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Structural Change through Vertical Integration: a practical Guide to Building Indicators in R

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Abstract: The advancement of digital technologies has transformed services into strategic inputs for manufacturing, intensifying intersectoral interactions. This shift challenges traditional sector-based approaches, which may yield biased indicators of structural change. This article presents an accessible and replicable methodological guide based on the vertical integration approach, which distinguishes outsourcing from the tertiarization of productive activities, providing more robust indicators of structural transformation. Excel spreadsheets are used to illustrate key concepts and procedures, while R scripts automate the calculations using data from the OECD's (2023) Inter-Country Input-Output Tables. The aim is to support researchers and policymakers in analyzing the interactions between manufacturing and services in the context of productive offshoring. By integrating up-to-date international databases, a methodology aligned with the contemporary productive structure, and accessible computational tools, this study contributes to advancing the research agenda on structural change.

Keywords: Structural change. KIBS. Manufacturing. Global Value Chains. Deindustrialization. Sectoral integration.
JEL Classification: C00; C10; O14.

Resumo: O avanço das tecnologias digitais transformou os serviços em insumos estratégicos para a manufatura, intensificando as interações intersetoriais. Essa mudança desafia abordagens setoriais tradicionais, que podem gerar indicadores enviesados de mudança estrutural. Este artigo apresenta um guia metodológico acessível e replicável baseado na abordagem de integração vertical, que permite distinguir terceirização de terciarização, oferecendo indicadores mais robustos de mudança estrutural. Planilhas em Excel são utilizadas para ilustrar os conceitos e procedimentos, e códigos em linguagem R para automatizar os cálculos, com base em dados disponibilizados pelas matrizes insumo-produto inter-

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regionais disponibilizadas pela OCDE (2023). A proposta busca apoiar pesquisadores e formuladores de políticas na análise das interações entre manufatura e serviços em um contexto de *offshoring* de atividades produtivas. Ao integrar bases internacionais de dados atualizadas, uma metodologia mais aderente à estrutura produtiva contemporânea e ferramentas computacionais acessíveis, o estudo contribui para a avanço da agenda de pesquisa sobre mudança estrutural.
Palavras-chave: Mudança estrutural. KIBS. Manufatura. Cadeias Globais de Valor. Desindustrialização. Integração setorial.
Classificação JEL: C00; C10; O14.

1. Introduction

The process of deindustrialization in developed economies, which began in the 1970s, sparked extensive and intense debates about the future of manufacturing. A significant part of this discussion focused on the implications of declining manufacturing value added and employment for innovation, productivity, and national income generation. Simultaneously, the spread of Information and Communication Technologies (ICTs) drastically reduced costs and increased the reliability of communication systems, helping to eliminate distance as a barrier to service provision (Müller; Zenker, 2001). As a result, an increasing share of services began to be delivered virtually, removing the need for physical interaction between providers and clients (Freeman; Louçã, 2001).

Over the past few decades, this process has accelerated with the rise of Industry 4.0 and the adoption of technologies such as Big Data, cloud computing, artificial intelligence, and the Internet of Things (Silva *et al*., 2022). The development of enabling technologies, particularly digital platforms, has made it possible to offer personalized, real-time services, removing geographic constraints and promoting economies of scale and scope (Abecassis-Moedas *et al*., 2012; Gawer, 2014, 2021).

These technological advancements have driven a profound reorganization of manufacturing activities. Firms began to outsource production stages to domestic and international service providers as a strategy to reduce costs and improve efficiency (Coe; Yeung, 2015). More recently, however, this trend has partially reversed. Rising geopolitical tensions have led many companies to reassess their global production networks, placing greater emphasis on resilience and production security (Baldwin *et al*., 2023; UNCTAD, 2023). In this new context, a reshoring movement has

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emerged, marked by the reinternalization of previously outsourced activities and the rebuilding of local productive capabilities and ecosystems (Fjellström *et al*., 2019).

These shifts in the productive structure challenge the traditional logic of sectoral approaches, which often simplistically assume that sectors primarily source inputs from within their own boundaries. This assumption overlooks the complexity of intersectoral interactions that characterize modern production chains and, as a result, produces biased indicators of structural change and deindustrialization (Montresor; Vittucci Marzetti, 2011).

Methodological aspects related to indicator construction therefore play a central role in advancing studies on structural change and deindustrialization. The way data are organized and indicators are calculated directly shapes researchers' ability to capture the real effects of productive transformations. This task requires not only a solid conceptual understanding of analytical frameworks but also proficiency in quantitative techniques capable of handling large datasets and complex intersectoral structures. The choice between traditional and alternative approaches, such as vertical integration, is not merely theoretical; it is also methodological and instrumental, demanding appropriate tools for empirical implementation.

In this context, the vertical integration approach offers a more robust analytical framework (Giovanini, 2021). By reintegrating outsourced activities into their final destination sectors, it more accurately measures the impacts of outsourcing, digitalization, and production reconfiguration. Recent studies have highlighted the value of this perspective for understanding the growing integration between manufacturing and services, capturing structural transformations, and informing more realistic public policy (Di Bernardino *et al*., 2024; Giovanini *et al*., 2025).

Despite its analytical potential, the vertical integration approach remains underutilized, largely due to the scarcity of step-by-step instructional materials and the prerequisite knowledge of input-output matrix manipulation, matrix algebra, and Big Data tools. These barriers still pose challenges for many researchers.

In light of this, the present study proposes an accessible and replicable methodological guide for constructing structural change indicators using the vertical integration approach. Combining technical rigor with instructional clarity, the study offers two complementary

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implementation pathways: (i) Excel spreadsheets to support initial familiarization with core concepts and procedures, and (ii) R language scripts to automate calculations, process large datasets, and generate indicators across various sectoral classifications.

By integrating up-to-date international databases, a methodology more aligned with the contemporary productive structure, and accessible computational tools, this study contributes to renewing the research agenda on structural change. It also adds to the literature by demonstrating the strategic role of manufacturing and its integration with service activities. More than a methodological proposal, this is an effort to democratize access to advanced analytical tools and foster a more open, replicable research culture that is responsive to ongoing transformations in the global productive landscape.

This article is organized into five sections, including this introduction. Section 2 presents a discussion of the sectoral and subsystem approaches. Section 3 formalizes the subsystem approach. Section 4 introduces the instructional examples used to present employment and value-added data through the subsystem lens. Finally, Section 5 offers concluding remarks.

2. A Comparative Analysis Between Vertical Integration and Subsystem Approaches

The structural change literature typically segments economic activities into sectors assumed to be homogeneous in terms of demand, production, and technology, thereby enabling the isolated analysis of each sector (Montresor; Marzetti, 2010). While this approach is useful, it has significant limitations. It presumes that intra-sector interactions are stronger than inter-sector ones, based on the assumption that most inputs are sourced within the same sector. As a result, each sector is treated as a self-contained unit, with inputs from other sectors considered external and of limited importance.

A major issue with this perspective is its high sensitivity to changes in firms' internal organization. Shifts such as outsourcing activities previously performed in-house by manufacturing firms to specialized service providers can artificially inflate the size of the service sector and create a misleading appearance of industrial decline, even when final demand remains unchanged. This

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distortion can lead to misinterpretations of structural change, exaggerating the extent of deindustrialization (Montresor; Marzetti, 2011; Chang, 2012).

Although these limitations were largely overlooked in earlier techno-economic paradigms, they have become increasingly relevant in the current context (Montresor; Marzetti, 2011). Advances in information and communication technologies (ICTs) have made production processes more complex and knowledge-intensive, significantly enhancing the importance of vertical relationships across sectors (Falk; Peng, 2013; Francois; Woerz, 2008).

The manufacturing sector has increasingly relied on specialized knowledge provided by modern service firms (Miroudot; Cadestin, 2017). Processes such as outsourcing, increasing firm specialization, and the fragmentation of global value chains have profoundly reshaped production organization. In this context, it becomes essential to distinguish between changes driven by final demand and those resulting from the use of intermediate inputs (Sarra *et al*., 2019).

