or major modifications occur in processes or products. For this author, if the interrelationships between producers and users are important in stimulating fresh innovations, then there is a clear "dynamic circle" of positive feedback. Thus, it can be seen that there is a mechanism which determines the degree of sophistication and innovation of industrial production in the economy.

Many aspects of Dosi's thinking were discussed by the economist Carlota Pérez. For Pérez (2010), a technological paradigm, in Dosi's sense, is a collectively shared logic in which technological potential, relative costs, market acceptance, functional coherence and other factors converge. The techno-economic paradigm, a concept introduced by Pérez (1985), is a model of best practices that guides the direction of innovation over time, emerging from experience with new technologies and establishing the most efficient and profitable way to use them. This paradigm identifies a predictable pattern of relative costs and productive organization, functioning as a "golden rule" for investments and technological development. According to Pérez (2001), it combines technical and organizational models to maximize the potential of technological revolutions and provides a new set of "common-sense" principles that guide the decision-making of economic agents. Furthermore, as Pérez (1992) explains, technical change is a continuous process in the economic system, occurring both through incremental innovations that improve products and processes and through radical innovations that create new industries and revolutionize entire technological systems.

3. The Kaldor-Dosi approach

An analytical approach that consists in connecting the theoretical frameworks of Kaldor (Kaldor's laws) and Dosi (technological paradigms and trajectories) will now be proposed as a way to create a single perspective capable of explaining a greater number of phenomena than if each approach were applied individually. In this proposed Kaldor-Dosi approach, the elements cited by Kaldor, especially the Kaldor-Verdoorn effect and the idea of cumulative circular causation generated by manufacturing, are conjoined with Dosi's ideas about market direction, whereby technological paradigms create technological trajectories. Table 1 synthesizes the main parameters of this approach.

Table 1
The Kaldor-Dosi approach: analytical uses

1.	Identifies whether an economic activity is capable of generating circular causation in the local economy.
2.	Identifies whether the most dynamic economic activity is a sector of manufacturing industry.
3.	Identifies which technological paradigm drives economic activity.
4.	Identifies whether the technological paradigm around which economic activity is oriented is able to foster diffusion of innovations internally.

Source: Prepared by the authors.

As shown in table 1, it is possible to combine Kaldor's and Dosi's perspectives to create a unified approach that can explain the level of economic growth in a country or region. By combining analysis from the macro- and microeconomic perspectives, this approach serves to identify distinct economic forces acting on the same environment that either reinforce one another or cancel out.

Table 2 identifies transmission channels that reflect the combined effects of Kaldor's laws and Dosi's paradigms and technological trajectories. The intersectoral supply and demand pattern illustrates the type of product bundle that needs to be consumed for an activity to operate, and thus the extent to which it can foster new production technologies and internalize the effects of cumulative circular causation, where the origin of the products allows. This is the link to the second transmission channel: the level of connection between the activity and the local economy, which depends on where its multiplier effects are distributed. The level of connection with the international economy determines how much the demand for and supply of activities influence and are influenced by the world economy.

Table 2
The Kaldor-Dosi approach: transmission channels

1.	Level of intersectoral supply of and demand for an activity.
2.	Level of intersectoral connection with the local economy.
3.	Level of intersectoral connection with the international economy.
4.	Level of productive density.
5.	Changes in multiplier effects.

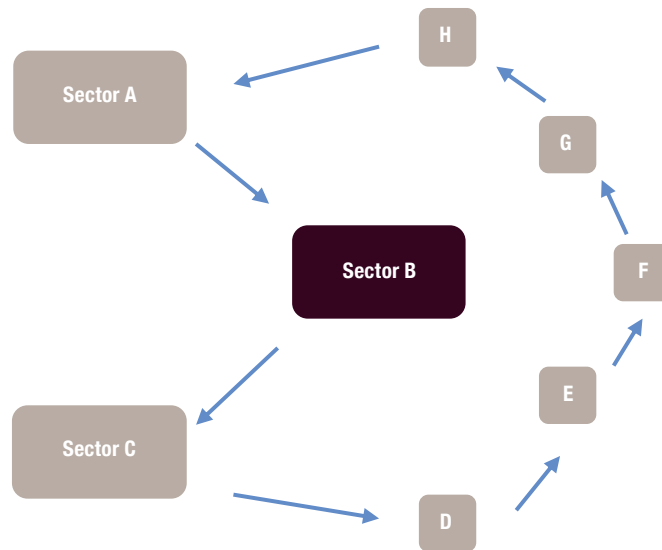
Source: Prepared by the authors.

The level of productive densification of an activity shows the extent to which it has been able to contribute to the creation of new links in production chains. Lastly, changes in the activity's multiplier effects over time show how effectively it has improved its capacity to generate cumulative circular causation.

In this context, there are three distinct transmission pathways for the effects of diffusion and cumulative circular causation, considering input-output relationships: local, national and international production chains. Even when all these intersectoral transmission pathways exist, the potential to internalize new technologies and activate new productive activities in the location of interest is ultimately reduced when international and national pathways predominate.

Diagram 1 illustrates how technology is propagated along the different sectoral pathways of the economy. The technology introduction sector (B) is the starting point where technological innovation is first introduced. The arrows connecting this sector with other adjacent sectors indicate the relationship between the sale of goods and services and the direct propagation of technology immediately affecting these sectors. The arrows connecting the directly affected sectors (A and C) with other sectors (D, E, F, G, and H) represent the indirect propagation of technology. This demonstrates how innovation spreads through economic interconnections, influencing multiple sectors along the way.

Diagram 1
Propagation of technology through sectoral linkages



Source: Prepared by the authors.

Input-output matrices capture relationships of interdependence between economic sectors, such that when a sector incorporates a new technology, there is an increase in demand for related inputs. This additional demand, in turn, stimulates production in other sectors, creating a multiplier effect that spreads throughout the economy. Furthermore, input-output matrices make it possible to distinguish between direct and indirect effects. The direct effect occurs in the sector that adopted the technology, while the indirect effects are transmitted to other sectors through production chains. This reflects the complex nature of technological diffusion and propagation in the economy.

The global fragmentation of production works in just this way, distributing technological and productive advances worldwide, but favouring the locations where technologies are developed (since it is there that externalities linked to the production of applied technological knowledge are concentrated) and where the most complex phases of industrial production are sited.

The approach described brings out the importance of having local technological paradigms strong enough to accelerate the effects of cumulative circular causation and thence structural change. The mobilization of institutional forces, including local production sectors, can be decisive in ensuring that the paradigms implemented have a configuration consistent with the economic, environmental, demographic, cultural and other characteristics of the location of interest.

Dosi, Roventini and Russo (2019) corroborate the argument for a theoretical relationship between the Kaldor and Dosi approaches when discussing endogenous growth and global divergence in an agent-based multi-country model. The authors argue that each of the countries they analyse has a Schumpeterian engine of endogenous technical change that interacts with mechanisms of Keynesian or Kaldorian demand generation, so that it undergoes a structural transformation of its production system during the development process.

