DOI: https://doi.org/10.14393/REE-v40n2a2025-77319
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Integration between the machinery and equipment sector and KIBS: applying the subsystem approach

Integração entre o setor de máquinas e equipamentos e KIBS: uma aplicação da abordagem de subsistemas

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Abstract: This paper applies the subsystem approach to analyze the Machinery and Equipment (M&E) sector between 2000 and 2014, focusing on the use of knowledge-intensive business services (KIBS) as production inputs. The objective is twofold: to assess whether countries with higher market shares have intensified their integration of KIBS, and to understand recent transformations in the Brazilian M&E subsystem. The findings reveal that the M&E sector remains highly vertically integrated and only marginally linked to KIBS, with notable exceptions in the United States and Germany—where the incorporation of programming services has increased. In contrast, Brazil and China display persistently low levels of KIBS integration, raising concerns about technological upgrading and innovation capacity.

Keywords: Subsystems; Machinery and Equipment; Capital Goods; KIBS; Integration.
JEL Classification: L16. L22. L84.

Resumo: Esse estudo aplica a abordagem de subsistemas ao setor de Máquinas e equipamentos (M&E), para dados tabulados para o período de 2000 a 2014, para verificar se a utilização de KIBS como insumos aumentou nos países com maior market-share e para entender as mudanças recentes observadas por esse subsistema no Brasil. Os resultados mostram que o subsistema de M&E exibe elevada integração vertical e baixa integração com atividades de KIBS. Entre os países com maior participação na produção global, apenas Estados Unidos e Alemanha apresentaram crescimento expressivo na incorporação de serviços de Programação, enquanto países como China e Brasil registram baixos níveis de integração com KIBS.

Palavras-chave: Subsistemas; Máquinas e equipamentos; Bens de capital; KIBS; Integração.
Classificação JEL: L16. L22. L84.

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1. Introduction

The capital goods sector occupies a central place in the literature on structural change, which views the production of these goods as one of the main drivers of economic growth. Kaldor (1966) identified three key factors behind accelerated economic growth and income divergence among countries: 1. The virtuous relationship between income and demand for manufactured goods, since industrialization raises per capita income, thereby increasing demand for such goods; 2. The promotion of investment in capital goods, as the internalization of supply conditions enables a self-sustained growth path in which supply and demand evolve synergistically; and 3. Capital goods exports, as an important source of stimulus for domestic demand.

In Kaldor's (1966) view, the development of the capital goods sector is central to enabling economic progress, as it allows supply conditions to be endogenously determined. The absence of such development ultimately imposes constraints that may hinder, or even prevent, progress toward higher income levels and, more importantly, the building of a mature economy (Storm, 2015).

Structuralist literature reinforces this view, arguing that economic development moves from agricultural production toward increasing diversification of the productive structure, culminating in the manufacture of more advanced industrial goods. This process is consolidated with the development of the capital goods sector, which may come to represent between 30% and 40% of national output (Cano, 2012). In lower-income countries that fail to develop this sector, the need to import capital goods rises-placing pressure on the balance of payments and increasing dependence on external financing, which may result in the collapse of the developmental efforts altogether (Storm, 2015).

The need for countries to internalize supply conditions underscores the importance of developing a domestic capital goods sector. However, such development requires large volumes of financial resources and access to cutting-edge technologies, factors whose scarcity on international markets often hinders economic advancement (Mello, 2009). In the 21st century, the rise of digital technologies and automation has introduced even greater

barriers, given the increasing demand for physical capital, human capital, and technical knowledge (Majerowicz & Medeiros, 2018). Much of this new knowledge is now supplied by knowledge-intensive business services (KIBS), which have specialized in developing technological solutions for manufacturing (Miles, 2008)[1].

Despite the growing technical challenges involved in building a domestic capital goods industry, a few countries, most notably China, India, and Turkey, managed to sustain consistent industrialization trajectories during the early decades of the 21st century (Storm, 2015). Indeed, China has become a major exporter of capital goods (Liao *et al*., 2023).

While previous studies show that high-tech sectors tend to make more intensive use of KIBS, no research was found that specifically analyzes the capital goods sector using the subsystem approach (Antonioli; Di Berardino; Onesti, 2020; Cadestin; Miroudot, 2020; Ciriaci; Palma, 2016). Existing studies generally examine the innovation embedded in KIBS activities as they spread through demand for capital goods (Mas-Verdú *et al*., 2011). Other contributions argue that as KIBS increase their share in production and employment, the capital goods sector declines in relative importance due to the outsourcing of productive activities (Desmarchelier; Djellal; Gallouj, 2013).

Against this background, this study applies to the subsystem approach to characterize the Machinery and Equipment (M&E) sector among the 13 countries with the largest market shares, measured by value added, from 2000 to 2014. The objective is twofold: first, to investigate whether these countries have seen an upward trend in the use of KIBS as inputs; and second, to understand recent changes in Brazil's M&E sector, including whether it has lost international relevance and reduced its integration with KIBS activities.

The rationale for applying the subsystem approach lies in the observation that the spread of information and communication technologies (ICTs) has increased the

[1] Bettencourt *et al*. (2002, p. 273) define KIBS as "enterprises whose primary value-added activities consist of the accumulation, creation, or dissemination of knowledge for the purpose of developing a customized service or product solution to satisfy the client's needs."

complexity and sophistication of production processes, thereby raising the relative importance of vertical over horizontal linkages. As vertical linkages grow stronger, the traditional sectoral approach, based on the assumption of vertically integrated production, fails to capture the increasingly blurred boundaries between manufacturing and services (Ciriaci; Palma, 2016).

In this context, the descriptive analysis of data and the vertical integration procedure developed by Sraffa and Pasinetti generate more robust indicators of structural change (Sarra; Mazzocchitti; Furia, 2020; Di Berardino; Quaglione, 2020). This methodology will be used to characterize the M&E sector, with emphasis on the use of inputs from the KIBS sector between 2000 and 2014.

In addition to this introduction, the article is organized into four further sections. Section 2 reviews the literature on the capital goods sector. Section 3 formalizes the subsystem approach. Section 4 presents descriptive statistics and the empirical results. Finally, Section 5 offers concluding remarks.

2. Theoretical Aspects

This section presents the theoretical foundations that support the analysis of the capital goods sector and KIBS, highlighting their role in structural change dynamics. Subsection 2.1 discusses the strategic importance of the capital goods sector for economic development, with emphasis on the emergence of KIBS as suppliers of knowledge and innovation. Next, subsection 2.2 examines the historical trajectory of the capital goods industry in Brazil, identifying the main obstacles faced in its consolidation, as well as the effects of structural transformations and economic policies on its competitiveness and international insertion.

2.1 The Role of the Capital Goods Sector and the Rise of KIBS

Defining the capital goods sector requires first recognizing that productive activities can be classified in several ways. This study adopts the distinction between consumer goods and capital goods, as categorized by Marx: 1. Department I, which produces means of production, that is, machinery and equipment (M&E) used in production processes; and 2. Department II, which produces consumer goods, or in other words, those products and services intended for final consumption (Alem; Pessoa, 2005).