Given the intensification of vertical linkages between manufacturing and services, the sectoral approach has become inadequate for capturing ongoing transformations in the production system. This limitation is evident in the difficulty of identifying the growing overlap between manufacturing and service activities (Ciriaci; Palma, 2016). As Pasinetti (1973) noted, few concepts in economic analysis are as widely used, and as seldom explicitly defined, as vertical integration.

For the author, a vertically integrated sector refers to an aggregation of all production activities, direct and indirect, that are necessary to produce a given final good. This concept abstracts the sectors as traditionally defined and instead focuses on the total set of production processes required for that specific final output.

Montresor and Vittucci Marzetti (2011) emphasize that traditional sectoral methods often overestimate or underestimate the effects of outsourcing and industrial decline. When activities formerly conducted within manufacturing are shifted to specialized service firms, conventional input-output analysis fails to capture this reconfiguration, leading to distorted estimates of the sectoral structure (Ciriaci; Palma, 2016).

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Thus, the sectoral approach is vulnerable to changes in the organizational structures of firms and may produce inaccurate conclusions regarding the nature of structural change. Furthermore, it does not sufficiently consider the impact of outsourcing on intersectoral production flows. Even the technical coefficients introduced by Leontief are inadequate to address this limitation, since outsourcing alters their values (Lind, 2020).

In response to these constraints the vertical integration method, through subsystems, originally developed by Sraffa (1960) and systematized by Pasinetti (1973), has been used to disaggregate service production destined for manufacturing from that aimed at final demand (Di Berardino *et al*., 2024).

Di Berardino and Onesti (2019) define the subsystem approach as a method that traces all activities directly or indirectly involved in fulfilling final demand for a given good, while holding the capital stock constant. This view aligns with a demand-led growth framework, in which inter-industry linkages are shaped by the relationships between final goods and their required inputs.

The post-Keynesian tradition, following Sraffa (1960), proposed this methodology as an alternative to conventional sectoral classifications, aiming to organize economic activities by their final use. This approach enables the measurement of both direct and indirect labor embodied in production processes driven by final demand, regardless of the sectoral origin of inputs (Sarra *et al*., 2019).

Pasinetti (1973) provided the theoretical foundation for this methodology, which was later applied empirically by Momigliano and Siniscalco (1982, 1986). These early studies tested the hypothesis that employment growth in services was driven by increased manufacturing demand for intermediate inputs, spurred by outsourcing and productive restructuring.

In this sense, the concept of vertical integration has become central to the economic debate, as it allows for the development of more robust indicators of structural change, indicators that are immune to the statistical distortions caused by outsourcing and firm reorganization. The next section outlines the calculation procedures, assumptions, and limitations of the subsystem approach.

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2.1 Subsystem Approach

Momigliano and Siniscalco (1982, 1986) developed a procedure capable of reclassifying any variable, transforming it from a sector-based framework to a subsystem-based one. For multiregional input-output matrices, this procedure can be formalized as follows (Di Bernardino *et al.*, 2024):

$$x = (I - A)^{-1}y = Ly, \tag{1}$$

where y is the final demand vector and $(I - A)^{-1}$ is the Leontief inverse matrix.

To construct manufacturing subsystems, this matrix is associated with the value-added vector:

$$E = \hat{e}_c x, \tag{2}$$

where $\hat{e}_c$ is a diagonalized matrix of value-added coefficients per unit of output in industry i and region r (along the rows). The elements of matrix E show the amount of value added directly and indirectly required from industry i in region r to meet the final demand for commodities from industry j in region s. The sum of each column in this matrix shows the total value added of the specific subsystem j in each region.

By analyzing intersectoral relationships, it is possible to construct indicators that differentiate the effects generated by distinct structural change processes. Productive changes can be decomposed into three components: **insourcing** (value added generated within the country's manufacturing sector), **outsourcing** (value added generated outside manufacturing but still within the country), and **offshoring** (value added generated abroad, whether in manufacturing or other sectors).

For example, Brazil's manufacturing subsystem can be expressed as:

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$$e_{.m}^{.BRA} = e_{mm}^{BRA\,BRA} + e_{nm}^{BRA\,BRA} + e_{mm}^{Outros\,BRA} + e_{nm}^{Outros\,BRA}, \qquad (3)$$

where, $e_{.m}^{.BRA}$ corresponds to the total value added (manufacturing and non-manufacturing) generated in Brazil and abroad. This is decomposed into: $e_{mm}^{BRA\,BRA}$, value added generated within Brazil's manufacturing sector; $e_{nm}^{BRA\,BRA}$, value added generated within Brazil's non-manufacturing sectors; $e_{mm}^{Outros\,BRA}$, value added generated in the manufacturing sector abroad; $e_{nm}^{Outros\,BRA}$, value added generated outside manufacturing abroad.

This equation identifies the value added generated inside and outside manufacturing, both domestically and internationally, to meet the final demand for Brazilian manufactured goods. This approach quantifies the true relevance of manufacturing, identifies outsourcing and offshoring patterns, and evaluates structural changes in global value chains.

It is important to note that the adoption of the subsystem approach relies on specific assumptions. This method is most appropriate for analyzing sectors where vertical linkages, that is, the acquisition of inputs from outside the sector, are more significant than horizontal linkages, which involve sourcing inputs within the same sector. However, not all sectors in an economy exhibit this pattern. In cases where horizontal linkages are more prominent, a sector-based approach is more suitable (Montresor; Marzetti, 2011).

The results obtained from the sectoral and subsystem approaches are not directly comparable, as each is grounded in a distinct logic of production organization. While the sectoral approach classifies activities according to the origin of inputs, the subsystem approach reorganizes them based on their final use, that is, their direct and indirect contribution to the production of a specific final good. Consequently, a single activity may be assigned to different categories depending on the approach adopted.

Additionally, attention must be paid to the assumptions underlying the subsystem approach. The most critical assumption is the rigidity of the technical production structure, expressed through the fixed Leontief technical coefficients, which implies no substitution among inputs. It is also assumed that production responds solely to final demand, ignoring supply shocks or short-term

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technological changes. Another consideration involves the assumption of product homogeneity within each sector and the absence of economies of scale.

Finally, since the method attributes all intermediate production to the satisfaction of final demand for a specific good, it does not capture co-production dynamics or multi-purpose goods. These aspects require careful interpretation of the results, especially in contexts characterized by rapid technological and organizational change.

In the next section, we present the database, and the taxonomies used in this article to illustrate the potential of the subsystem approach.

3. Database and Taxonomies Used

The decomposition procedure formalized above can be applied to different classifications of productive activities. The first sectoral classification dates to Fisher (1933), who divided the economy into three sectors, namely: the primary sector (agriculture), the secondary sector (manufacturing), and the tertiary sector. Today, several classifications exist, each based on specific criteria and various levels of disaggregation. For illustration purposes, we can mention the Global Industry Classification Standard (GICS) [3], the North American Industry Classification System (NAICS)[4], the Statistical Classification of Economic Activities in the European Community (NACE)[5], and the International Standard Industrial Classification (ISIC)[6]. In the Brazilian case, we use the Classificação Nacional de Atividades Econômicas (CNAE)[7].

Other forms of aggregation can also be used, such as the Technology Intensity Classification (OECD, 2011; 2016)[8], or combinations aimed at analyzing specific segments, such as the classification of modern service activities by Eichengreen and Gupta (2013), or the

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3 For more details see: https://www.msci.com/our-solutions/indexes/gics
4 For more details see: https://www.census.gov/naics/
5 For more details see: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Statistical_classification_of_economic_activities_in_the_European_Community_(NACE)
6 For more details see: https://unstats.un.org/unsd/classifications/Econ/isic
7 For more details see: https://concla.ibge.gov.br/classificacoes/por-tema/atividades-economicas
8 Technical appendix see: https://ncses.nsf.gov/pubs/nsb20247/technical-appendix

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classification for Knowledge-Intensive Business Services (KIBS) developed by Miles et al. (1995), in order to generate robust indicators of structural change.