III. Methodology

Miller and Blair (2009) show that, in its most basic form, an input-output model consists of a system of linear equations, each of which describes the distribution of an industry's output throughout the economy. Leontief's basic input-output model is generally constructed from observed economic data for a specific geographical region (country, state, county, etc.). The present analysis aims to examine the activity of a group of industries that both produce goods (outputs) and consume goods from other industries (inputs) in the process of producing their own outputs.

In the model, the economy is categorized into n sectors. Let x_i denote the total output of sector i and f_i the total final demand for sector i 's output. A simple equation can then be written to explain how sector i distributes its products, which are divided between sales to other sectors and final demand, as equation (1) shows:

$$x_i = z_{ij} + \dots + z_{ij} + \dots + z_{in} + f_i = \sum_{j=1}^n z_{ij} \quad (1)$$

Selling sectors supply inputs for the output of buying sectors. Sellers also supply goods and services for final demand, represented by household and government consumption, investment and exports. Buying sectors, for their part, pay taxes and add value through wages and profits in the process of producing goods and services, while also importing.

The input-output matrix allows us to establish the technical coefficients of production, calculated as the ratio of each sector's total intermediate input purchases to its gross output. Knowledge of these coefficients makes it possible to ascertain the origin of each sector's inputs and thence its cost structure.

The matrix of direct and indirect technical coefficients or total requirements matrix, also known as the Leontief inverse matrix, is represented by $(I-A)^{-1}$ and captures all effects on the entire production process of the economy from a quantitative change in any component of final demand.

Two important analytical tools of the input-output model originate from intermediate demand:

- (i) The matrix of direct coefficients (matrix A): this shows each sector's relationship with total output. Mathematically, each element of the matrix is given by equation (2):

$$a_{ij} = \frac{x_{ij}}{X_{ij}} \quad (2)$$

where each element a_{ij} represents the relationship of each sector (x_{ij}) with total output (X_{ij}). In matrix form, equation 3 is obtained.

$$A = [a_{ij}] \quad (3)$$

- (ii) The matrix of direct and indirect technical coefficients, also called the total requirements matrix: this indicates the total repercussions in all economic sectors of a change in any component of final demand. It is obtained by inverting the matrix resulting from the difference between an identity matrix I and matrix A . It may be denoted matrix B and represented by equation 4.

$$B = [I - A]^{-1} \quad (4)$$

From matrix B it is possible to capture the direct and indirect effects on output X of a change in final demand Y , leading to equation 5.

$$\Delta X = [I - A]^{-1} \Delta Y \quad (5)$$

In addition, the output multiplier for each economic activity is defined as the total value of output in all activities of the economy that is required to satisfy one monetary unit of final demand for that activity. The initial output effect on the economy is defined as only the initial monetary value of that activity's output necessary to meet that additional unit of final demand. Thus, formally, the output multiplier is the ratio between the total (direct and indirect) effect and the initial effect. Income and employment multipliers capture the wider economic impacts of new final demand, such as jobs created and increases in household income and value added. Multipliers can be calculated according to equation (6):

$$GV_j = \sum_{i=1}^n b_{ij} v_i \quad (6)$$

in which GV_j is the total (direct and indirect) impact on the variable concerned, b_{ij} is the ij -th element of the Leontief inverse matrix and v_i is the direct coefficient of the variable concerned.

Leontief's classic approach assumes a fixed production structure in which the relationships between sectors are described by constant technical coefficients. This means that the multipliers reflect the economy's response to a demand shock, but take no account of dynamic adjustments over time. In this article, however, two points in time are taken to increase the explanatory power of multiplier effects in temporally distinct production structures.

The output multiplier in the input-output model is based on assumptions such as fixed proportionality between inputs and output, constant prices and the absence of financial or productive constraints in the short term. The matrix of technical coefficients is treated as stable, implying that an increase in final demand generates a proportional increase in output. In practice, however, demand expansion may face constraints such as limited production capacity, input and labour shortages, inflationary impacts and external constraints.

This study applies an interregional model, in which transactions are distributed across more than one region, following the procedure used by Guilhoto (2011) and Miller and Blair (2009). Table 3 presents this configuration with a two-region model in which the block of intersectoral transactions and the vectors of final demand are subdivided to reflect interregional flows.

Table 3
Basic model of the interregional input-output matrix

Destination		→		Intermediate demand (endogenous)	Final demand (exogenous)	Total demand
Origin		↓		Sectors in region M	Sectors in region E	
Agents	Sectors in region M	Intermediate inputs MM	Intermediate inputs ME	Final demand MM	Final demand ME	M
	Sectors in region E	Intermediate inputs EM	Intermediate inputs EE	Final demand EM	Final demand EE	E
Total demand		(M)	(M)	(M)		(M)
Net indirect taxes (NIT)		(NIT)	(NIT)	(NIT)		(NIT)
Value added (VA)		VA	VA			
Gross value of total output		Region M	Region E			

Source: Prepared by the authors, on the basis of Guilhoto, J. J. M. (2011). *Análise de insumo-produto: teoria e fundamentos*. <https://mpira.ub.uni-muenchen.de/32566/>.

For this purpose, participation indicators derived from the intraregional output block for Pará are used to assess the contribution of the sector of interest to total output. The following indicators are calculated:

- Intermediate purchase coefficient: the ratio between the total intersectoral purchases of each economic activity in the input-output matrix and its gross output;
- Intermediate sales coefficient: the ratio between the total intersectoral sales of each economic activity in the input-output matrix and its total demand;
- Import coefficient: the ratio between the total imports of each economic activity in the input-output matrix and its gross output;
- Export coefficient: the ratio between the total exports of each economic activity in the input-output matrix and its total demand.

The first part of the results section that follows looks at the participation indicators for the 67 economic activities in Pará as of 2015, while the second section analyses the multiplier effects of the same activities, comparing the years 2011 and 2015.

IV. Results and discussion

1. Analysis of mining industry participation in 2015

This section presents the results of applying the input-output methodology to support the theoretical discussion in section II. Table 4 synthesizes Pará's 2015 interregional input-output matrix with aggregate values for intra- and interregional output, imports and exports.

Table 4
Pará: summary interregional input-output matrix, 2015
(Millions of reais)

		Destination			Total
		Pará	Rest of Brazil	Rest of world	
Origin	Pará	135 900.61	34 249.44	28 515.41	198 665.47
	Rest of Brazil	74 453.72	9 235 326.83	738 516.58	10 048 297.13
	Rest of world	15 292.44	826 327.04	0.00	841 619.48
Total		225 646.76	10 095 903.32	767 032.00	11 088 582.07

Source: Amazon Development Superintendence. (2022). Matriz interestadual de insumo-produto para o Estado do Pará 2015. In E. A. Haddad (Coord.), *Matrizes de Insumo-Produto da Amazônia Legal, 2019*. Institute of Economic Research Foundation. <https://www.gov.br/sudam/pt-br/central-de-conteudo/mip>.