Whether a good qualifies as a capital good depends entirely on its use: only goods employed repeatedly in the production of other goods and services belong to this category. In other words, capital goods are those that do not undergo transformation during the production process, unlike materials and labor, which are consumed as inputs (Alem; Pessoa, 2005).

The literature examining the capital goods sector shows that only a few countries master the technologies required for its production. Output and exports are concentrated in a handful of economies, chiefly Germany, the United States, and Japan— while most developing countries depend on imports to access these goods and expand their productive base (Herrerias; Orts, 2013).

The absence of a domestic capital goods sector can become a serious constraint on long-term economic performance. Countries that adopt growth-oriented policies tend to experience an increase in capital goods imports, which are necessary to raise productive capacity and improve productivity (Herrerias; Orts, 2013). That is, while these countries must import capital goods to support growth, they face balance of payments constraints due to limited access to international capital, which ultimately restricts national development strategies (Storm, 2015).

Latin American structuralist literature places this difficulty at the center of the main obstacles to economic development. Furtado (2007) argues that the capital goods sector plays the most widespread role in disseminating technical progress. However, when developing countries emulate production standards that are capital-intensive and low in labor use—standards developed in advanced economies, they create unfavorable

conditions for the endogenous absorption of technical progress and deepen structural unemployment.

For economically lagging countries, the effort to develop a domestic capital goods sector becomes even more challenging in a context of deindustrialization. This phenomenon appeared in developed countries in the 1970s and in Latin American countries in the 1980s. Unlike developed countries, where the decline in manufacturing's share of employment and value added was offset by the rise of modern service sectors, in Latin America this compensatory dynamic failed to materialize. The modern services sector in this region has generally been uncompetitive and heavily dependent on imported technologies, thereby reinforcing the core-periphery divide observed at the industrial level (Pereira; Missio; Jayme Jr, 2021).

This type of structural change has serious implications for the broader economy, as it limits the capacity to internalize technical progress within the industrial sector.

2.2 The Development of the Capital Goods Sector in Brazil

Brazil's industrial development was significant but failed to achieve a fully consolidated national industry. Mello (2009) helps explain this trajectory by noting that capital accumulation in Brazil began relatively late, at a time when production in advanced economies had already reached large scales and was firmly structured under oligopolistic competition. This historical delay imposed both technical and financial constraints on the development of Brazil's intermediate and capital goods industries. As a result, the expansion of the national industrial base remained restricted throughout the 1930s to 1950s, due to the persistent need to import capital goods.

Only by the mid-1950s was Brazil able to overcome the external constraints related to dollar availability and start importing the production equipment necessary to boost installed capacity. To overcome external constraints and accelerate industrialization, Brazil opted to attract foreign firms, which soon came to dominate the most dynamic segments of the economy (Mello, 2009).

According to Tavares (2000), Brazil began its import substitution strategy by producing simple, low-tech goods and gradually moved toward more complex products. However, as the process advanced, foreign dependence deepened, since the domestic industry required increasing volumes of intermediate and capital goods.

As sectors became more capital-intensive, technological change increasingly depended on imported capital goods, which deepened rather than reduced external dependence. Eventually, Brazil was forced to substitute imports in increasingly oligopolized sectors, employing labor-saving technologies developed abroad. As a result, the economy achieved industrial growth and higher per capita income but remained structurally immature, since industrialization relied heavily on imported capital and generated persistent structural weaknesses (Tavares, 2000).

The initial optimism surrounding the country's strategy of fostering economic development through industrial policy began to give way, by the late 1970s, to growing skepticism. Brazil's limited ability to manufacture capital goods contributed to growing external imbalances, pressures that eventually derailed its developmental strategy (Storm, 2015). Even after the ambitious efforts of the Second National Development Plan (PND – *Plano Nacional de Desenvolvimento Econômico*), the debt crisis of the 1980s and subsequent macroeconomic stabilization efforts undermined any momentum. At the same time, initiatives to insert Brazil into emerging communication technologies faltered, constrained by the country's growing external vulnerability (Laplane; Sarti, 2006).

Alongside these structural barriers, Brazil entered a phase of deindustrialization. The adoption of a neoliberal economic agenda in the 1990s, combined with the abrupt liberalization of trade, ushered in a regressive pattern of structural change: sectors with low technological intensity expanded, while more sophisticated industries lost ground (McMillan; Rodrik, 2011). The opening of the economy and an overvalued exchange rate led to cheaper imported capital goods and intermediate inputs. As a result, firms reduced their manufacturing workforce (Nassif, 2008), and many local suppliers of components and parts were forced to shut down (Cano, 2011). To survive heightened international

competition, firms cut costs, often at the expense of research and innovation. This short-term focus contributed to a loss in diversification and technological sophistication (Laplane, 2015).

The reorganization of Global Value Chains during the 2000s, characterized by vertical disintegration and relocation of production stages to low-cost Asian economies, only deepened Brazil's productive disarticulation (Lian *et al*., 2020). China's accession to the World Trade Organization (WTO) in 2001 added hundreds of millions of low-wage workers to global production networks, intensifying global competition and driving down capital goods prices by about 20% between 2001 and 2012. Meanwhile, China's growing production capacity helped push up global commodity prices. Together, these trends created a context conducive to exchange rate appreciation and a renewed shift toward primary exports in Brazil (Hiratuka; Sarti, 2017).

Under these conditions, Brazil's manufacturing industry lost ground as a source of national income, and the prospect of developing a domestic capital goods sector became increasingly remote. In the face of industrial decline, assessing Brazil's relative position vis-à-vis other countries has become even more critical. The analysis that follows seeks to address this issue in detail.

2.3 KIBS and the Capital Goods Sector

In recent decades, knowledge-intensive business services (KIBS) have assumed a strategic role in economic development, acting as agents of innovation, technological diffusion, and specialized support to the manufacturing sector. The concept of KIBS was formalized by Miles *et al*. (1995), who defined them as activities focused on the creation, accumulation, and dissemination of specialized knowledge, typically contracted to solve complex problems and respond to specific demands, especially in manufacturing.

Subsequent research has expanded and refined the definition. Den Hertog (2000) characterizes KIBS as organizations that rely heavily on knowledge to deliver specialized intermediate services. Bettencourt *et al*. (2002) emphasize the customization of solutions;

Toivonen (2006) emphasizes their specialization in serving other organizations; while Muller and Doloreux (2009) stress the integration of multiple knowledge sources into innovation processes.

The emergence and expansion of KIBS are linked to three structural transformations:

1. **Outsourcing:** As business operations became more complex, many firms began to externalize specialized functions to KIBS providers to reduce fixed costs and access advanced capabilities without needing to internalize them (Sako, 2006).
2. **Servitization:** In industrial contexts, the shift from pure product models to hybrid product-service offerings expanded the space for KIBS. Servitization requires the provision of maintenance, technological upgrades, operational support, and consulting, all areas where KIBS function as integrators, connecting physical goods with use and performance requirements (Baines *et al*., 2009).
3. **Digitalization:** Digital transformation has greatly enhanced the scope and productivity of KIBS. These services now offer solutions involving big data, artificial intelligence, automation, and digital platforms, making them increasingly embedded in global production chains and digitally integrated industrial processes (Marino-Romero *et al*., 2022, 2023).