For this practical guide, the information was extracted from the Inter-Country Input-Output (ICIO) database, provided by the OECD (2023), which offers annual data for 76 countries and 45 sectors covering the period from 2000 to 2020 (see Table 1). Data extraction and processing were carried out using the *exvatools package*, developed by Borin and Mancini (2023), which also supports the analysis of other compatible databases, such as WIOD and FIGARO. The classification of productive activities in the ICIO database presents both limitations and important advantages that should be noted. Among the limitations, the high level of sectoral aggregation stands out, as it may obscure relevant dynamics in more disaggregated sectors.

For this study, only three activities are classified as KIBS, namely: 1) Telecommunications, 2) Information technology and other information services, and 3) Professional, scientific, and technical activities. This aggregation overlooks the internal diversity of activities that make up the KIBS sector, hindering the precise identification of their specific contributions to the contemporary productive structure.

Table 1 – Classifications of Productive Activities

Activity	**Classical**	**OECD**
Agriculture, hunting, forestry	Primary	Primary
Fishing and aquaculture	Primary	Primary
Mining and quarrying, energy producing products	Primary	Primary
Mining and quarrying, non-energy producing products	Primary	Primary
Mining support service activities	Primary	Primary
Food products, beverages and tobacco	Secondary	Secondary
Textiles, textile products, leather and footwear	Secondary	Secondary
Wood and products of wood and cork	Secondary	Secondary
Paper products and printing	Secondary	Secondary
Coke and refined petroleum products	Secondary	Secondary
Chemical and chemical products	Secondary	Secondary
Pharmaceuticals, medicinal chemical and botanical products	Secondary	Secondary
Rubber and plastics products	Secondary	Secondary
Other non-metallic mineral products	Secondary	Secondary
Basic metals	Secondary	Secondary
Fabricated metal products	Secondary	Secondary
Computer, electronic and optical equipment	Secondary	Secondary
Electrical equipment	Secondary	Secondary
Machinery and equipment, nec	Secondary	Secondary
Motor vehicles, trailers and semi-trailers	Secondary	Secondary
Other transport equipment	Secondary	Secondary

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Manufacturing nec; repair and installation of machinery and equipment	Secondary	Secondary
Electricity, gas, steam and air conditioning supply	Tertiary	Tertiary
Water supply; sewerage, waste management and remediation activities	Tertiary	Tertiary
Construction	Tertiary	Tertiary
Wholesale and retail trade; repair of motor vehicles	Tertiary	Tertiary
Land transport and transport via pipelines	Tertiary	Tertiary
Water transport	Tertiary	Tertiary
Air transport	Tertiary	Tertiary
Warehousing and support activities for transportation	Tertiary	Tertiary
Postal and courier activities	Tertiary	Tertiary
Accommodation and food service activities	Tertiary	Tertiary
Publishing, audiovisual and broadcasting activities	Tertiary	Tertiary
Telecommunications	Tertiary	KIBS
IT and other information services	Tertiary	KIBS
Financial and insurance activities	Tertiary	Tertiary
Real estate activities	Tertiary	Tertiary
Professional, scientific and technical activities	Tertiary	KIBS
Administrative and support services	Tertiary	Tertiary
Public administration and defence; compulsory social security	Tertiary	Tertiary
Education	Tertiary	Tertiary
Human health and social work activities	Tertiary	Tertiary
Arts, entertainment and recreation	Tertiary	Tertiary
Other service activities	Tertiary	Tertiary
Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	Tertiary	Tertiary

Source: The authors

The aggregation of activities within the category "IT and other information services" for example, imposes significant limitations on the analysis of digital transformation and the knowledge-based economy. By grouping together heterogeneous activities, such as software development, cloud hosting, data processing, and internet portals, under a single classification, the ability to distinguish between segments with varying technological intensities and levels of sophistication is lost.

This limitation hinders the identification of digital services that truly function as strategic inputs for the modernization of manufacturing, such as industrial automation systems, big data, and the Internet of Things. It also constrains efforts to assess whether countries are specializing in high-value-added digital activities or in more standardized, lower-tech services. As a result, the formulation of public policies aimed at strengthening digital sectors becomes less precise, as the available data does not allow for the isolation of the most dynamic segments within the information technology sector.

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Similarly, the broad category "Professional, Scientific, and Technical Activities" presents analytical constraints. By merging diverse services, such as legal, accounting, advertising, design, architecture, engineering, and R&D, into a single grouping, it becomes difficult to isolate the specific effects of each, particularly R&D, on productivity, innovation, and industrial competitiveness. This limitation impairs the measurement of countries' or regions' technological capabilities, as well as the identification of strategic linkages between these services and the manufacturing sector.

Moreover, it weakens the effectiveness of public policies intended to promote innovation systems, since the lack of disaggregated data complicates the monitoring of the evolution, internationalization, and strategic role of activities such as R&D and design as productive inputs.

Despite these limitations, the ICIO database offers important advantages for the study of structural transformation. Its primary strength lies in the construction of harmonized international input-output tables, which enable the tracking of intersectoral and interregional flows based on a standardized methodology. This facilitates comparative analyses across countries and regions, the investigation of global production linkages, and the calculation of advanced indicators of vertical integration and foreign value added.

Furthermore, the database is periodically updated and covers many countries and regions, with data aligned with major international classification systems. Therefore, although sectoral aggregation presents analytical challenges, particularly for knowledge-intensive sectors, the ICIO remains a valuable tool for mapping global production interactions, provided its limitations are acknowledged and addressed through complementary methodological strategies.

4. Results

This section is divided into three subsections. Subsection 4.1 formalizes a didactic example in Excel aimed at showing the steps required to obtain structural change indicators for the subsystem approach and how to interpret the matrix with the results. Subsection 4.2 formalizes the procedure used in the R software to generate structural change indicators for the classification of productive activities in manufacturing and KIBS. Subsection 4.3 presents the step-by-step process

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to build structural change indicators for this approach based on disaggregated data for the 45 activities included in the ICIO database.

4.1 Excel Solution for Domestic Input-Output Matrices

As formalized in **Equation 2**, the transition from the sectoral to a subsystem approach requires four components: the Leontief matrix, the diagonalized total production vector, the diagonalized value-added (or employment) vector, and the diagonalized total demand vector. Assuming a hypothetical matrix, the starting point is the Leontief matrix, presented in **Table 2**, which contains the technical production coefficients between different sectors.

Table 2 – Leontief Matrix

	Primary	Low	Medium-Low	Medium-High	High	KIBS	Other
Primary	1,076	0,221	0,281	0,097	0,022	0,038	0,023
Low	0,038	1,200	0,045	0,055	0,034	0,047	0,047
Medium-Low	0,087	0,123	1,393	0,206	0,054	0,085	0,044
Medium-High	0,123	0,116	0,157	1,251	0,059	0,044	0,031
High	0,011	0,009	0,007	0,010	1,213	0,009	0,021
KIBS	0,228	0,376	0,429	0,349	0,224	1,340	0,344
Other	0,036	0,069	0,065	0,076	0,086	0,062	1,118

Source: The authors

The diagonalized total demand matrix (**Table 3**) can be obtained from the total demand column vector in the Input-Output Matrix using the Excel formula =IF($B103=C$102;Leontief!$K4;0). This formula returns the corresponding element from the final demand vector on the main diagonal and zero for elements outside the main diagonal.

Table 3 – Diagonalized Total Demand

	Primary	Low	Medium-Low	Medium-High	High	KIBS	Other
Primary	139.862	0	0	0	0	0	0
Low	0	240.422	0	0	0	0	0
Medium-Low	0	0	196.522	0	0	0	0
Medium-High	0	0	0	247.470	0	0	0
High	0	0	0	0	63.781	0	0
KIBS	0	0	0	0	0	1.245.674	0
Other	0	0	0	0	0	0	107.519

Source: The authors

Similarly, the diagonalized Value Added matrix (**Table 4**) can be extracted from the value-added row vector in the Input-Output Matrix using an IF function in Excel, which returns a value

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of zero for the elements outside the main diagonal. The formula in Excel is =IF($B113=C$112;C$11;0).