The data in the table show that Pará's economy has a strong trading relationship with the rest of Brazil when it comes to purchases of goods and services, and with the rest of the world when it comes to exports. Even so, the state's internal trade outweighs its trade with both combined.

The following charts use intermediate and foreign trade ratios to detail these flows. Figure 1, based on matrix *A*, presents the ratios of intermediate purchases by the different sectors in Pará, meaning the extent to which they purchase goods and services from one another. It can be seen that sectors 8, 10 and 20 have the highest demand for goods and services from the state's own economy.

An understanding of the matrix elements helps confirm that, as Dosi (1984) discusses, the effects of technical change are not restricted to a single industrial branch. The dynamics of each branch influence and are influenced by patterns of change in other branches through the interindustrial spread of innovations. Figure 1 shows that the iron ore mining industry (sector 6) has an intermediate purchase ratio of 20.2%, compared to the cross-sector average of 21.6%: a relatively low value for an industrial sector that acquires a considerable range of inputs in order to produce.

Figure 2 follows the same logic as figure 1, but this time measuring the ratio between each sector's imports and its gross output and so showing which sectors' final products have the largest import shares. In this case, the average is 6.1% for all sectors and 5.3% for the mining industry, which thus falls below the state average. Combining these indicators with the first set provides evidence that there is considerable demand for goods and services from the rest of Brazil in the case of the iron ore extractive industry.

Figure 3 presents intermediate sales ratios for Pará, showing the proportion of sales that takes place between sectors within the state relative to total demand. This makes it possible to identify which sectors are being directly activated by the local economy.

The average intermediate sales ratio is 28.8%, while the iron ore mining industry has a ratio of only 1.3%, showing that its production is not geared toward the local economy. This indicates that technological diffusion effects have not been sufficient to generate dynamic local activities capable of acquiring a significant portion of mining output.

Figure 4 follows the same logic as figure 3, but shows the ratio of Pará's exports to total demand. The average across sectors is 12.8%, while the value observed for the iron ore extractive industry is 87.6%. Kaldor highlights the importance of increasing the technological intensity of the industrial export basket as a means of boosting output and productivity growth, something that is not observed at the local level in the case of iron ore mining, as products are exported in the early phases of industrial processing.

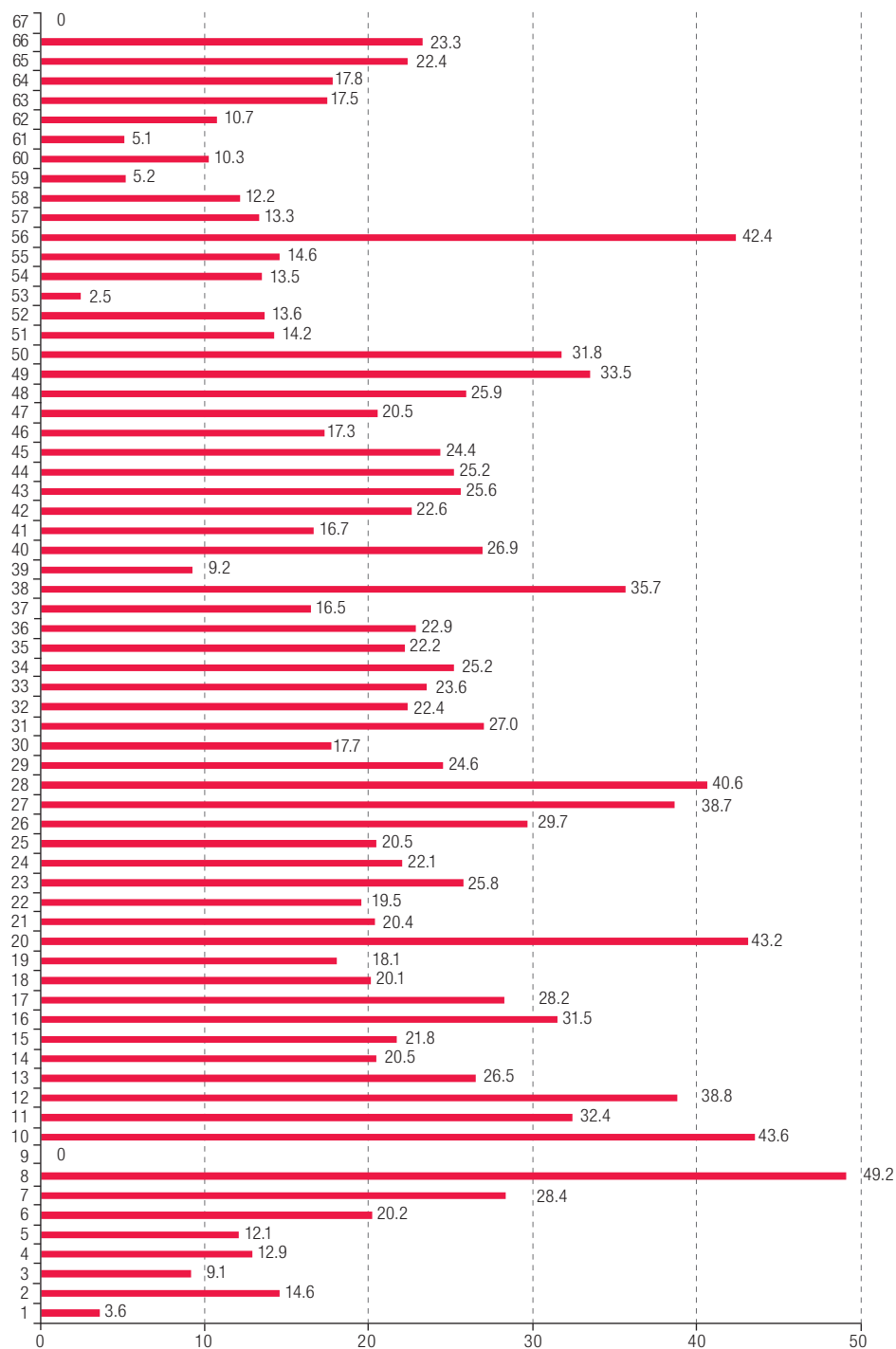
Following Hirschman (1961), it is also evident that the limited activation of intersectoral linkages in the state hampers the formation of new ventures, contributing to lower production density and, consequently, a slower pace of economic activity compared to what the situation would be if mining production were more directly linked to local economic activities.

These results suggest that the technological trajectory and paradigm of mining in Pará are oriented towards global production. Exports are from extractive sectors, and there is thus a lack of local productive-technological densification. Although they are a link in the global industrial chain, the implementation of additional stages within the state would increase the multiplier power of output via the gains identified in Kaldor's laws.