The international literature finds that KIBS tend to be associated with specific manufacturing activities. Chichkanov (2022), Antonioli, Di Berardino and Onesti (2020), Seclen and Barrutia (2018), and Ciriaci and Palma (2015) all show that these services are most often used as inputs in medium-high and high-tech industries. Ciriaci, Montresor and Palma (2015) estimate that the industries most intensive in KIBS include pharmaceuticals, electrical and electronic equipment, precision instruments, machinery and equipment, and automotive & aerospace.

In the specific case of capital goods, the literature highlights the central role played by services such as software, programming, engineering, and R&D. These services

promote automation, control, and digital integration of both products and production processes. The composition and intensity of KIBS incorporation vary widely across countries. It is typically higher in segments with dense intangible assets and strong requirements for codification and engineering, conditions that are especially present in the capital goods sector (Antonioli; Di Berardino; Onesti, 2020; Ciriaci; Palma, 2016; European Commission, 2013).

In Brazil, the development of KIBS has followed regional and structural asymmetries. Most KIBS firms are concentrated in major urban centers like São Paulo and Rio de Janeiro (Guimarães; Meirelles, 2014). This spatial concentration limits diffusion and reinforces regional disparities (Lima; do Nascimento, 2024). Although there is no specific research focused solely on the capital goods sector, some studies suggest that firms in this industry could benefit substantially from integrating KIBS to foster innovation and enhance competitiveness (Kubota, 2009; Leão; Cardoso; Afonso, 2022).

Despite this potential, the KIBS sector in Brazil faces significant challenges, including limited internationalization, reliance on local markets, restricted access to financial and technological resources, and a lack of targeted public policy (Silva *et al*., 2022; Raiher, 2023). Strengthening this segment requires long-term strategies for technological capability-building, innovation incentives, and productive integration—so that KIBS can fulfill their strategic role as a bridge between industry and knowledge (J-Figueiredo; Ferreira, 2019).

3. Methodological Procedures

This section presents the methodological procedures adopted for the empirical investigation of the relationship between structural change and the dynamics of KIBS and the M&E industry. Subsection 3.1 discusses the subsystem approach as a methodological alternative to conventional sectoral analysis, highlighting its ability to measure direct and

indirect inter-industry linkages based on the input-output matrix. Subsection 3.2 details the data sources used and the sectoral and spatial criteria employed in the analysis.

3.1 The Subsystem Approach

Di Berardino and Onesti (2018) define subsystems as an aggregation that identifies the activities which serve, directly or indirectly, the final demand for a given good or service. Inter-industry linkages are revealed through the connections between final goods and the inputs used in their production. Sraffa (1960) originally proposed this approach to measure the amount of direct and indirect labor embedded in final demand.

While Pasinetti (1973) provided a theoretical formalization of the subsystem approach, he did not apply it empirically. Momigliano and Siniscalco (1982) developed an empirical procedure to translate sectoral structures into subsystems. They used this method to test the hypothesis that employment growth in service activities could be explained by increased demand for intermediate inputs from manufacturing, resulting from outsourcing and the internal reorganization of production processes.

Thus, a concept that originated in theoretical discussions of vertical integration entered mainstream economic analysis, enabling the construction of structural change indicators that are robust to outsourcing and internal organizational shifts. The subsystem approach, by aggregating both direct and indirect inputs based on inter-sectoral linkages, generates indicators that are not distorted by changes in relative prices or by shifts in outsourcing practices. As a result, these indicators more accurately capture the dynamics of structural transformation at the national level (Ciriaci; Palma, 2016).

To operationalize this approach, Momigliano and Siniscalco (1982) propose the operator B, which reclassifies the variable h from a sectoral base to a subsystem base:

$$\beta = \hat{h}B, \tag{1}$$

$$B = (\hat{x})^{-1}(I - A)\hat{f}(t), \tag{2}$$

where $(I - A)^{-1}$ is the Leontief inverse matrix; x is the total output vector at current prices; $f(t)$ is the vector of final production at current prices; and the "^" symbol indicates that the vectors have been diagonalized.

3.2 Database

Descriptive statistics on establishments, employment, and value added were compiled to analyze the M&E sector. International statistics were sourced from the United Nations Industrial Development Organization (UNIDO, 2024) and the Brazilian Secretariat of Foreign Trade (Comex, 2024), covering the period 2000–2021. Brazilian data were drawn from the Annual Social Information Report (RAIS – *Relação Anual de Informações Sociais*, 2024), with activities disaggregated by Division according to the National Classification of Economic Activities (CNAE – *Classificação Nacional de Atividades Econômicas*), for the period 2006–2021.

Data on Hours Worked and the Supply and Use Tables, which are required to calculate operator B, were obtained from the World Input-Output Database, available only for the years 2000–2014 (WIOD, 2016). The classification of KIBS activities is presented in Table 1.

Due to data limitations, some sectoral definitions had to be narrowed. Since disaggregated international data were not available for certain activities, particularly those related to communication and information equipment, the definition of capital goods used here was restricted to M&E, classified as ISIC 29 – Machinery and Equipment n.e.c. in UNIDO and WIOD, and CNAE Division 28 – Manufacture of Machinery and Equipment in RAIS.

Table 1 – Classification of KIBS Activities, ISIC Rev. 3

Classification	ISIC	Activity	Classification	ISIC	Activity
KIBS	62	Programming	**KIBS**	71	Architecture
KIBS	63	Information Services	**KIBS**	72	R&D
KIBS	69	Legal	**KIBS**	73	Advertising
KIBS	70	Head offices	**KIBS**	74	Other Professional Activities

Source: Compiled by the authors. Note: Adapted from Muller and Zenker (2001).

The spatial sample was defined based on each country's market share of M&E sector employment in 2014. Data were compiled for the 13 countries that together accounted for 80% of total M&E employment, according to UNIDO.