Table 4 – Diagonalized Value Added Matrix

	Primary	Low	Medium-Low	Medium-High	High	KIBS	Other
Primary	21900	0	0	0	0	0	0
Low	0	12454	0	0	0	0	0
Medium-Low	0	0	2395	0	0	0	0
Medium-High	0	0	0	2350	0	0	0
High	0	0	0	0	615	0	0
KIBS	0	0	0	0	0	39075	0
Other	0	0	0	0	0	0	70383

Source: The authors

From the diagonalized matrices of Total Demand and Value Added, the Value Added per unit of total demand can be calculated using the formula =IFERROR(C113/C103;0), as shown in **Table 5**.

Table 5 – Value Added per Unit of Total Demand

	Primary	Low	Medium-Low	Medium-High	High	KIBS	Other
Primary	0,157	0	0	0	0	0	0
Low	0	0,052	0	0	0	0	0
Medium-Low	0	0	0,012	0	0	0	0
Medium-High	0	0	0	0,009	0	0	0
High	0	0	0	0	0,010	0	0
KIBS	0	0	0	0	0	0,031	0
Other	0	0	0	0	0	0	0,655

Source: The authors

A similar procedure used to obtain the diagonalized total demand matrix can be applied to obtain the diagonalized final demand matrix, =IF($B103=C$102;Leontief!$J4;0), as shown in **Table 6**.

Table 6 – Diagonalized Final Demand Matrix

	Primary	Low	Medium-Low	Medium-High	High	KIBS	Other
Primary	41.524	0	0	0	0	0	0
Low	0	156.516	0	0	0	0	0
Medium-Low	0	0	51.890	0	0	0	0
Medium-High	0	0	0	141.317	0	0	0
High	0	0	0	0	43.079	0	0
KIBS	0	0	0	0	0	811.717	0
Other	0	0	0	0	0	0	23.843

Source: The authors

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With the diagonalized Value Added per unit of Final Demand matrix (C123:I129), the Leontief matrix (C92:I98), and the diagonalized Final Demand matrix, the direct and indirect value added for each subsystem is calculated based on its final destination. The Excel formula to obtain this matrix is =MMULT(MMULT(C123:I129;C92:I98);C133:I139), as shown in **Table 7**.

Table 7 – Direct and Indirect Value Added

	Primary	Low	Medium-Low	Medium-High	High	KIBS	Other
Primary	6.993	5.409	2.284	2.145	149	4.834	86
Low	82	9.731	120	403	75	1.983	59
Medium-Low	44	235	881	354	29	839	13
Medium-High	49	173	77	1.678	24	342	7
High	4	14	4	14	504	71	5
KIBS	297	1.847	698	1.545	303	34.127	257
Other	983	7.116	2.202	7.061	2.436	33.135	17.448

Source: The authors

Since the subsystem approach relies on accounting identities, it is possible to verify if the calculations are correct. To do this, the inverse total demand matrix is obtained using the formula =MINVERSE(C103:I109), as shown in **Table 8**.

Table 8 – Inverse of Total Demand Matrix

	Primary	Low	Medium-Low	Medium-High	High	KIBS	Other
Primary	0.0000071	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Low	0.0000000	0.0000042	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Medium-Low	0.0000000	0.0000000	0.0000051	0.0000000	0.0000000	0.0000000	0.0000000
Medium-High	0.0000000	0.0000000	0.0000000	0.0000040	0.0000000	0.0000000	0.0000000
High	0.0000000	0.0000000	0.0000000	0.0000000	0.0000157	0.0000000	0.0000000
KIBS	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000008	0.0000000
Other	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000093

Source: The authors

The relative share of each sector in the total final demand is obtained by multiplying the Inverse Total Demand Matrix (Table 8) by the Leontief matrix (Table 2) and the Final Demand matrix (Table 6), respectively. The calculation is done using the formula =MMULT(MMULT(C159:I165;C92:I98);C133:I139), as shown in **Table 9**.

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Table 9 – Shares of Each Sector in Final Demand

	Primary	Low	Medium-Low	Medium-High	High	KIBS	Other	Sum
Primary	0.319	0.247	0.104	0.098	0.007	0.221	0.004	**1.000**
Low	0.007	0.781	0.010	0.032	0.006	0.159	0.005	**1.000**
Medium-Low	0.018	0.098	0.368	0.148	0.012	0.350	0.005	**1.000**
Medium-High	0.021	0.073	0.033	0.714	0.010	0.146	0.003	**1.000**
High	0.007	0.022	0.006	0.023	0.819	0.115	0.008	**1.000**
KIBS	0.008	0.047	0.018	0.040	0.008	0.873	0.007	**1.000**
Other	0.014	0.101	0.031	0.100	0.035	0.471	0.248	**1.000**

Source: The authors

The results show, for each row, the decomposition of final demand in terms of the sectors that fulfilled it. The sum of the columns for each row should equal 1, confirming the accuracy of the calculations.

From Table 7 **(**Direct and Indirect Value Added), it is possible to construct distinct indicators of structural change. Each column in the table identifies a subsystem, and each row represents the branch of origin for the direct and indirect value added. Thus, the sum of all the rows in each column indicates the total direct and indirect value added for the respective subsystem. For example, the sum of all rows in column 1 (6.993 + 82 + 44 + 49 + 4 + 297 = 8.453) identifies the total direct and indirect value added for the Primary subsystem. Meanwhile, the sum of all rows in column 2 (5.409 + 9.731 + 235 + 173 + 14 + 1.847 + 7.116 = 24.525) corresponds to the direct and indirect value added for the Low-tech manufacturing subsystem.

This matrix allows for the calculation of various structural change indicators. The sum of the cells on the main diagonal indicates the degree of vertical integration, that is, the amount of direct and indirect inputs originating within the subsystem itself (Giovanini et al., 2025). For example, in Table 7, dividing the value in cell M22 (9.731) by the sum of column 2 (24.525) yields 0.397 (or 39.7%), which indicates the degree of vertical integration for the Low-tech subsystem. A higher degree of vertical integration is typically reflected by values close to 50%.

It is also possible to determine each subsystem's share in domestic value added. This is done by dividing the total column for the subsystem by the total value added in the country (i.e., the sum of all matrix entries). For example, the share of the Low-tech subsystem is 16.44% ((5.409 + 9.731 + 235 + 173 + 14 + 1.847 + 7.116) / 149.170), while the share of the KIBS subsystem is

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51% ((4.834 + 1.983 + 839 + 342 + 71 + 34.127 + 33.135)/149.170). In other words, 16.44% of final demand is fulfilled by the Low-tech subsystem.

The sum of multiple columns can be used to obtain the share of aggregated subsystems. For instance, summing the values from the Low-tech, Medium-Low-tech, Medium-High-tech, and High-tech columns and dividing by the total value added ((24.525 + 6.266 + 13.200 + 3.520)/149.170) yields the manufacturing subsystem's share, which is 32%.

One of the main advantages of the subsystem approach is that it identifies the direct and indirect inputs destined for the manufacturing subsystem. In Table 7, for example, inputs from manufacturing branches directed toward the manufacturing subsystem are highlighted in blue, while inputs from the KIBS sector are highlighted in yellow. Inputs destined for the KIBS subsystem are shown in green. In other words, the table distinguishes between KIBS inputs used by manufacturing subsystems and those used to meet final demand.

It is also possible to identify the value added from KIBS sector inputs destined for the High-tech subsystem (303), as well as the total value added from the KIBS subsystem itself, calculated as the sum of all relevant branches (4.834 + 1.983 + 839 + 342 + 71 + 34.127 + 33.135 = 75.333). These figures can be used to calculate both the share of KIBS inputs used as intermediate inputs in the subsystem and the share of the KIBS subsystem in the total value added.

As emphasized earlier, this is one of the key advantages of the subsystem approach: it does not conflate outsourcing with offshoring, thereby enabling a more accurate analysis of the factors underlying structural change. Organizational changes in manufacturing that affect intersectoral relationships lead to shifts in direct and indirect inputs, which, over time, are reflected in changes to the values in the rows corresponding to the respective manufacturing subsystem columns.