Pérez-Oviedo, Cajas-Guijarro and Vallejo (2018) show that the international trade network underwent significant changes from 1992 to 2014, especially with the consolidation of the United States and China as "global centres". Over the course of those years, conversely, no South American country joined the "core" of the global trade network.

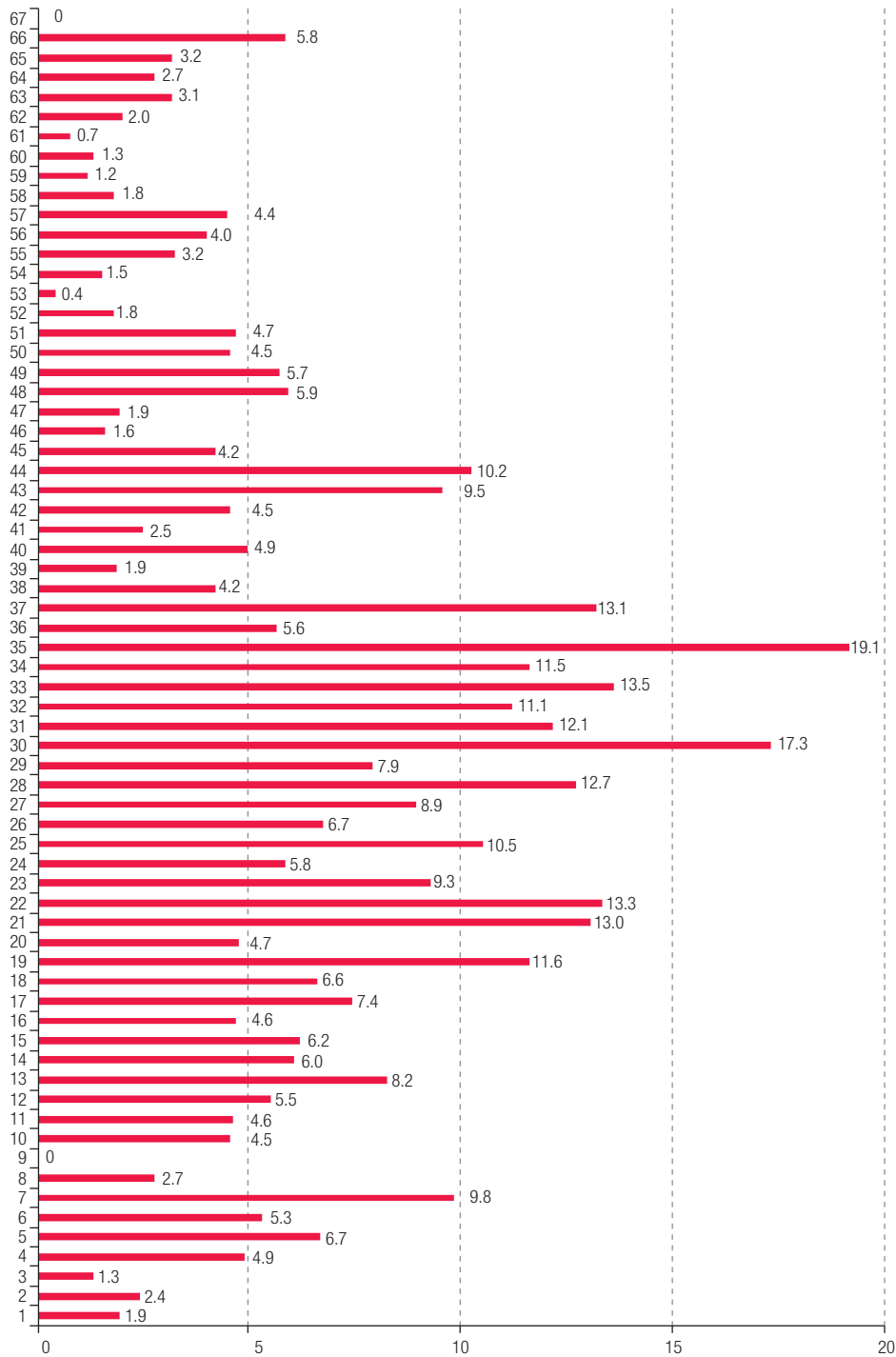
Callegari, Melo and Carvalho (2018) show that Brazil's participation in global value chains is characterized by strong forward linkages, since it is a primary supplier of products, and limited backward linkages, with limited use of imports in exports. The Brazilian economy leverages exports to the rest of the world, especially developed countries, as it is a supplier of low value added, highly competitive goods. The country is not able to use imports to promote the competitive advantage of its own exports.

Figure 1
Pará: intermediate purchase ratios, 2015
(Sectors and percentages)