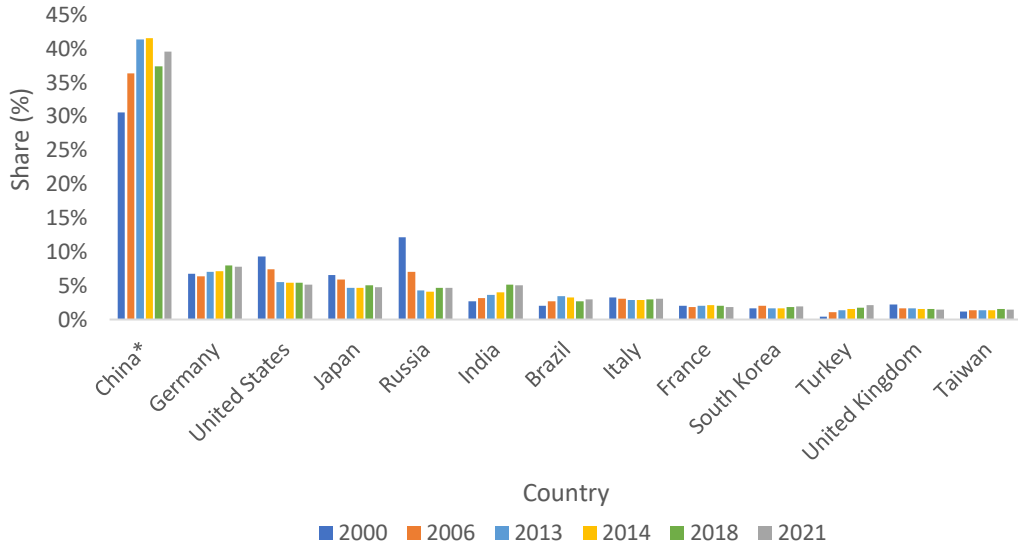
4. Results

This section is organized into two subsections. Subsection 4.1 provides an international and national overview of employment trends, trade balance, value added, and productivity in the M&E sector. Subsection 4.2 applies the subsystem approach to measure the degree of vertical integration in the M&E sector and its links with KIBS.

4.1 Descriptive Analysis

Figure 1 presents the 13 countries that jointly accounted for 80.27% of global employment in the M&E sector in 2000 and 78.48% in 2021. In 2000, the largest shares belonged to China (30.53%), Germany (6.77%), the United States (9.30%), Japan (6.57%), and Russia (12.10%). Together, these five countries represented 65.26% of employment in the sector. Brazil's share grew from 2.00% in 2000 to 3.43% in 2013, before falling to 2.68% in 2018 and slightly rising again to 2.95% in 2021.

Figure 1 – Share of Employment in the M&E Sector (%)



Source: Adapted from UNIDO (2024). Note: *2000 includes office, accounting, and computing machinery. Figures for the year 2020 are used due to missing data for 2021.

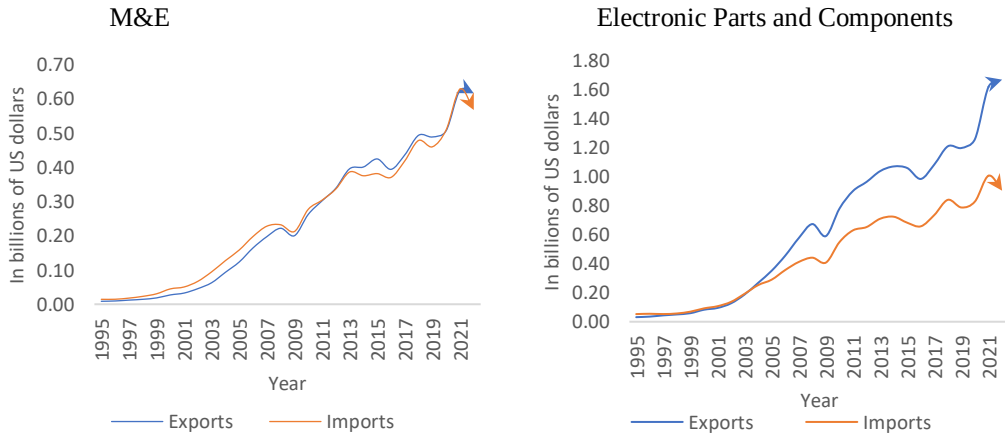
Throughout this period, China's share increased sharply, reaching 36.36% in 2006 and 41.30% in 2013, before declining slightly to 37.36% in 2018 and climbing again to 39.57% in 2020. This growth occurred in tandem with declining shares in the United States, Japan, Russia, and the United Kingdom. For instance, the U.S. share dropped from 9.30% in 2000 to 5.13% in 2021. In contrast, Germany, India, and Turkey expanded their shares.

These figures support the argument that China's accession to the World Trade Organization in 2001 accelerated the reorganization of Global Value Chains, with labor-intensive and large-scale production shifting to China (Lian *et al*., 2020). Germany's increased participation reflects the high technological intensity of its M&E exports (Sarra; Di Berardino; Quaglione, 2020).

China's trade balance in M&E (**Figure 2**) was roughly balanced between 1995 and 2021, with a growing surplus in electronic parts and components. While China has a clear advantage in labor-intensive stages of production due to low labor costs and economies of scale, it faces barriers to entry in high-skill segments dominated by high-income countries

with entrenched positions in oligopolistic markets. This has led to commercial and technological tensions, especially with the United States (Majerowicz; Medeiros, 2018; Liu; Woo, 2018).

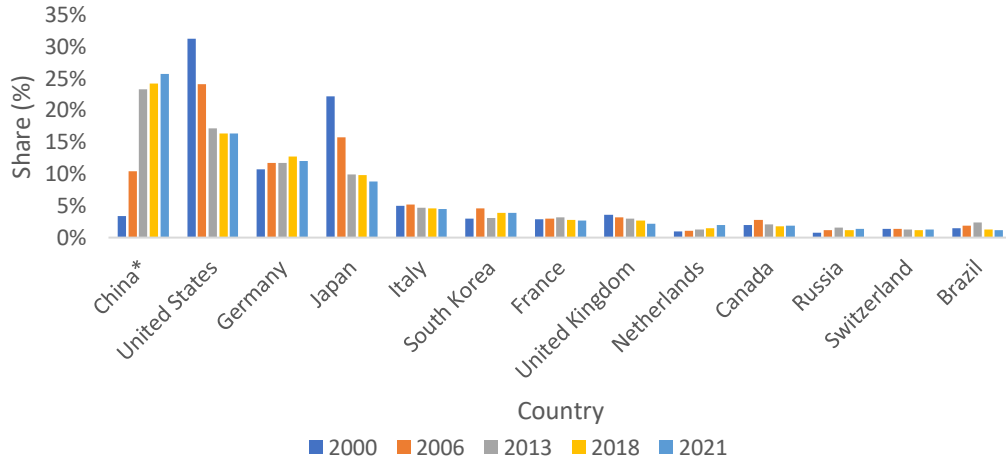
Figure 2 – Chinese Exports and Imports of M&E and Electronic Parts and Components (in US$ billions)



Source: Unctad (2024)

The value-added data (**Figure 3**) reinforces this narrative. China's participation rises significantly, from 3.35% in 2000 (US$ 17.17 billion) to 10.42% in 2006 (US$ 78.37 billion), then to 23.33% in 2013. Afterward, growth slowed but continued, reaching 24.21% in 2018 and 25.69% in 2021 (US$ 303.68 billion).