4.2 Solution in R for Inter-Regional Input-Output Matrices

The following formalized code enables the construction of structural change indicators from three distinct databases: the ICIO dataset provided by the OECD (2023), which is extracted using the *exvatools* package developed by Borin and Mancini (2023). This package also supports processing other databases such as WIOD and FIGARO. It facilitates the generation of indicators

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based on inter-country input-output tables, value-added flows in global value chains, and bilateral trade decompositions, thereby offering a comprehensive framework for analyzing sectoral transformations in economies over time.

The package can generate indicators for both domestic and foreign value-added based on an inter-regional input-output matrix structure. This feature enables the analysis of international integration of economies by decomposing value added along global value chains. In this study, the functions of this package are used to generate the matrices needed to estimate the direct and indirect value added of each subsystem, following the vertical integration approach.

The analysis was conducted for 75 countries and 45 sectors available in the ICIO database, covering the period from 1995 to 2020. Indicators of participation for the manufacturing and KIBS subsystems will be constructed. For accurate calculations, it is necessary to download the compressed OECD data (Extended ICIO) before running the R code. The data can be accessed via the link below: https://www.oecd.org/en/data/datasets/inter-country-input-output-tables.html

The five available files cover the following periods: 1995-2000, 2001-2005, 2006-2010, 2011-2015, and 2016-2020.

In R, the first step is to prepare the working environment. The functions rm(list = ls()) and setwd() are used to clear previously created objects and to declare the working directory:

```
rm(list = ls())
setwd("G:/Meu Drive/UDESC/Artigo Mudança estrutural e KIBS/Matrizes estendidas")
```

The forward slashes "/" should be used to define the path to the directory, which must contain the data downloaded from the OECD.

The next step is to load the exvatools library:

```
library(exvatools)
```

Then, the main loop is started, which will generate results for each year, from 1995 to 2020:

```
for (ano in 1995:2020) {
```


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It is important to note that the procedures below require high computational capacity due to the size of the matrices being used. Therefore, performing calculations for all years in a single loop requires both time and processing power.

The function make_wio structures the global input-output matrix data from the OECD's ICIO database, preparing it for analysis. By selecting the year and version of the database, the function organizes the economic flows between countries and activities, creating an object of type wio (a name given by the exvatools library), which contains the key matrices of interest. The most important matrices are: 1) the Leontief matrix; 2) the intermediate transactions matrix, Z; 3) the final demand matrix, Y; 4) the total production vector, X; and 5) the value-added matrix, VA. The command is expressed as follows:

```
wio <- make_wio("icio2023", year = ano, src_dir = getwd())
```

The function summary(wio) can be used to query the provided data.

In addition to ICIO, the function make_wio() also allows the use of WIOD[9] and FIGARO[10] databases. The syntax is similar, and it is necessary to specify the name and edition of the database. Examples:

```
wio_wiod <- make_wio("wiod2016", year = 2014, src_dir = getwd())

wio_figaro <- make_wio("figaro2023", year = 2020, src_dir = getwd())
```

Since the code presented below was developed for the ICIO data, applying it to WIOD and FIGARO databases requires adaptation, as the data provided by these sources results in matrices of different dimensions.

After loading the necessary matrices and vectors, objects are created for the intermediate inputs, total production, final demand, global Leontief matrix, and value-added. The function meld

[9] Available for 56 activities and 44 countries for the years 2000 to 2014: https://www.rug.nl/ggdc/valuechain/wiod/wiod-2016-release

[10] Available for 64 industries and 45 countries for the years 2010 to 2020: https://ec.europa.eu/eurostat/web/esa-supply-use-input-tables/database#Input-output%20tables%20industry%20by%20industry

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is used to merge data for China and Mexico, for which ICIO provides the data in two vectors, domestic and foreign. A total of five distinct objects need to be created, specifically:

1. Intermediate inputs:
```
Z <- meld(wio$Z)
```

2. Total output:
```
X <- meld(wio$X)
```

3. Final demand:
```
Y <- meld(wio$Y)
```

4. Global Leontief inverse:
```
B <- meld(wio$B)
```

5. Value added:
```
VA <- meld(wio$VA)
```

The value-added and total production matrices need to be declared as numeric using the following commands:

```
va <- as.numeric(VA)
x <- as.numeric(X)
```

From which the value added per unit of production is obtained:

```
h <- ifelse(x == 0, 0, va / x)
```

This is diagonalized with the diag() function, which is native to R:

```
h_hat <- diag(h)
```

The total final demand by country is obtained by summing the rows of the final demand matrix using the following command:

```
y_vector <- rowSums(Y)
```

This also needs to be diagonalized:

```
y_hat <- diag(y_vector)
```

Once all the necessary matrices are prepared, the value added is calculated according to the subsystem approach with the command:

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```
V <- h_hat %*% B %*% y_hat
```

Finally, the row and column names are added:

```
rownames(V) <- rownames(B)
colnames(V) <- colnames(B)
```

The result will be a matrix like the one obtained in **Table 7**, containing the total value added broken down by country and activity.

Table 10 illustrates, through a fictitious example, how the V matrix (Value Added) is structured. Each column identifies a subsystem, and each row represents the source sectors of the direct and indirect inputs used by the respective subsystem. Since the ICIO provides data for 45 activities, the first 45 columns identify the subsystems of Country 1, the next 45 columns identify the subsystems of Country 2, and the last 45 rows correspond to the last country (in this case, the rest of the world). The rows show the origin of the direct and indirect inputs used by the subsystem of the corresponding column. For example, the cell V12 identifies the inputs from the manufacturing sector of Country 1 destined for the Agriculture subsystem of Country 1.

Table 10 – Illustrative Example of the Structure of the Matrix Generated by the Subsystem Approach

		Country 1			**Country 2**			**Country 3**		
		Agriculture	**Industry**	**Services**	**Agriculture**	**Industry**	**Services**	**Agriculture**	**Industry**	**Services**
	Agriculture									
	Industry	V_{12}								
Country 1	**Services**									
	Agriculture									
	Industry									
Country 2	**Services**									
	Agriculture									
	Industry									
Country 3	**Services**									

Source: The authors

In the matrices along the main diagonal, in blue, the inputs from domestic industries are found, used both directly and indirectly in each domestic subsystem. Outside the main diagonal, the inputs from other countries are located. This matrix can be decomposed to create distinct indicators that identify changes in the origin of the external inputs used in each subsystem.

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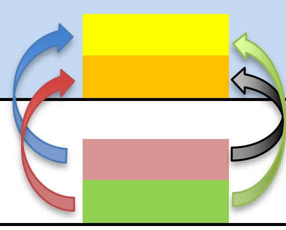
Increases in the share of external inputs highlight offshoring of productive activities. Conversely, decreases in the share of external inputs highlight reshoring of productive activities. Furthermore, in the case of reshoring, distinct movements of the return of productive activities over time can be identified, as shown in Table 10.

Table 11 reproduces Table 10 for only two countries. It is possible to identify four distinct cases of reshoring for Country 1, which are: 1) The return of outsourced inputs for external KIBS activities to domestic manufacturing firms, green arrow; 2) The return of outsourced inputs for external KIBS activities to domestic KIBS firms, red arrow; 3) The return of outsourced inputs for external manufacturing activities to domestic manufacturing firms, blue arrow; and 4) The return of outsourced inputs for external manufacturing activities to domestic KIBS firms, black arrow.

Table 11 – Illustrative Example of the Structure of the Matrix Generated by the Subsystem Approach

		Country 1			**Country 2**		
		Services	**Agriculture**	**Services**	**Agriculture**	**Services**	**Agriculture**
	Agriculture						
	Industry						
Country 1	**Services**						
	Agriculture						
	Industry						
Country 2	**Services**						



Source: The authors

In other words, it is possible to identify whether the relocation of productive activities resulted in a process of reindustrialization (Cases 1 and 3) or if it increased the dependence of the manufacturing sector on domestic KIBS, at the expense of foreign manufacturing and KIBS inputs (Cases 2 and 4).

Since offshoring occurs to different countries, calculating the total outsourced activities requires the use of more advanced programming tools. **Table 12** illustrates how offshoring data is distributed within the V matrix. In this example, Country 1 outsources manufacturing activities to service firms in Countries 2 and 3, highlighted in yellow cells. Therefore, to obtain the total value added from Industry services in Country 1 arising from outsourced activities to other countries, it is necessary to sum these cells.

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Table 12 – Offshoring of Manufacturing Activities to Service Activities

		Country 1			Country 2			Country 3		
		Agriculture	Industry	Services	Agriculture	Industry	Services	Agriculture	Indústria	Serviços
Country 1	Agriculture									
	Industry									
	Services									
Country 2	Agriculture									
	Industry									
	Services									
Country 3	Agriculture									
	Industry									
	Services									

Source: The authors

In R, the developed code aims to calculate participation indicators in value-added based on the V matrix. In this matrix, since each country has 45 subsystems, processing is done in blocks of 45 columns. The first step of the code is to define the initial parameters: the total number of countries (77), the number of subsystems (columns) per country (45), and the total number of rows in the V matrix:

```
num_countries <- 77
cols_per_country <- 45
total_rows <- nrow(V)
```

Next, the rows corresponding to the sectors (in the rows) are identified. Since the matrix structure repeats the 45 sectors for each country across the 3,454 rows, the lapply function is used to construct sequences that capture the specific positions of these sectors in all countries. Each resulting vector represents the KIBS and manufacturing sectors:

```
kibs_rows <- unlist(lapply(c(34, 35, 38), function(x) seq(x, 3454, by = 45)))
ind_rows  <- unlist(lapply(6:22, function(x) seq(x, 3454, by = 45)))
```

Before calculating each indicator, it is necessary to pre-allocate a dataframe to store the results, with variables related to the total and domestic participation of KIBS and manufacturing sectors in the added value of the manufacturing subsystem, and the participation of each subsystem in the total added value:

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```
  indicators <- c(
  "kibs_all", "ind_all","kibs_domestic", "ind_domestic",
  "kibs_country", "ind_country","kibs", "ind")
```

```
 results <- data.frame(matrix(NA, nrow = num_countries, ncol = length(indicators)))
 colnames(results) <- indicators
```

With all the elements defined, the loop that iterates over the countries begins. For each country i, the initial column, start_col, and final column, end_col, of the corresponding block are defined, from which the submatrix V_sub is extracted. In other words, the matrix with data for the 45 subsystems of country i:

```
 for (i in 1:num_countries) {
```

```
  # Define column range for country i
  start_col <- (i - 1) * cols_per_country + 1
  end_col <- min(i * cols_per_country, ncol(V))  # Avoid overflow
```

```
  # Extract country-specific submatrix
  V_sub <- as.data.frame(V[, start_col:end_col])
```

From this submatrix, the total participation of domestic and foreign KIBS and manufacturing inputs in the manufacturing added value is calculated:

a) KIBS

```
  kibs_all <- sum(V_sub[kibs_rows, 6:22]) / sum(V_sub[, 6:22])
```

b) Manufaxturing

```
  ind_all  <- sum(V_sub[ind_rows, 6:22]) / sum(V_sub[, 6:22])
```

The share of domestic inputs from the KIBS and manufacturing sectors in the total (domestic + foreign) added value of the manufacturing subsystem:

a) KIBS

```
  kibs_domestic<- sum(V_sub[c(start_col + 33,start_col + 34, start_col + 37), 6:22])/
sum(V_sub[,6:22])
```

b) Manufacturing

```
  ind_domestic <-sum(V_sub[(start_col + 5):(start_col + 21), 6:22])/ sum(V_sub[,6:22])
```


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The participation of domestic KIBS and manufacturing inputs in the domestic manufacturing added value:

a) KIBS

```
   kibs_country<- sum(V_sub[c(start_col + 33, start_col + 34, start_col + 37), 6:22])/
sum(V_sub[start_col:(start_col+44), 6:22])
```

b) Manufacturing

```
   ind_country <-sum(V_sub[(start_col + 5):(start_col + 21), 6:22])/
sum(V_sub[start_col:(start_col+44), 6:22])
```

Also, the participation of KIBS and manufacturing subsystems in the total direct and indirect added value:

```
kibs<-sum(V_sub[,c(34,35,38)])/ sum(V_sub)
ind<-sum(V_sub[,c(6:22)])/ sum(V_sub)
```

Then, the results of each iteration are stored in the results dataframe:

```
   results[i, ] <- c(kibs_all, ind_all,kibs_domestic,
                     ind_domestic, kibs_country, ind_country,kibs, ind)

 }
```

Finally, the country names are assigned to the rows of the results table based on the first three characters of the rows in matrix Z, and the results are exported to a .csv file, completing the loop for the respective year:

```
country_codes <- unique(substr(rownames(wio$Z), 1, 3))[1:77]
 rownames(results) <- country_codes

write.csv(results, paste0("country_results_", year, "_Bogliacino.csv"),
   row.names = TRUE
}
```

Table 13 shows the structure of the results exported in the .csv spreadsheet, with the information organized and exemplified for the first ten countries of the sample in 1996, in percentage terms. Each row of the table corresponds to a country, identified by its three-letter code, and each column represents an indicator constructed using the subsystem approach.

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Table 13 – Organization of results in the .csv spreadsheet

	kibs_all	ind_all	kibs_domestic	ind_domestic	kibs_country	ind_country	kibs	ind
ARG	4.5%	56.5%	3.9%	52.8%	4.3%	57.8%	4.7%	24.8%
AUS	5.2%	53.4%	4.1%	46.6%	4.9%	56.1%	4.5%	15.6%
AUT	5.4%	60.0%	3.0%	49.0%	4.1%	66.8%	3.2%	22.4%
BEL	7.1%	54.0%	4.0%	39.7%	6.6%	64.6%	3.1%	26.4%
BGD	3.0%	51.3%	2.2%	43.7%	2.8%	54.1%	3.3%	27.3%
BGR	6.3%	41.6%	4.5%	34.6%	6.2%	47.2%	2.7%	17.7%
BLR	2.8%	57.7%	1.1%	45.0%	1.6%	68.4%	2.9%	38.9%
BRA	6.3%	52.9%	5.6%	49.5%	6.2%	54.8%	1.6%	20.7%
BRN	1.2%	47.5%	0.3%	41.7%	0.4%	48.7%	7.2%	7.1%
CAN	4.3%	58.0%	2.3%	44.1%	3.3%	64.1%	2.4%	20.9%

Source: The authors

In the case of Argentina, for example, it is observed that the inputs from the KIBS sector, both domestic and foreign (kibs_all), accounted for 4.5% of the total inputs (domestic and foreign) used by the manufacturing subsystem. When considering only domestic KIBS inputs (kibs_domestic), this participation was 3.9%. Moreover, when the analysis is restricted to the domestic added value of the manufacturing subsystem, the participation of domestic KIBS inputs (kibs_country) increases to 4.3%, highlighting the relative importance of these services in the domestic content of manufacturing production.

A similar analysis can be conducted for inputs from the manufacturing sector. In the same year, the manufacturing inputs (both domestic and foreign) used by Argentina's manufacturing subsystem (ind_all) accounted for 56.5% of the total inputs employed, with 52.8% (ind_domestic) coming from domestic manufacturing itself. When considering only domestic added value, the participation of domestic manufacturing inputs (ind_country) rises to 57.8%.

The last two columns of the table show the participation of the KIBS and manufacturing subsystems in the total direct and indirect added value of the entire economy, which, for Argentina in 1996, were 4.7% and 24.8%, respectively. This result structure allows for the tracking of the degree of integration of knowledge-intensive services and manufacturing industries in the production chains, and their importance for value generation, in a comparable manner across countries and over time. Appendix 1 provides the complete code in a Script created using RStudio.

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4.3 Results by Activity in

The code described in this section allows for the calculation of structural change indicators by activity. The initial part of the code is similar to the previous one (Subsection 4.2), since it is necessary to obtain matrix V, which identifies the value added by each activity for the subsystem approach. However, the second part of the code is considerably different, as it requires executing two loops, one over countries and the other over sectors.