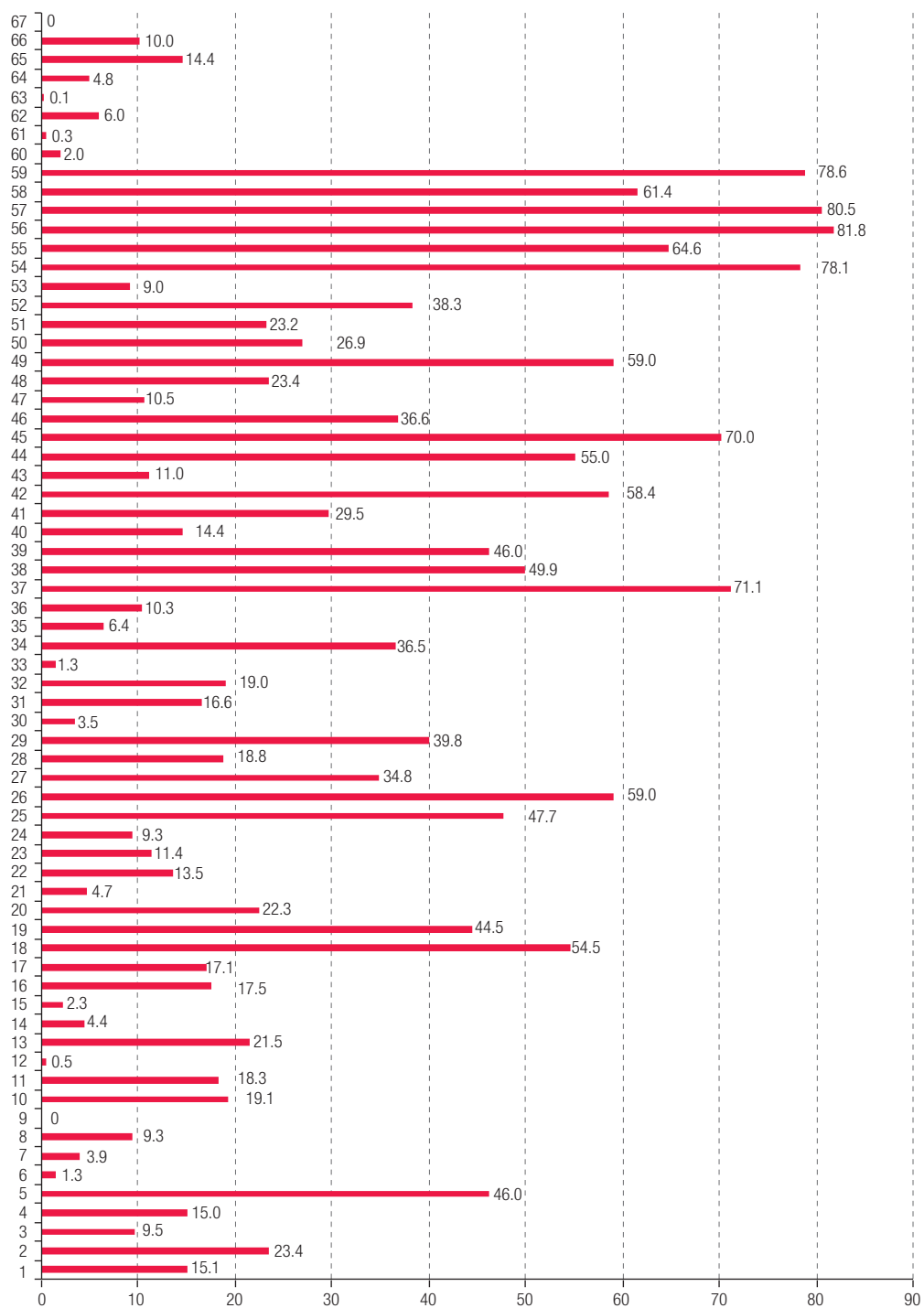
Source: Prepared by the authors, on the basis of Amazon Development Superintendence. (2022). Matriz interestadual de insumo-produto para o Estado do Pará 2015. In E. A. Haddad (Coord.), *Matrizes de Insumo-Produto da Amazônia Legal*, 2019. Institute of Economic Research Foundation. <https://www.gov.br/sudam/pt-br/central-de-conteudo/mip>.

Figure 2
Pará: import ratios, 2015
(Sectors and percentages)



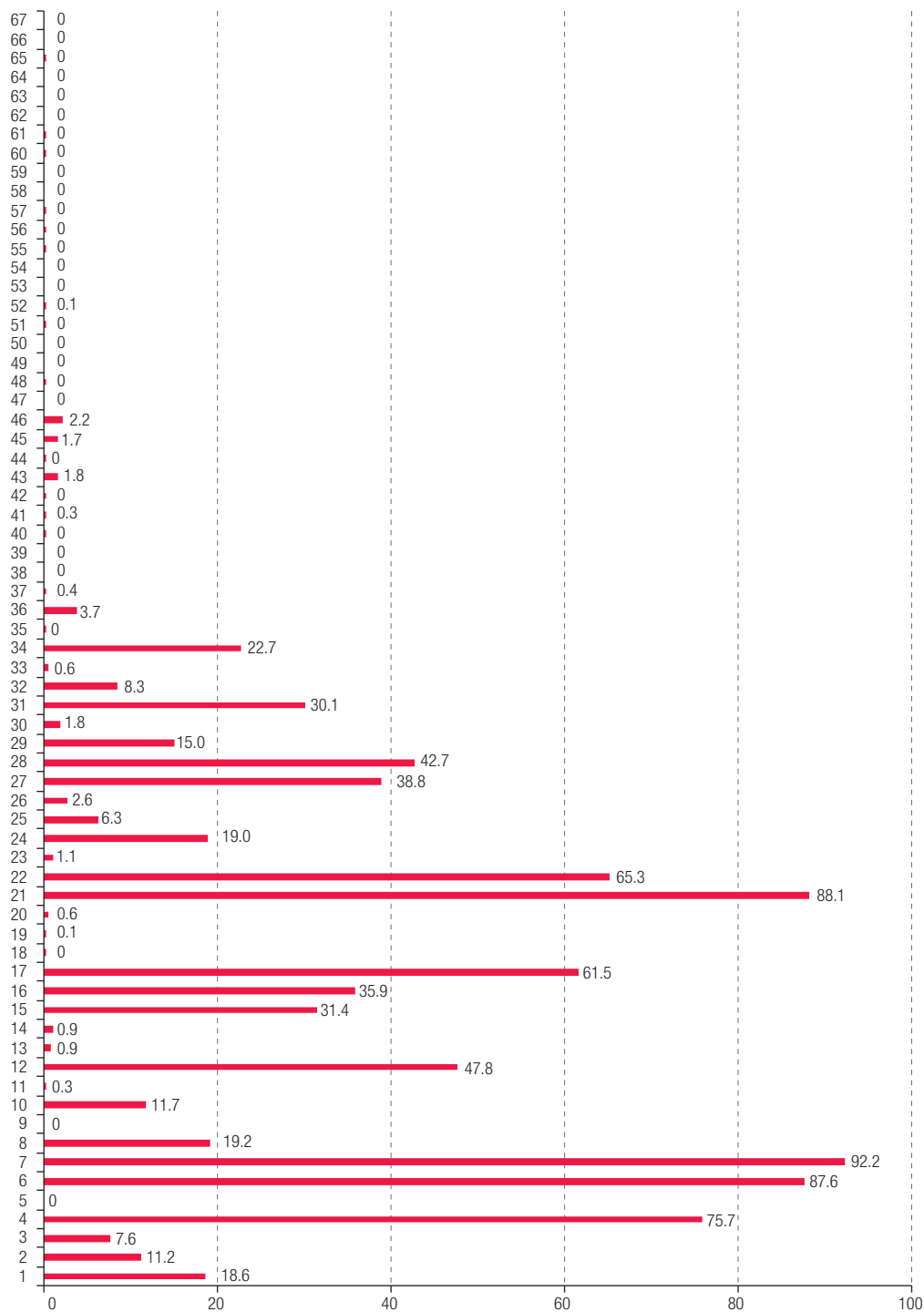
Source: Prepared by the authors, on the basis of Amazon Development Superintendence. (2022). Matriz interestadual de insumo-produto para o Estado do Pará 2015. In E. A. Haddad (Coord.), *Matrizes de Insumo-Produto da Amazônia Legal*, 2019. Institute of Economic Research Foundation. <https://www.gov.br/sudam/pt-br/central-de-conteudo/mip>.