Figure 3 – Share of Global Value Added in M&E, 2000 to 2021 (%)



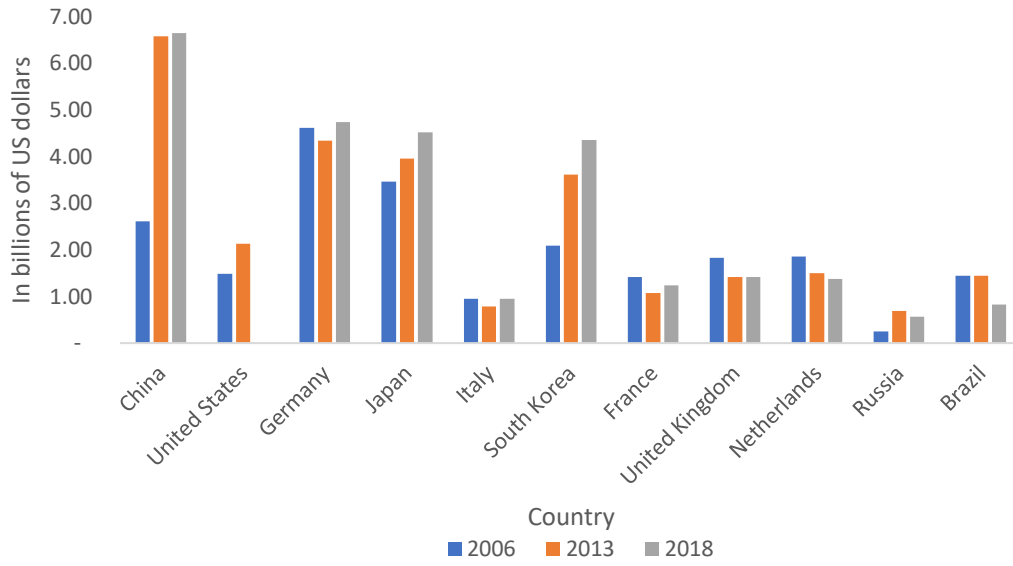
Source: Adapted from UNIDO (2024). Note: *2000 includes office, accounting, and computing machinery. Figures for the year 2020 are used due to missing data for 2021.

In contrast, the United States' share declined from 31.20% in 2000 (US$ 159.79 billion) to 24.07% in 2006 and 17.18% in 2013, stabilizing around 16.35% by 2021 (US$ 193.33 billion). Japan saw similar behavior, with a sharp decline in its share. Italy, France, the United Kingdom, and Canada also recorded declines, despite accounting for a smaller proportion of global value added. This stabilization likely reflects renewed industrial policy efforts and a shift from outsourcing strategies toward vertical reintegration (Bramucci *et al*., 2021; Cimoli; Dosi; Stiglitz, 2015; Nordås; Kim, 2013; European Commission, 2012; Pisano; Shih, 2009).

Brazil's value-added share was modest in 2000, 1.43% (US$ 7.32 billion), and rose to 2.33% in 2013 before falling to 1,27% in 2018 and 1.15% in 2021 (US$ 13.55 billion). These fluctuations mirror changes in Gross Fixed Capital Formation during the country's growth cycle between 2004 and 2014. Following the end of this expansionary period, the sector faced sharp setbacks (Pereira Sampaio, 2019).

Based on the data on value added and the number of establishments, productivity (value added per firm) was calculated in millions of U.S. dollars, as shown in **Figure 4**.

Figure 4 – Productivity in the M&E Sector (in US$ millions)



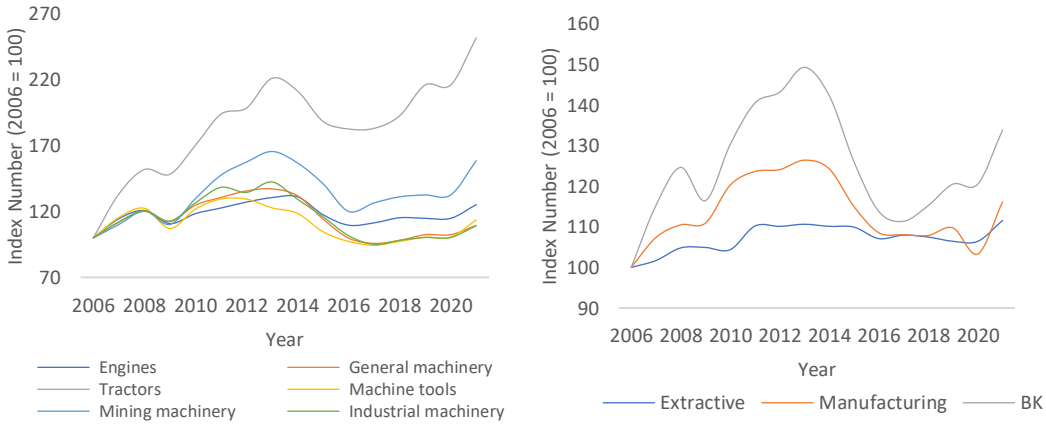
Source: Adapted from UNIDO (2024). Note: The absence of data on establishments prevents the calculation of productivity for the United States in 2018.

China recorded the highest growth in productivity, which rose from US$ 2.61 million in 2006 to US$ 6.58 million in 2013, followed by a slight decline to US$ 6.63 million in 2018. The United States, Japan, and South Korea also experienced increases in productivity. By contrast, the Netherlands, and to a lesser extent France and the United Kingdom, showed declines. Not only was Brazil's productivity low, but it also remained virtually unchanged between 2006 and 2013 at US$ 1.44 million, before dropping sharply to US$ 0.82 million in 2018.

The international comparison thus reveals an intense transfer of M&E production to China, which took place rapidly between 2006 and 2013 and more moderately thereafter. This surge in production was accompanied by a parallel increase in Chinese productivity, a shift that most strongly affected the United States, Japan, and Russia.

A more detailed analysis for Brazil, shown in **Figure 5**, indicates that employment in the M&E sector, measured by an index number (2006 = 100), grew faster than in other sectors between 2006 and 2013, reaching 149, before falling to 111 in 2017 and rising again to 134 in 2021. The employment gains were driven primarily by the Manufacture of Tractors and Mining Machinery and, to a lesser extent, by the production of Engines.

Figure 5 – Employment by Productive Activity (Index Number 2006 = 100)

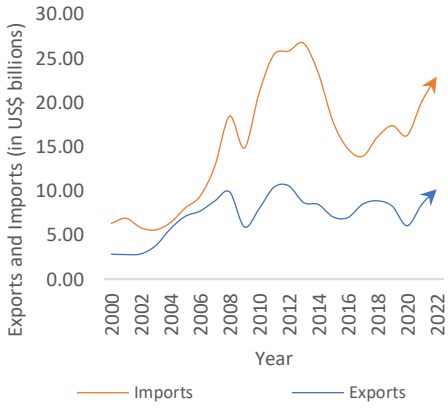


Source: Adapted from RAIS (2024)

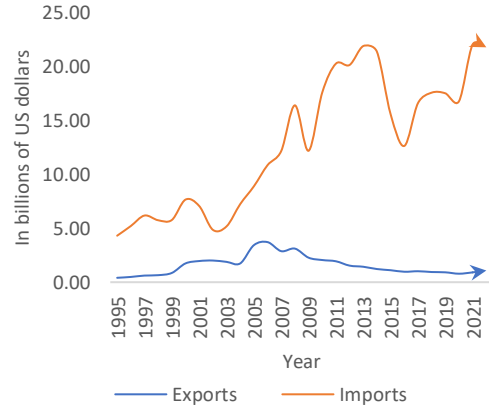
As gross fixed capital formation (GFCF) rates increased, **Figure 6** shows that, in a context of rising international commodity prices, both exports and imports followed an upward trend, moving from a near balance in 2004 to a growing trade deficit. Between 2009 and 2013, following the global financial crisis of 2008, imports of M&E surged from US$ 14.84 billion to US$ 26.69 billion, while exports remained nearly stagnant, rising only slightly from US$ 5.90 billion in 2009 to US$ 10.56 billion in 2012. This resulted in a total trade deficit of US$ 18.03 billion.