The first part of the code is:

```
rm(list = ls())
setwd("G:/Meu Drive/UDESC/Artigo Mudança estrutural e KIBS/Matrizes estendidas")

library(exvatools)

for (ano in 1995:2020) {

 wio <- make_wio("icio2023", year = ano, src_dir = getwd())
 Z <- meld(wio$Z); X <- meld(wio$X); Y <- meld(wio$Y)
 B <- meld(wio$B); VA <- meld(wio$VA)

 va <- as.numeric(VA)
 x <- as.numeric(X)
 h <- ifelse(x == 0, 0, va / x)
 h_hat <- diag(h)
 y_vector <- rowSums(Y)
 y_hat <- diag(y_vector)
 V <- h_hat %*% B %*% y_hat

 rownames(V) <- rownames(B)
 colnames(V) <- colnames(B)

 num_countries <- 77
 cols_per_country <- 45
 total_rows <- nrow(V)
```

The second part of the code creates a list with the row indices for each sector across countries. This is necessary to compute offshoring by country and activity as follows:

```
 sector_rows <- lapply(1:45, function(s) seq(s, total_rows, by = cols_per_country))
```

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Then, it defines variable names for each activity, for domestic value added, total value added, and offshoring:

```
variables <- c(
  paste0("domestic_", 1:45),
  paste0("total_", 1:45),
  paste0("offshoring_", 1:45),
  paste0("subsystem_", 1:45)
)
```

A blank dataframe is created to store results for each country and sector:

```
results <- data.frame(matrix(NA, nrow = num_countries, ncol = length(variables)))
colnames(results) <- variables
```

The loop over countries begins, where the starting and ending columns are defined, and a submatrix for country i is extracted:

```
#Loop ao longo das colunas
for (i in 1:num_countries) {
  start_col <- (i - 1) * cols_per_country + 1
  end_col <- min(i * cols_per_country, ncol(V))
  V_sub <- as.data.frame(V[, start_col:end_col])
```

Next, the loop over sectors begins:

```
  #Loop ao longo das linhas
  for (s in 1:45) {
```

It calculates the share of domestic value added from sector s used as input by the manufacturing subsystem:

```
    domestic_s <- sum(V_sub[start_col + (s - 1), 6:22]) / sum(V_sub[, 6:22])
```

It computes the total value added share (domestic and foreign) from sector s for the manufacturing subsystem:

```
    total_s <- sum(V_sub[sector_rows[[s]], 6:22]) / sum(V_sub[, 6:22])
```

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It obtains the share of value added from sector *s* supplied by other countries to the manufacturing subsystem:

```
  offshoring_s <- total_s - domestic_s
```

These values are then stored in the results matrix:

```
     results[i, paste0("total_", s)] <- total_s
    results[i, paste0("domestic_", s)] <- domestic_s
    results[i, paste0("offshoring_", s)] <- offshoring_s
  }
```

After the loop over sectors is completed, the code calculates the contribution of each of the 45 subsystems. These values are added to the results matrix, concluding the loop over countries:

```
    subsystem <- t(as.data.frame(colSums(V_sub) / sum(V_sub)))
    results[i, paste0("subsystem_", 1:45)] <- subsystem
 }
```

Finally, the results are saved to a .csv file, and the loop over years is completed:

```
 write.csv(results, file = paste0("results_", year, ".csv"), row.names = TRUE)
}
```

Table 14 consolidates the results saved in the .csv file, with all values expressed as percentages. The table is structured into four distinct sections, each offering a complementary perspective on the value-added structure of the manufacturing subsystem:

1. **Share in Domestic Value Added** (domestic_1 to domestic_45): This section shows the share of each sector (from sector 1 to sector 45) in the direct and indirect domestic value added of the manufacturing subsystem. It captures how much each sector contributes to manufacturing through domestically produced inputs.

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Tabela 14 – Results by activity

	domestic_1	⋯	domestic_45	total_1	⋯	total_45	offshoring_1	⋯	offshoring_45	subsystem_1	⋯	subsystem_45
ARG	8.06%	⋯	0.00%	8.47%	⋯	0.00%	0.41%	⋯	0.00%	2.82%	⋯	0.91%
AUS	4.37%	⋯	0.00%	4.93%	⋯	0.00%	0.57%	⋯	0.00%	2.25%	⋯	0.00%
AUT	3.47%	⋯	0.00%	4.48%	⋯	0.00%	1.01%	⋯	0.00%	1.54%	⋯	0.13%
BEL	2.50%	⋯	0.00%	4.30%	⋯	0.00%	1.80%	⋯	0.00%	0.97%	⋯	0.23%
BGD	14.47%	⋯	0.00%	16.34%	⋯	0.00%	1.87%	⋯	0.00%	12.39%	⋯	0.00%
BGR	10.84%	⋯	0.00%	11.55%	⋯	0.00%	0.70%	⋯	0.00%	8.66%	⋯	0.13%
BLR	9.54%	⋯	0.00%	12.09%	⋯	0.00%	2.55%	⋯	0.00%	7.87%	⋯	0.00%
BRA	12.72%	⋯	0.00%	13.18%	⋯	0.00%	0.46%	⋯	0.00%	1.15%	⋯	1.20%
BRN	0.11%	⋯	0.00%	0.74%	⋯	0.00%	0.63%	⋯	0.00%	0.50%	⋯	0.12%
CAN	3.62%	⋯	0.00%	4.40%	⋯	0.00%	0.78%	⋯	0.00%	1.25%	⋯	0.15%

Source: The authors

2. **Participation in Total Value Added** (total_1 to total_45): This section shows the total contribution, encompassing both domestic and foreign sources, of each sector to manufacturing value added. It measures the embedded contribution of each sector along national and global value chains.
3. **Participation of Foreign Inputs** (offshoring_1 to offshoring_45): This section isolates the foreign component of each sector's contribution, calculated as the difference between total and domestic shares. It reflects the importance of imported inputs from each sector to manufacturing, serving as an indicator of vertical specialization and offshoring intensity.
4. **Export Subsystem Structure** (subsystem_1 to subsystem_45): The final part identifies the share of each sector in the total (direct and indirect) value added generated by the export subsystem. It provides a comprehensive view of each sector's relative importance within the export-oriented production structure. **Appendix 2** provides this code in a script developed using RStudio.

5. Conclusion

This study aimed to develop an accessible and replicable methodological guide based on the vertical integration approach. An illustrative example in Excel was used to provide a didactic explanation of the procedures required to obtain indicators for the subsystem approach and to demonstrate how these indicators should be interpreted. Furthermore, using data from the 2023

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edition of the Inter-Country Input-Output (ICIO) tables, covering the period from 1995 to 2020, the necessary steps were systematized to generate indicators from real data, processed with the exvatools package in R.

The adopted method enabled the construction of a matrix that distinguishes the originating sectors and destination subsystems of direct and indirect value added (V). From this matrix, a set of systematic and comparable indicators was derived to measure the participation of the manufacturing and KIBS sectors within the manufacturing subsystem, distinguishing between domestic and foreign inputs. Additional indicators were developed to capture the contribution of each subsystem to the total direct and indirect value added. This procedure was replicated for all 45 activities available in the ICIO database.

The approach proved particularly useful in distinguishing offshoring and reshoring dynamics over time, based on the disaggregation of value-added flows by country and sector. By employing a classification that differentiates KIBS used as inputs by the manufacturing subsystem from those directed toward final demand, it was possible to identify relevant structural transformations associated with the reconfiguration of productive activities.

The systematic treatment of data allowed for the construction of standardized indicators of participation in value added, distinguishing between domestic and international sources of inputs used by each subsystem. These indicators can be employed in cross-country comparative analyses or to monitor the trajectory of productive integration (or disintegration) over time, offering valuable input for the formulation of industrial and innovation policies.

In this way, the study provides tools that can substantially contribute to advancing research on structural change, particularly in the current context of escalating geopolitical tensions and increasing integration between manufacturing and services, driven by the advancement of digital technologies. When appropriately applied, these tools can yield valuable insights to support the design of public policies focused on economic development, international trade, and innovation.

As a future research agenda, it is worth exploring the expansion of the developed tools to accommodate alternative sector classifications or to incorporate institutional and public policy dimensions that have influenced observed processes of structural transformation. In this regard,

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topics related to macroeconomic policies, such as exchange rates, fiscal, monetary, financial, and redistributive policies, are of particular relevance. Moreover, the indicators developed in this study may be integrated into econometric models of growth or productivity to investigate the dynamic impacts of global value chain participation on countries' economic performance.