Figure 3
Pará: intermediate sales ratios, 2015
(Sectors and percentages)



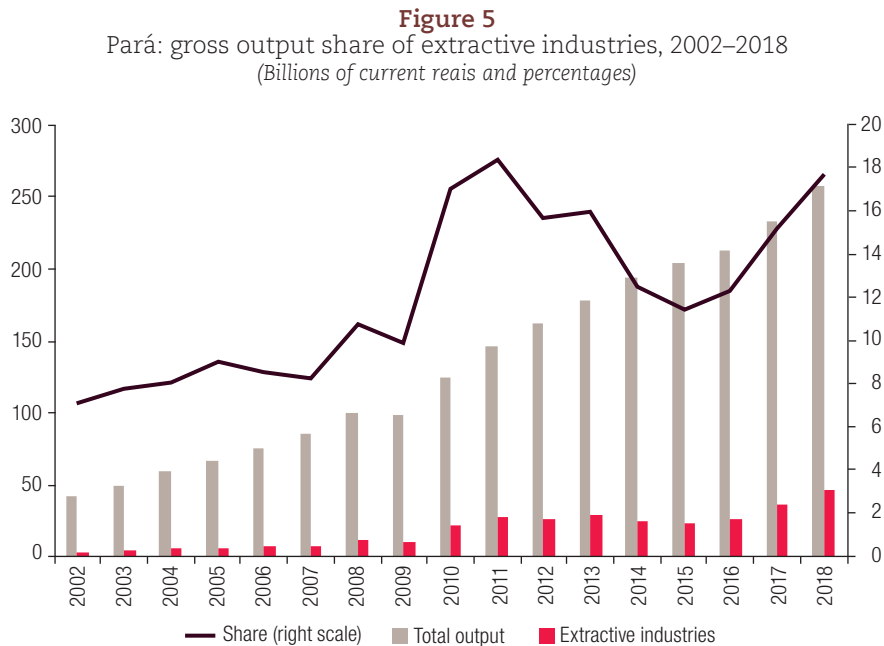
Source: Prepared by the authors, on the basis of Amazon Development Superintendence. (2022). Matriz interestadual de insumo-produto para o Estado do Pará 2015. In E. A. Haddad (Coord.), *Matrizes de Insumo-Produto da Amazônia Legal, 2019*. Institute of Economic Research Foundation. <https://www.gov.br/sudam/pt-br/central-de-conteudo/mip>.

Figure 4
Pará: export ratios, 2015
(Sectors and percentages)



Source: Prepared by the authors, on the basis of Amazon Development Superintendence. (2022). Matriz interestadual de insumo-produto para o Estado do Pará 2015. In E. A. Haddad (Coord.), *Matrizes de Insumo-Produto da Amazônia Legal*, 2019. Institute of Economic Research Foundation. <https://www.gov.br/sudam/pt-br/central-de-conteudo/mip>.

Figure 5 shows the evolution of the extractive industries' share of Pará's gross output from 2008 to 2018, in current values.



Source: Prepared by the authors, on the basis of Brazilian Institute of Geography and Statistics. (2021). *Sistema de Contas Regionais 2019*. <https://www.ibge.gov.br/estatisticas/economicas/contas-nacionais/9054-contas-regionais-do-brasil.html?=&t=publicacoes>.

Kaldor's third law refers to the well-known "export-led growth" model; however, the exports concerned are those of manufacturing industry, which benefits from intersectoral linkages and increasing returns to scale. The mining economy, conversely, is a sector that forms part of a global value chain and does not interact in a significant way with others in the local economy.

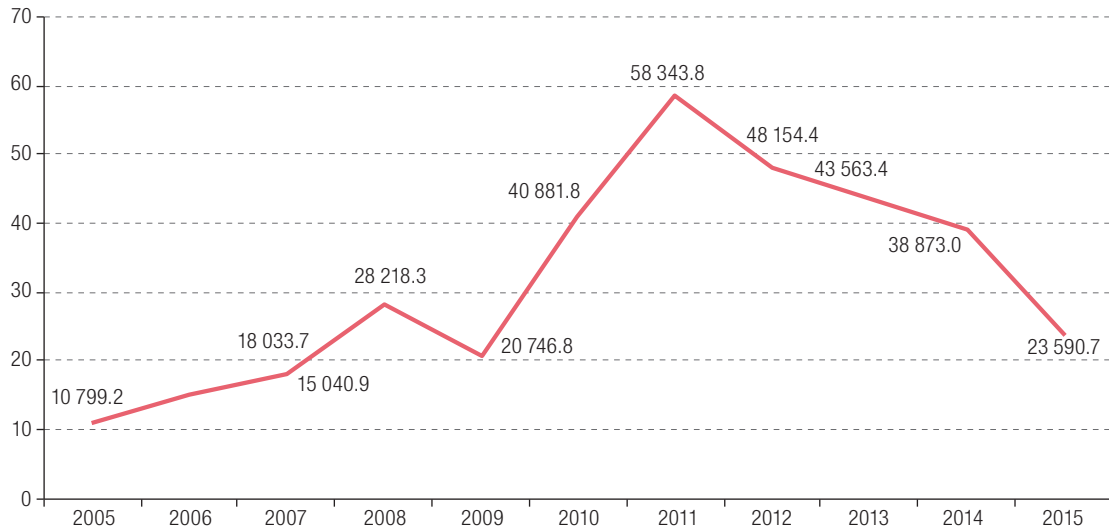
This result is consistent with the analysis of Sanguinet, Alvim and Atienza (2022), who examined the effect of regional trade agreements on the participation of Latin American countries in global value chains between 1995 and 2015. To summarize, they found that, for Latin American exporters, the elasticities of regional trade agreements were more significant for trade that was less intensive in research and development.

This pattern suggests that trade policy might be encouraging the export of inputs with lower technological content and lower levels of value added. Low-complexity industries incorporate little knowledge and technology into global value chains, reducing the opportunities for upgrading and development in the region's countries.

The data in figure 6 come from international input-output matrices and can be taken as indicating the extent of Pará's participation in global value chains, with the OECD TiVA indicators being the main source. Dosi (1984) points out that changes in the economic environment are a permanent feature of the system, and these changes often stimulate straightforward technical progress along a technological trajectory.

Thus, figures 5 and 6 show that mining is subject to its own dynamics and to the economic fluctuations stemming from global developments in the sector, since the state's total gross output value increased throughout the period, whereas there were fluctuations in the gross output of the mining industry. Again, the value added of Brazil's mining industry decreased during the same period in which the gross output of the mining industry in Pará likewise declined.

Figure 6
Brazil: domestic content of value added in mining exports, 2005–2015
(Billions of current reais)



Source: Prepared by the authors on the basis of figures from the Organisation for Economic Co-operation and Development (OECD).

Dosi (1984) explains that certain fundamental forces in capitalist economies (such as liquidity criteria, profitability, efforts to reduce production costs and the search for new markets) act as selection mechanisms between different technological developments. In the production structure of Pará, mining is export-oriented and therefore tied to global technological trajectories in the sectors for which it produces its inputs.