Figure 6 – Imports and Exports of M&E and Electronic Parts and Components, 2000–2022

M&E



Electronic Parts and Components



Source: Comex (2024).

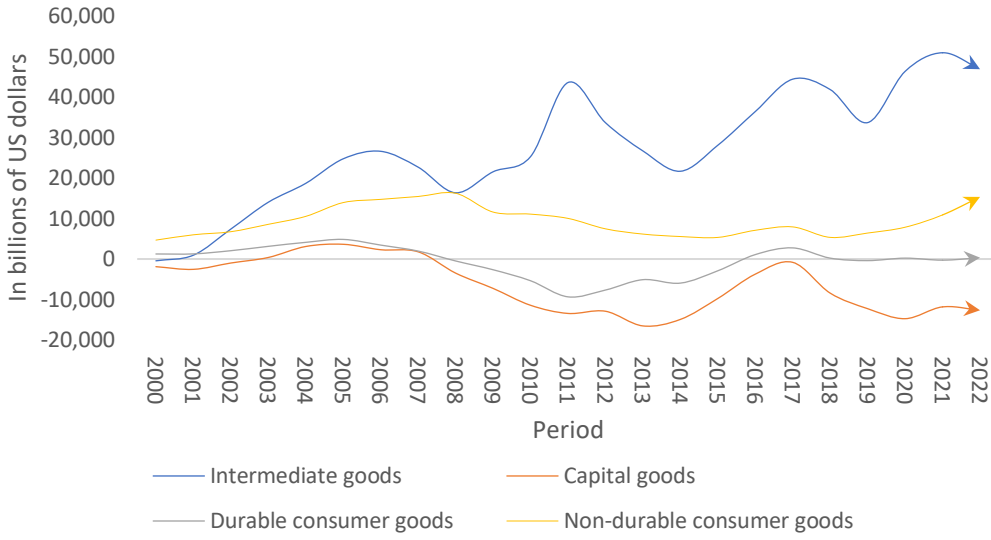
The data indicate a growing dependence on M&E imports (Cassiolato; Lastres, 2015), exacerbated by the persistence of an appreciated exchange rate (Mazzucato; Penna, 2016). Even during the economic expansion between 2004 and 2014, domestic M&E production failed to keep pace with rising demand, while the production of information technology equipment declined (Silva; León, 2023).

The electronic parts and components sector shows a similar pattern. Since Brazil was unable to effectively integrate into information and communication technologies (ICTs) and given the limited scope of public policies targeting this sector, exports fell steadily after 2006. Imports, in contrast, followed the economic cycle, resulting in persistently high trade deficits.

The sharp increase in capital goods imports, shown in **Figure 7**, is consistent with the literature. As demonstrated by Tavares (2000), given the large volume of capital required, Brazil was unable to complete its industrialization process. As a result, it has struggled to sustain an endogenous and self-reinforcing growth trajectory, since higher

growth rates systematically generate greater demand for imported capital goods, which in turn places pressure on the balance of payments.

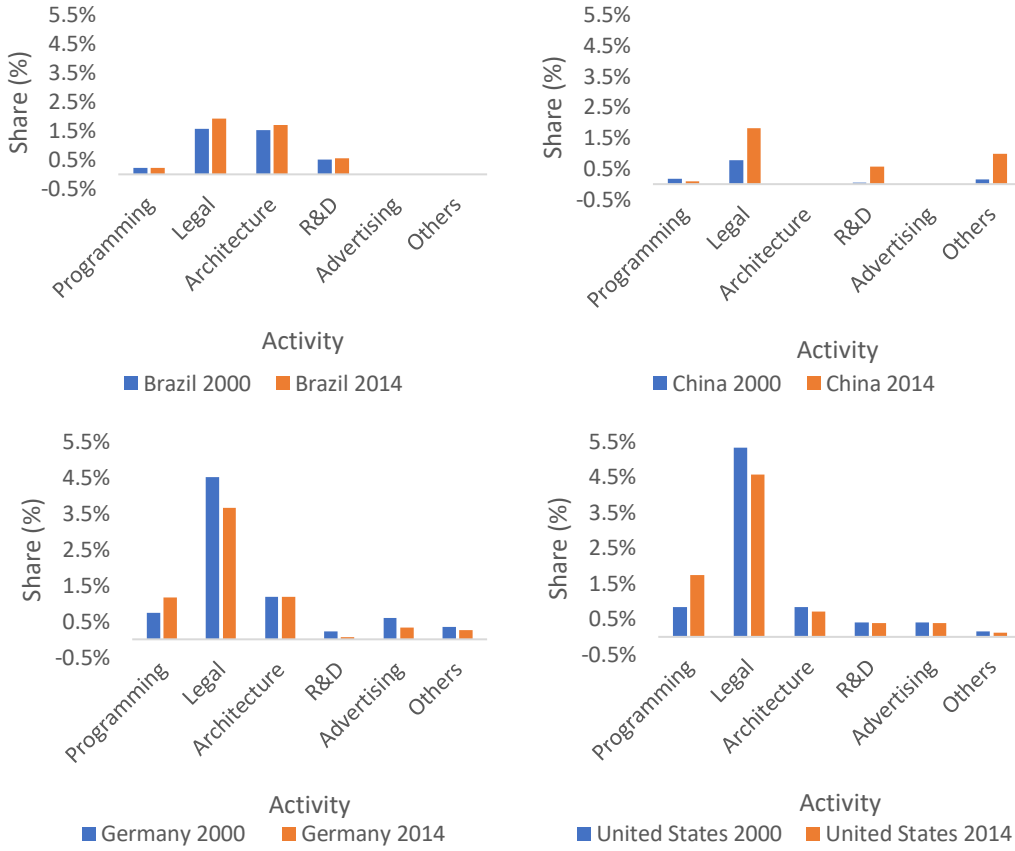
Figure 7 – Trade Balance by Major Economic Categories, 2000–2022



Source: Comex (2024)

The analysis of direct inputs used by the M&E sector, shown in **Figure 8**, reveals Brazil's limited use of inputs originating from KIBS activities. In 2000, only inputs from the Architecture sector represented a significant share, at 1.5%, exceeding the levels observed in Germany (1.2%) and the United States (0.8%). By contrast, Germany and the United States made greater use of inputs from Programming (0.7% and 0.8%), Legal (4.5% and 5.3%), and Advertising (0.6% and 0.4%). The share of inputs from programming activities increased substantially in Germany and the United States, to 0.30% and 1.00%, respectively, while remaining stagnant at around 0.2% in Brazil.