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Appendix 1 – R code for IND-KIBS taxonomy

```
# Clean the environment and set the working directory
rm(list = ls())
setwd("G:/Meu Drive/UDESC/Di berardino/Matrizes extendidas")

# Load required packages
library(exvatools)
library(dplyr)
library(writexl)

# Main loop for years from 1995 to 1996 (adjust as needed)
for (year in 1995:1996) {

  ##########################################
  ### PART 1: VALUE ADDED - SUBSYSTEM APPROACH
  ##########################################

  # Load ICIO data for the selected year
  wio <- make_wio("icio2023", year = year, src_dir = getwd())

  # Merge vectors for China and Mexico using `meld`
  Z <- meld(wio$Z)   # Intermediate inputs
  X <- meld(wio$X)   # Total output
  Y <- meld(wio$Y)   # Final demand
  B <- meld(wio$B)   # Global Leontief inverse
  VA <- meld(wio$VA) # Value added

  # Convert to numeric
  va <- as.numeric(VA)
  x <- as.numeric(X)

  # Compute value added per unit of output (h vector)
  h <- ifelse(x == 0, 0, va / x)
  h_hat <- diag(h)  # Convert to diagonal matrix

  # Total final demand per country
  y_vector <- rowSums(Y)
  y_hat <- diag(y_vector)  # Convert to diagonal matrix

  # Value added matrix according to subsystem approach
  V <- h_hat %*% B %*% y_hat

  # Assign row and column names for interpretability
```


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```
rownames(V) <- rownames(B)
colnames(V) <- colnames(B)


##########################################################
### PART 2: INDICATORS BASED ON OECD-KIBS TAXONOMY
##########################################################

# Configuration: number of countries and sectors per country
num_countries <- 77
cols_per_country <- 45
total_rows <- nrow(V)

# Define row indices for KIBS and Manufacturing sectors
kibs_rows <- unlist(lapply(c(34, 35, 38), function(x) seq(x, 3454, by = 45)))
ind_rows  <- unlist(lapply(6:22, function(x) seq(x, 3454, by = 45)))

# Prepare a dataframe to store results
indicators <- c(
  "kibs_all", "ind_all","kibs_domestic", "ind_domestic",
  "kibs_country", "ind_country","kibs", "ind")

results <- data.frame(matrix(NA, nrow = num_countries, ncol = length(indicators)))
colnames(results) <- indicators

# Loop over each country to compute indicators
for (i in 1:num_countries) {

  # Define column range for country i
  start_col <- (i - 1) * cols_per_country + 1
  end_col <- min(i * cols_per_country, ncol(V))  # Avoid overflow

  # Extract country-specific submatrix
  V_sub <- as.data.frame(V[, start_col:end_col])



  # 1. Share of total inputs (domestic and foreign) in total manufacturing
  # value added (domestic and foreign)
  kibs_all <- sum(V_sub[kibs_rows, 6:22]) / sum(V_sub[, 6:22])
  ind_all  <- sum(V_sub[ind_rows, 6:22]) / sum(V_sub[, 6:22])
```

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```
  # 2. Share of domestic inputs in total manufacturing value
  # added (domestic + foreign)
  kibs_domestic <- sum(V_sub[c(start_col + 33, start_col + 34, start_col + 37), 6:22]) /
    sum(V_sub[, 6:22])
  ind_domestic  <- sum(V_sub[(start_col + 5):(start_col + 21), 6:22]) /
    sum(V_sub[, 6:22])



  # 3. Share of domestic inputs in domestic manufacturing value added
  kibs_country <- sum(V_sub[c(start_col + 33, start_col + 34, start_col + 37), 6:22]) /
    sum(V_sub[start_col:(start_col + 44), 6:22])
   ind_country  <- sum(V_sub[(start_col + 5):(start_col + 21), 6:22]) /
    sum(V_sub[start_col:(start_col + 44), 6:22])



  # 4. Share of subsystems (KIBS and Manufacturing) in total value added
  kibs <- sum(V_sub[, c(34, 35, 38)]) / sum(V_sub)
  ind  <- sum(V_sub[, 6:22]) / sum(V_sub)

  # Store results for country i
  results[i, ] <- c(kibs_all, ind_all,kibs_domestic,
  ind_domestic, kibs_country, ind_country,kibs, ind
  )
 }

 # Add country codes as row names
 country_codes <- unique(substr(rownames(wio$Z), 1, 3))[1:77]
 rownames(results) <- country_codes

 # Export the final results matrix
 write.csv(results,paste0("country_results_", year, "_Bogliacino.csv"),
  row.names = TRUE
 )
}
```


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Appendix 2 – R code for value added broken down by activities

```
# Clear the environment and set the working directory
rm(list = ls())
setwd("G:/Meu Drive/UDESC/Artigo Mudança estrutural e KIBS/Matrizes extendidas")

# Load the required package
library(exvatools)

# Loop over the years 1995 to 2020
for (year in 1995:1996) {

  # Load the ICIO database for the given year
  wio <- make_wio("icio2023", year = year, src_dir = getwd())

  # Extract and combine matrices
  Z <- meld(wio$Z)      # Intermediate inputs
  X <- meld(wio$X)      # Total output
  Y <- meld(wio$Y)      # Final demand
  B <- meld(wio$B)      # Leontief inverse
  VA <- meld(wio$VA)    # Value added

  # Convert value added and total output to numeric vectors
  va <- as.numeric(VA)
  x <- as.numeric(X)

  # Compute value added per unit of output (h)
  h <- ifelse(x == 0, 0, va / x)

  # Diagonalize the value added vector
  h_hat <- diag(h)

  # Aggregate final demand vector and diagonalize it
  y_vector <- rowSums(Y)
  y_hat <- diag(y_vector)

  # Compute the value added matrix from the subsystem approach
  V <- h_hat %*% B %*% y_hat

  # Assign row and column names
  rownames(V) <- rownames(B)
  colnames(V) <- colnames(B)

  # Define number of countries and sectors per country
```

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```
num_countries <- 77
cols_per_country <- 45
total_rows <- nrow(V)

# Create a list of row indices for each sector across all countries
sector_rows <- lapply(1:45, function(s) seq(s, total_rows, by = cols_per_country))

# Define variable names for output table
variables <- c(
  paste0("domestic_", 1:45),
  paste0("total_", 1:45),
  paste0("offshoring_", 1:45),
  paste0("subsystem_", 1:45)
)

# Initialize a results data frame
results <- data.frame(matrix(NA, nrow = num_countries, ncol = length(variables)))
colnames(results) <- variables

# Loop through each country
for (i in 1:num_countries) {
  # Define column range for country i
  start_col <- (i - 1) * cols_per_country + 1
  end_col <- min(i * cols_per_country, ncol(V))

  # Extract country-specific matrix
  V_sub <- as.data.frame(V[, start_col:end_col])

  # Loop through each sector
  for (s in 1:45) {
    # Domestic contribution: sector s, domestic columns (6 to 22)
    domestic_s <- sum(V_sub[start_col + (s - 1), 6:22]) / sum(V_sub[, 6:22])

    # Total contribution: sector s across all countries
    total_s <- sum(V_sub[sector_rows[[s]], 6:22]) / sum(V_sub[, 6:22])

    # Offshoring contribution
    offshoring_s <- total_s - domestic_s

    # Store results
    results[i, paste0("total_", s)] <- total_s
    results[i, paste0("domestic_", s)] <- domestic_s
    results[i, paste0("offshoring_", s)] <- offshoring_s
```

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```
    }

    # Sectoral distribution of the exporting subsystem
    subsystem <- t(as.data.frame(colSums(V_sub) / sum(V_sub)))

    # Store subsystem vector in results
    results[i, paste0("subsystem_", 1:45)] <- subsystem
  }

  country_codes <- unique(substr(rownames(wio$Z), 1, 3))[1:77]
  rownames(results) <- country_codes

  # Export results to CSV
  write.csv(results, file = paste0("results_", year, ".csv"), row.names = TRUE)
}
```

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