2. Comparative analysis of the multiplier effects of industrial sectors in Pará (2011–2015)

The data for this section are presented in the annex and are simple output multipliers for Pará's industrial sectors, showing the multiplier effect on the sector of interest from final demand shocks that generate direct and indirect repercussions in the economy.

Annex figure A1.1 shows output multipliers for Pará industry in 2011. It can be seen that oil refining and coke (2.578), manufacture of organic and inorganic chemicals (2.422) and slaughter and meat products (2.412) were the sectors that showed the highest output multiplier effects, with indicators close to 2.500. The iron ore extractive sector had the lowest multiplier effects in 2011, with an indicator of 1.206. This is consistent with Kaldor's laws, which do not treat the mining sector as one that generates cumulative circular causation, unlike manufacturing industry.

Annex figure A1.2 presents the output multipliers for Pará's industrial sector in 2015. The results show the oil refining and coke sector (2.471) again topping the ranking. Slaughter and meat products (2.383) and manufacture of organic and inorganic chemicals (2.331) also reappeared.

Although the multipliers for these three sectors were still among the highest, they were lower than formerly. The largest decrease was in the sugar manufacturing and refining sector, whose multiplier fell from 2.066 in 2011 to 1.000 in 2015, meaning that it no longer generated additional effects from an increase in final demand.

In the iron ore extraction sector, the 2015 figure of 2.050 represented a jump of some 70% from 2011. This result indicates a sectoral evolution contrary to what would be expected from Kaldor's laws, with the mining sector apparently increasing its intersectoral linkages with the economy of which it forms part.

Consideration should also be given here to the evidence found by Florensa et al. (2015) that regional and global production networks are present in Latin America. The positive effect of intermediate goods imports from China on trade flows between members of the Latin American Integration Association (LAIA) can be explained by Latin America's trade policy strategy of facilitating access to intermediate goods.

Banacloche et al. (2020) show that the high level of value added embodied in South American exports is not matched by a comparable level of domestic content in imported intermediates, reflecting limited integration into global value chains, with the exception of Uruguay. Although import penetration in South American exports is greater than in the rest of the world, it is still low, suggesting that the region is not fully leveraging imported inputs to improve the quality and variety of its exports.

As seen in the previous point, the intermediate purchase ratio of the mining industry was below the average for other sectors of Pará's economy in 2015 (20.2%), showing that, despite its leading role in output, the sector is not a leader in the diffusion and multiplication of effects in Pará's production structure. Moreover, the intermediate sales ratio of the iron ore extractive sector was considerably below the average in 2015 (1.3%).

The jump in the sector's multiplier effects is explained, then, by rising values for the intermediate purchases indicator in sectors that have a greater multiplier effect in the economy, boosting the indirect effects of the iron ore extractive industry. Thus, it was other sectors that had spread productive multiplication effects through Pará's economy by 2015, as shown in table A1.2.

It should be noted that large-scale mining activity generates major related effects. One example is the impact on municipal revenues, particularly in the areas where projects are located, via contributions from the Financial Compensation for the Exploitation of Mineral Resources (CFEM) fund and the municipalities' share of the tax on the circulation of goods and services (ICMS). According to the National Mining Agency (ANM, 2022), CFEM, established by art. 20, paragraph 1 of Brazil's 1988 constitution, is allocated to states, the Federal District, municipalities and federal government agencies as compensation for the economic use of mineral resources within their jurisdictions.

Through CFEM, part of the impact of mining activities is transferred to public budgets, contributing to broader aspects of economic development. However, these effects are not transmitted to other activities through intersectoral linkages involving purchases and sales. By way of example, in 2022, municipalities in Pará received just over 2 billion reais in CFEM transfers.

V. Conclusions

This paper set out to analyse Pará's economy by making a theoretical connection between the ideas of Nicholas Kaldor and Giovanni Dosi and examining the technological structure of regional output using the input-output methodology created by Wassily Leontief. For illustrative purposes, the focus was placed on the mining sector, which accounts for a large share of the state's economy.

A preliminary application of the Kaldor-Dosi perspective, with the aid of the Leontief input-output matrix, allowed specific conclusions to be drawn about the dynamics of the mining industry in relation to Pará's production structure. The analysis indicates that mining is export-oriented and therefore linked to global technological trajectories in the sectors for which it produces inputs.

The evidence shows that the mining sector is part of a global value chain and does not interact in a substantial way with other sectors in the local economy. In other words, technological diffusion effects are not sufficient to generate dynamic local activities capable of absorbing a significant portion of mining output.

In short, applying the Kaldor-Dosi approach made it possible to identify the importance of intersectoral technological diffusion at the international level, specifically through global value chains and their effects on local economic dynamics and technological trajectories. Given global trade patterns, dynamic activities may lack links to local activities and thus may fail to transfer technology through the diffusion mechanisms described by Dosi (1984). Similarly, they may fail to contribute to the formation of a dynamic local industrial base capable of attaining high levels of productivity and technological sophistication in the Kaldorian sense.

It is important to note that the paradigm and technological trajectory approach aligns with the input-output framework in the sense that both are tools for understanding the structure of an economy. However, the two approaches differ in their methods and purpose.

The paradigm and trajectory approach focuses on the role of technological innovation as a central driver of economic growth and describes how economies evolve over time in response to technological change. Conversely, the input-output framework is a tool for analysing the structure of an economy at a specific point in time. Thus, the findings from the analysis in this study highlight temporal and spatial points in the production structure that arise from a productive dynamic shaped by technological paradigms and trajectories.