Figure 8 – Share of Direct Inputs Used by the M&E Sector, 2000 and 2014 (%)



Source: WIOD (2016)

China still shows an incipient level of integration between the M&E sector and KIBS, with a low share of KIBS in the sector's direct value added. Over the period under review, the share of inputs originating from Legal, R&D, and Other business services increased considerably, although these levels remain well below those observed in the United States and Germany. The only exception is R&D, whose share in China's M&E industry (0.6%) exceeds that of Germany (0.2%) and the United States (0.4%). This phenomenon is likely explained by China's aggressive industrial policies, which have been strongly oriented toward R&D, in contrast with the decline in both public and private R&D

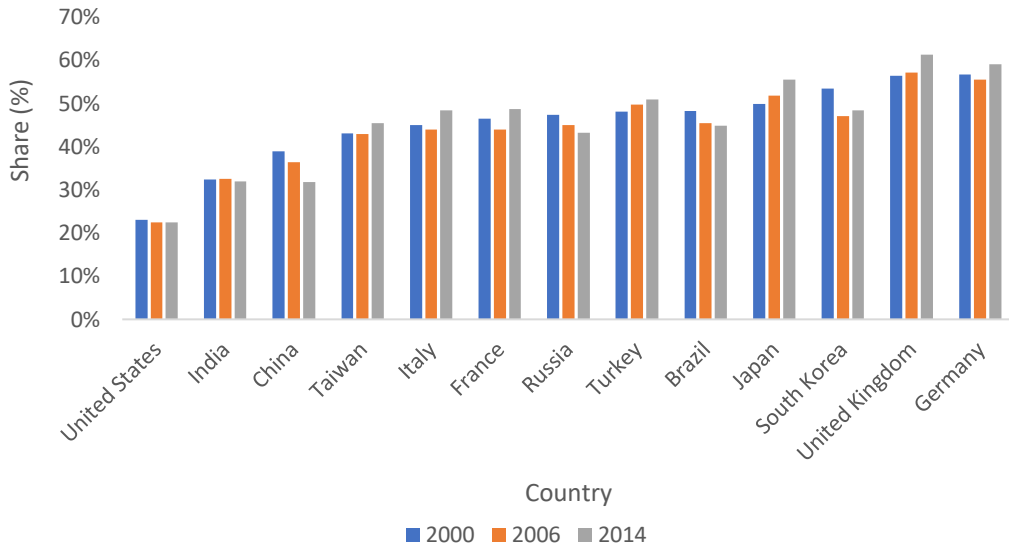
investment, particularly in European countries, following the global economic crisis (Simonazzi, 2015; Stöllinger *et al.*, 2013).

4.2 Subsystem Approach

Applying the subsystem approach makes it possible to construct a set of indicators that describe, in greater detail, the transformations occurring in the production relationships within the M&E sector. The share of direct and indirect inputs originating from the M&E segment in the sector's total value added reflects the degree of vertical integration within the subsystem, that is, whether the inputs used come mainly from within the same subsystem or from other productive activities.

As shown in **Figure 9**, the M&E subsystem is characterized by a high level of vertical integration. On average, for the countries included in the analysis, 45% of inputs in 2000 came from within the same subsystem. Germany, the United Kingdom, South Korea, Japan, and Brazil had the highest degrees of vertical integration, meaning their M&E sectors relied less on inputs from other sectors. By contrast, the United States, India, China, and Taiwan exhibited lower degrees of vertical integration, with their M&E subsystems more interconnected and more reliant on inputs from other parts of the economy. These results indicate that the M&E sector has been less affected by outsourcing, and that advances in communication technologies have not led to extensive internal reorganization in this industry. In other words, the observed pattern runs counter to the general tendency reported in the literature for manufacturing (Sarra; Di Berardino; Quaglione, 2019; Giovanini, 2021).

Figure 9 – Degree of Vertical Integration in the M&E Subsystem

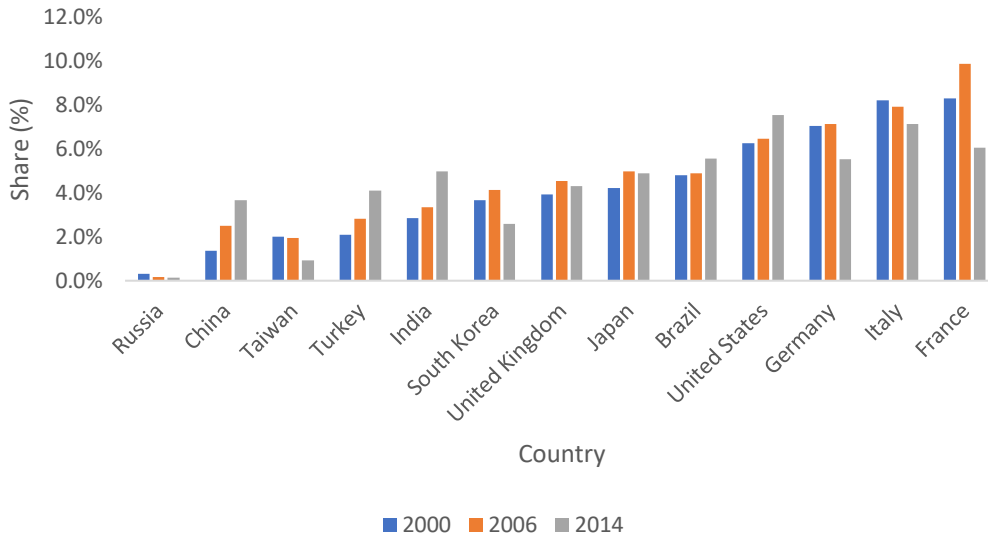


Source: WIOD (2016)

Only five countries (India, China, Russia, Brazil, South Korea, and, to a lesser extent, the United States) experienced a decline in the degree of vertical integration between 2000 and 2014. These economies pursued strategies of increasing outsourcing or offshoring, consistent with their integration into Global Value Chains, a process that, in Brazil's case, was accompanied by a weakening of its manufacturing base.

The rise in vertical integration within the M&E subsystem directly affects the use of inputs from the KIBS subsystem. In the year 2000, France (8.3%), Italy (8.2%), Germany (7.0%), and the United States (6.2%) displayed the highest combined direct and indirect shares of KIBS in the value added of the M&E subsystem (**Figure 10**). In contrast, Russia (0.3%), China (1.4%), and Taiwan (2.0%) had the lowest participation rates. During the period under analysis, the United States, Brazil, Japan, the United Kingdom, India, Turkey, and China increased their use of KIBS-derived inputs, with notable growth in China (up 2.3 percentage points), India (2.1 pp), and Turkey (2.0 pp).

Figure 10 – Direct and Indirect Share of KIBS in the Value Added of the M&E Subsystem (%)



Source: WIOD (2016)

Meanwhile, France, Italy, Germany, South Korea, Taiwan, and Russia experienced declines in the proportion of direct and indirect value added from KIBS activities. These results support the argument that the M&E subsystem diverged from the broader pattern of internal reorganization and rising KIBS intensity observed in manufacturing in general, maintaining vertical integration as a key strategy for preserving competitive advantage (Sarra; Di Berardino; Quaglione, 2019). It is worth noting that, in recent years, policies promoting vertical integration have reemerged in the political agenda of high-income countries, to protect strategic industries from unfair competition, especially from China (Cimoli; Dosi; Stiglitz, 2015; Bramucci *et al*., 2021).

A disaggregated analysis shows that Germany and the United States exhibit the highest direct and indirect shares of Programming-related inputs in the value added of the M&E subsystem (**Table 2**), which increased significantly from 0.78% and 0.58% in 2000 to 1.38% and 1.40%, respectively. By contrast, this category accounted for only 0.57% of

the M&E subsystem in Brazil and 0.15% in China in 2000, with the Chinese share falling to 0.11% in 2014. These findings highlight the advantageous position of high-income countries in adopting digital technologies, compared to their developing counterparts. The literature emphasizes Brazil's persistent difficulty in integrating into digital technologies and in developing a modern, dynamic, and innovative business services sector (Brynjolfsson; McAfee, 2014; Giovanini, 2021; Pereira; Missio; Jayme Jr, 2023).

Table 2 – Share of Direct and Indirect Inputs Used by the M&E Subsystem, 2000 and 2014 (%)

	Programming		Legal		Architecture		R&D		Advertising		Other	
Country	**2000**	**2014**	**2000**	**2014**	**2000**	**2014**	**2000**	**2014**	**2000**	**2014**	**2000**	**2014**
DEU	0.78	1.38	4.00	3.13	1.10	1.07	0.38	0.01	0.62	0.34	0.30	0.25
USA	0.58	1.40	4.32	4.66	0.86	0.82	0.42	0.44	0.41	0.44	0.15	0.15
BRA	0.57	0.59	2.41	2.88	1.22	1.44	0.45	0.51	0.00	0.00	0.00	0.00
CHN	0.15	0.11	0.85	1.82	0.00	0.00	0.05	0.51	0.00	0.00	0.24	1.23

Source: WIOD (2016)

Germany and the United States also show a higher participation of Legal services inputs compared to Brazil and China. Only in Germany did the share of Legal services decline, reaching 3.1% in 2014. Brazil, in turn, shows the highest participation of architecture and engineering services, 1.2% in 2000, and was the only country to experience an increase in this activity, reaching 1.4% in 2014.

The share of R&D services rose from 0.1% to 0.5% in China, a level comparable to Brazil's, and exceeded that of the United States (0.4%). Germany, affected by the international economic crisis, recorded a sharp decline in R&D-related inputs. Thus, the reduction in KIBS use in Germany's M&E subsystem can be explained by lower shares of Legal and R&D services, which were not offset by higher use of Programming services.

The shares of Advertising and Other Business Services were nearly zero for Brazil and China in 2000, though the latter saw strong growth in the latter category, reaching 1.2% in 2014. These results highlight the contrast between KIBS used as inputs in M&E

industries in countries with emerging productive structures (Brazil and China) and those with consolidated ones (Germany and the United States). In Brazil, the M&E subsystem is less intensive in KIBS-derived inputs, except for Architecture and Engineering, while the share of Programming services, precisely the activity associated with the diffusion of digital technologies, declined. Legal and accounting services also have a relatively low share compared with countries like Germany and the United States, indicating the need to strengthen the domestic supply of these services.

China, meanwhile, has successfully increased the use of R&D services through aggressive industrial policy, but still shows low participation of other KIBS, particularly Programming and Architecture and Engineering. These results suggest potential limits to China's industrialization process, which remains constrained by a relatively underdeveloped domestic KIBS base, essential for improving competitiveness and technological sophistication.

5. Final Considerations

In light of the growing role of KIBS as manufacturing inputs and the global reorganization of production systems, driven by the relocation of production stages to China, this study employed the subsystem approach to examine structural change in the Machinery and Equipment (M&E) subsystem over the period 2000-2014. The article had two main objectives: first, to examine whether countries with higher market shares experienced a rising trajectory in the participation of KIBS activities as inputs in the M&E subsystem; and second, to analyze recent developments in Brazil's M&E sector, specifically whether it has lost international relevance and whether it relies little on KIBS-related inputs.

Descriptive statistics revealed an intense transfer of global M&E production to China. Only Germany, and to a lesser extent the Netherlands, were not severely affected by this process, mainly because their M&E production features higher technological content, which allows these countries to compete with China's scale and low production costs.

The results obtained through the subsystem approach showed that the shares of KIBS in the M&E subsystem increased between 2000 and 2014 in Brazil, China, India, and Turkey. These countries underwent internal reorganization and a greater outsourcing of activities to specialized service firms. By contrast, in countries such as Germany, Italy, and France, the opposite pattern was observed. These findings indicate that there is still room to expand the use of digital technologies and KIBS in the M&E sector, an expansion that could contribute to productivity gains in countries like Brazil.

The evidence for Brazil supports the view that the country has not completed its industrialization process, and the M&E subsystem clearly reflects this limitation. Consequently, the economy struggles to sustain an endogenous and self-determined growth path, since higher economic growth rates lead to increased imports of M&E, which then trigger external constraints.

Moreover, the data show that Brazil ranks among the developing countries with the highest direct and indirect participation of KIBS in the value added of the M&E subsystem. This indicates that the subsystem relies considerably on service activities that support manufacturing innovation. However, this result should be interpreted with caution. Within the KIBS used by Brazil's M&E subsystem, the most significant contributions come from Architecture and Engineering and R&D, both with shares higher than those in Germany and the United States, while Programming services, the activity most closely associated with digital technology diffusion, remain limited and even declined over time. The shares of Legal and Accounting services, Advertising, and Other Professional Activities are also much lower than those of advanced economies.

These results reinforce the importance of vertical and technological industrial policies aimed at strengthening the capital goods sector and fostering the strategic internalization of KIBS within firms, while simultaneously promoting integration with specialized external services that enhance innovation capacity and productivity. At the same time, outsourcing and servitization can serve as complementary instruments for

improving productive performance, particularly when combined with policies that strengthen technological absorption and human capital.

This study contributes to the literature by applying the subsystem approach to the M&E sector, providing empirical evidence of the interdependence between capital goods and KIBS and the distinct patterns of productive reorganization across countries. Methodological limitations include the use of aggregated tabulated data, which prevent capturing firm-level heterogeneity, and the inability to establish causality between KIBS incorporation and productivity gains.

Future research could explore microeconomic analyses on the effects of internalization versus outsourcing of KIBS on firm productivity, sectoral studies focusing on specific KIBS types, and international comparisons examining how technological content and scale interact to sustain growth in the capital goods sector. Overall, the study highlights that the sustainable development of the M&E sector depends not only on access to advanced technologies and KIBS but also on structural policies that foster the creation of domestic capabilities, thereby enabling the endogenous determination of supply conditions and supporting sustained economic growth.

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