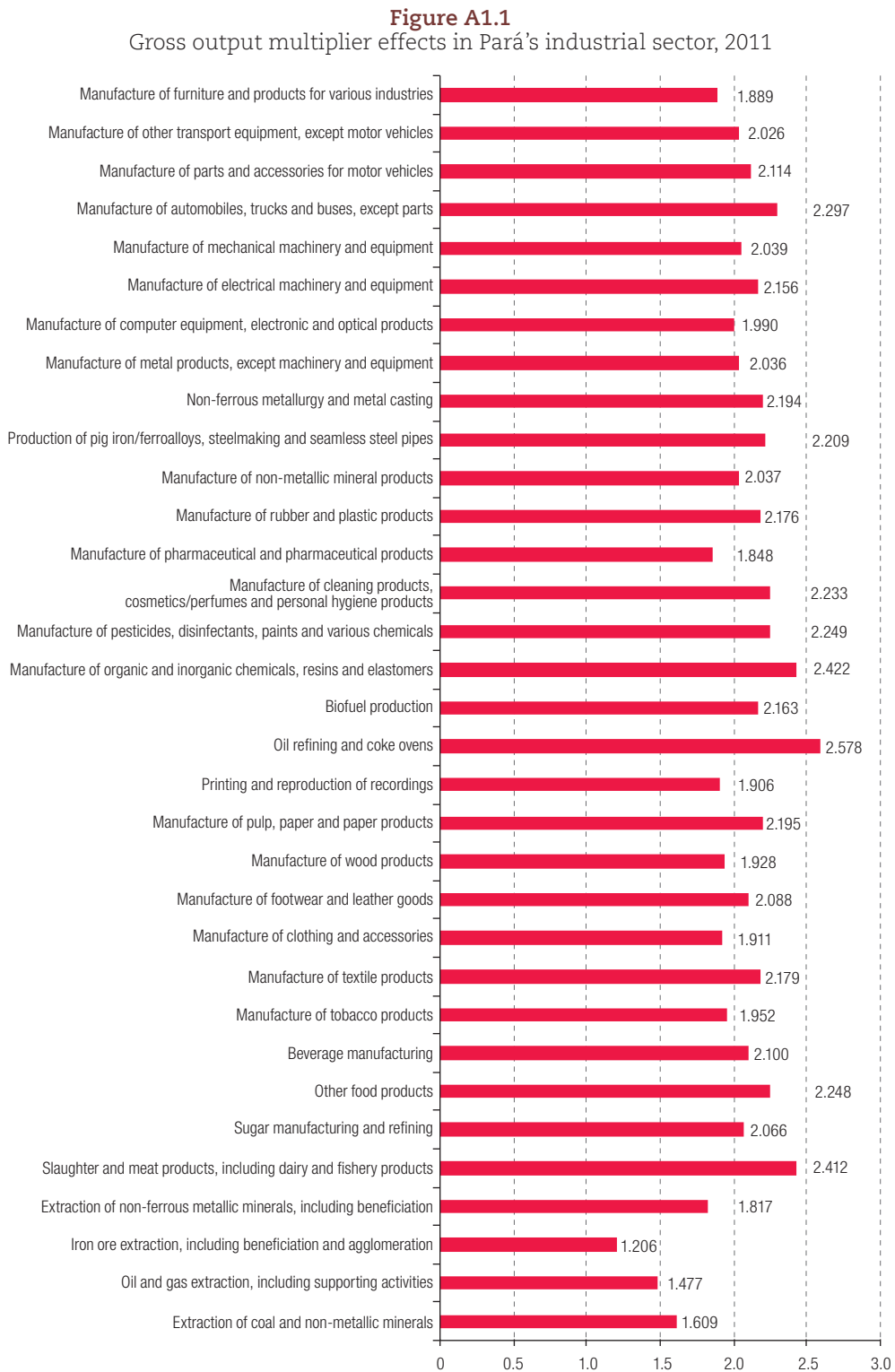
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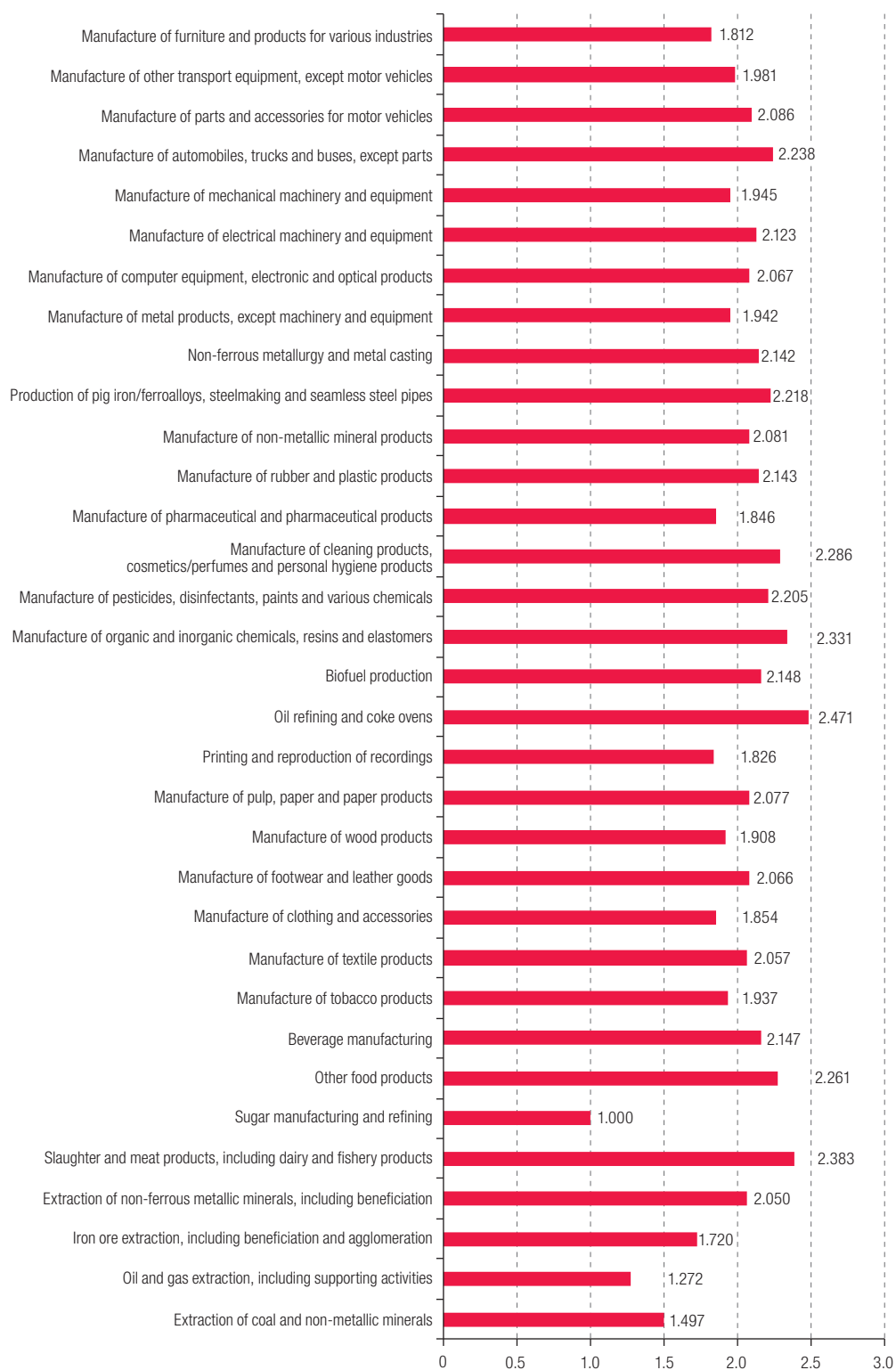
Annex A1

Output multipliers in Pará industry



Source: Prepared by the authors on the basis of figures from the Organisation for Economic Co-operation and Development (OECD).

Figure A1.2
Gross output multiplier effects in Pará's industrial sector, 2015



Source: Prepared by the authors on the basis of figures from the Organisation for Economic Co-operation and Development (OECD).